

6. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Ghana

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6.1 Soil nutrient management, including fertilizer use in Ghana

Ghana's agriculture is characterized by low crop yields due to low soil fertility, soil erosion, inappropriate land use and nutrient depletion through crop harvest and exports without corresponding replacement of these nutrients by fertilizer use, leading to soil degradation. Food security is therefore at risk, with increased dependence on imported food and expenditure of Ghana's foreign exchange reserves.

The important food crops in Ghana are maize, rice, sorghum, millet, cassava and legumes.

Among the cereals, maize is the most important with about 750,000 ha/year of production. Cowpea is a very important legume food crop and soybean is becoming important as a cash crop. The yields of these crops are, however, low because of low soil fertility and low input use. The Abuja summit on fertilizer declared that Sub-Saharan Africa (SSA) can only increase food production and alleviate poverty when fertilizer use is increased.

However, the mean maize yield is 1.5 t/ha compared to potential yield of 6 t/ha. Two major reasons for low crop productivity include low soil

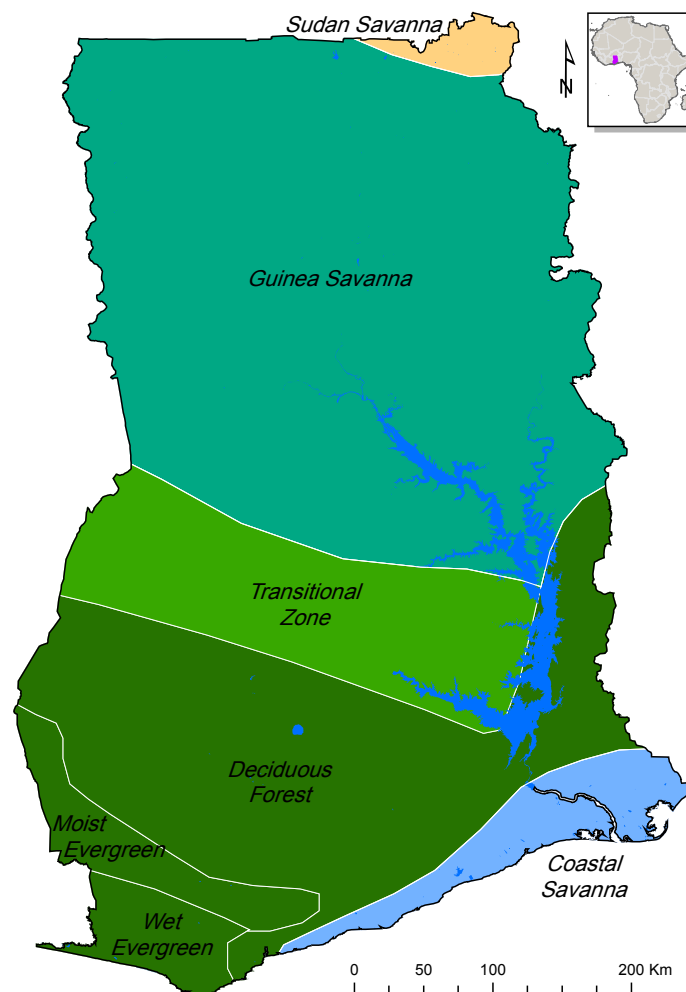


Figure 6.1: Agro-ecological zones (AEZ) of Ghana.

fertility and low input use. 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) (Benneh et al., 1990; Adu 1995). A large proportion of the soils are also shallow with iron and magnesium concretions (Adu 1969).

Despite these shortcomings, soil fertility management receives little attention from farmers. Fertilizer nutrient application in Ghana is approximately 12 kg/ha (FAO 2005) while depletion rates, which range from about 40 to 60 kg of nitrogen, phosphorus and potassium (NPK) per ha/yr (FAO 2005), are 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.

Ghana's farming systems vary with agro-ecological zones although certain agricultural

practices cut across all zones (Figure 6.1). The bush fallow system prevails wherever there is ample land to permit a plot to replenish its fertility after one to three years of cultivation (Ofori and Stern 1987; MoFA 1998). Staple food crops are often mixed-crop while cash crops are usually monocropped.

In the forest zone, tree crops are significant with cocoa, oil palm, coffee and rubber being the dominant crops. Food crops in these areas are mainly intercropped mixtures of maize, plantain, cocoyam and cassava.

The middle belt is characterized by mixed or sole cropping of maize, legumes, cocoyam or yam with tobacco and cashew being the predominant cash crops.

The food crops in the northern sector are mainly sorghum, maize, millet, cowpeas, groundnuts and yam with tobacco and cotton as the predominant cash crops.

Table 6.1: Mean monthly rainfall (mm), maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of selected AEZ of Ghana

	J	F	M	A	M	J	J	A	S	O	N	D
Deciduous, Abourtem												
Rainfall	19	62	140	151	180	223	146	91	173	194	89	34
Tmax	31.8	33.2	33.1	32.3	31.6	29.7	28.1	28.3	29.0	30.3	31.5	30.7
Tmin	20.6	27.3	27.4	27.2	27.0	25.8	24.7	24.3	25.2	25.8	26.6	25.8
Derived Transitional, Wenchi												
Rainfall	6	30	106	143	163	171	115	83	187	182	46	14
Tmax	32.1	33.7	33.4	32.4	31.2	28.9	27.4	26.5	27.8	28.6	29.7	29.6
Tmin	19.8	21.5	21.9	22.0	21.6	21.1	20.7	20.4	20.7	20.5	20.6	19.8
Guinea Savanna, Nyankpala												
Rainfall	2	8	43	86	123	149	156	185	225	99	11	4
Tmax	35.9	37.5	37.3	36.0	33.9	31.6	30.1	29.9	30.4	32.6	35.2	35.3
Tmin	20.7	23.2	24.8	24.7	24.0	22.8	22.4	22.1	22.0	22.2	21.8	20.2
South Sudan Savanna, Navrongo												
Rainfall	1	3	14	43	92	122	181	259	172	47	4	2
Tmax	35.2	37.1	38.3	37.6	35.2	32.2	30.3	29.7	30.4	33.2	36.1	35.0
Tmin	19.4	21.5	24.4	25.3	24.6	23.0	22.2	22.0	21.9	21.9	20.5	18.8
North Sudan Savanna, Wa												
Rainfall	2	5	34	79	125	129	161	201	195	80	9	6
Tmax	34.6	36.1	36.2	35.3	32.9	30.9	29.5	29.1	29.7	32.3	34.9	34.2
Tmin	19.5	21.6	23.7	24.1	23.0	22.0	21.5	21.4	21.2	21.5	20.9	19.4

Source: climatedata.org/Ghana

In the Guinea savanna zone about 88% of farmers intercropped cowpea with sorghum or millet (GGDP 1991).

Rice is grown in all the ecological zones. The traditional method of land clearing and preparation is the use of rudimentary tools for slashing and burning of the debris.

Poultry production is the main livestock sector in the south while cattle production is concentrated in the savanna zones. Sheep and goat production is important throughout the country (MoFA 1998). Manures from poultry, cattle, sheep and goats are used by smallholder farmers in home gardens especially in the northern savanna zone.

Ghana is divided into six major agro-ecological zones: these are Rain Forest, Deciduous Forest, Forest-savanna Transition, Coastal Savanna and Northern (interior) Savanna which comprises Guinea and Sudan Savannas (Figure 6.1; Table 6.1).

Ghana's climate ranges from equatorial bimodal rainfall in the south to the tropical unimodal monsoon type in the north. The mean monthly temperature over most of the country never falls below 25°C, a consequence of low latitude and low altitude. Mean annual temperature average is 27°C. Absolute maxima approach 40°C, especially in the north, with absolute minima descending to about 15°C. In the coastal areas, with the influence of the sea breeze, monthly annual mean temperatures differ by 5 to 6°C. In the interior, this temperature range is about 7 to 9°C (Dickson and Benneh, 1988; Benneh et al., 1990). The rainfall generally decreases from the south to the north. The wettest area is the extreme southwest where the mean rainfall is over 2000 mm/yr. In the extreme north, the annual rainfall is less than 1100 mm/yr.

Most of the soils of Ghana are developed on thoroughly weathered parent materials, with alluvial soils (Fluvisols) and eroded shallow soils (Leptosols) common to all the ecological zones. Generally most of the soils are affected with inherently or humanly induced infertility (MoFA 1998).

The soils in the forest zone are grouped under Forest Oxysols and Forest Acid Gleysols. These are porous, well drained and generally loamy and are distinguished from those of the savanna zones by the greater accumulation of organic

matter in the surface resulting from higher accumulation of biomass. They occur in areas underlain by various igneous, metamorphic and sedimentary rocks, which have influenced the nature and properties of the soil.

Soils of the savanna zones, especially in the interior savanna, are low in organic matter (less than 2% in the topsoil), have high levels of iron concretions and are susceptible to severe erosion. Thus well-drained upland areas tend to be droughty and when exposed to severe incident sunshine, tend to develop cement-like plinthite. These conditions make it imperative that manure be incorporated regularly into the soils in the savanna zones (MoFA 1998).

6.2 Fertilizer use and recommendations

Current recommended rates of fertilizer application on food crops were formulated about 30 years ago. At that time, long fallow periods and less intensive cropping coupled with crop varieties with low response to nutrients resulted in low to medium rates of recommended nutrient levels of application.

With agriculture developing fast and improved crop varieties with high nutrient requirements, there is the need to improve nutrient supply to crops if the full yield potential of the crop is to be realized. Even with subsidization, fertilizer use is expensive to the smallholder farmers who form the bulk of production force. However, it is in the interest of farmers to invest in fertilizer rates that are economically and scientifically sound so as to derive benefit and keep the soil productive. More so, the price of maize is steadily high and attractive to make farmers invest in fertilizer to increase production. A key limitation to farmers' use of fertilizer in Ghana is also lack of fertilizer recommendations that could result in good profits for farmers.

Soil fertility and productivity conditions vary considerably between geographic areas and among farms and fields in the same soil area, so blanket fertilizer-use recommendations may be entirely unprofitable for a whole region or area while profitable in a few areas. This is because fertilizer-use recommendations are site- and situation-specific. That is why several general fertilizer-use recommendations in Ghana have been inconsistent and not popular among farmers and agricultural scientists.

6.3 Current fertilizer use

Cost-effective soil fertility management and increased agricultural productivity goes with good soil information and fertilizer recommendations that are current and specific for crops and agro-ecologies. This has been inadequate in Ghana. Fertilizer recommendations were made for maize, rice, cassava, cotton and groundnut. The fertilizer recommendation for maize was updated in 1974 and since then only sporadic and inconclusive attempts have been made to update these recommendations.

For example, from 2002 to 2005, an attempt was made under the Ghana Soil Fertility Management Action Plan to update the fertilizer recommendation for maize but no specific recommendations have been made for the different agro-ecologies. The old and blanket fertilizer recommendation is two bags of blended fertilizer and one bag of sulphate of ammonium per acre for maize, irrespective of the AEZ.

Currently there is no effective soil test service for farmers and as a result fertilizer application is not based on soil test information. Soil conditions have changed over the years and the old recommendations are not the most efficient today. There is need to update fertilizer recommendations for maize and other crops in Ghana and provide soil analysis service to farmers.

In 2008, the government re-introduced fertilizer subsidies through a voucher-based system to promote fertilizer use and improve crop productivity of smallholder farmers. The vouchers were worth 50% of the price of fertilizer on selected fertilizers for use on staple food crops (urea, 15-15-15 NPK, 23-10-5 NPK and sulphate of ammonia). The subsidy on fertilizer has, however, declined over the years from 50% in 2008 to 20% in 2015 as a way of equalizing fertilizer price in Ghana and the neighboring countries to discourage smuggling of subsidized fertilizer. Farmers were encouraged to use the fertilizers on mainly the key food crops – maize, rice, millet and sorghum. The total cost of the subsidy was valued at GH¢ 20.7 million and GH¢ 80 million in 2008 and 2015, respectively.

The performance of the subsidy programme has so far been commendable. It is estimated

that yields of major food crops have increased by 4% in targeted areas. Fertilizer use has also increased thereby stimulating fertilizer supplies in the country. For example, fertilizer imports in 2009 were estimated at about 223,000 t/yr compared with 113,000 and 150,000 t/yr in 2007 and 2008, respectively. This is expected to grow in the coming years.

Over the period of the implementation of the fertilizer subsidy programme from 2008 to 2013, a total of 737,248 metric tons of fertilizer was subsidized at a total cost of GH¢ 341,239,000 (US\$ 183,334,000). After successfully implementing the fertilizer subsidy, seeds of maize, rice and soybean were added to the programme in 2012. After four years of implementation the fertilizer application rate increased from 8 to 10 kg per hectare. This has led to increased productivity of the country's major staple food crops. The target is to increase application rate to at least 50 kg per hectare as recommended in the Medium Term Agricultural Sector Investment Programme (METASIP), the policy document of the Ministry of Food and Agriculture.

The Ministry of Food and Agriculture implemented targeted measures in the 2013 subsidy programme to ensure maximum reach to resource poor farmers and greater efficiency of distribution and value for money. Instead of universal fertilizer subsidy, the 2013 subsidy programme targeted smallholder farmers cultivating maize, rice, sorghum and millet with priority on food crop farmers in the savanna area of the country, out-grower farmers registered under recognized nucleus farmers/companies, food crop farmers, either on their own or as members of an out-grower scheme, and women farmers. The package for a hectare of land was four bags (50 kg each) of compound fertilizer (NPK-15-15-15 or 23-10-5) and two bags of sulphate of ammonia or urea.

6.4 Fertilizer use integrated with other practices

Integrated soil fertility management (ISFM) is the approach advocated by the Alliance for a Green Revolution in Africa (AGRA) to improve the soil fertility status of African soils. ISFM is the application of soil fertility management practices, and the knowledge to adapt these to local

conditions, which optimize fertilizer and organic resource use efficiency and crop productivity. ISFM practices include appropriate fertilizer and organic input management in combination with the utilization of improved crop varieties.

Substantial knowledge on soil management practices and technologies has been accumulated over the last 20 years, enabling the project to adequately address the intensification of maize-legume rotation and intercropping systems among small-scale Ghanaian farmers in a sustainable and environmentally beneficial manner. For example, ISFM in maize-cowpea rotation/intercropping is a proven success in northern Ghana with strong synergies between the cereal and legume phases.

Soil fertility management relies upon retention of legume residues, judicious application of mineral fertilizer, targeting fertilizer to specific phases of the rotation/intercrop (e.g. P fertilizer to the cowpea phase and N fertilizer to the maize phase).

Soybean cultivation has also caught on fairly well in Ghana and significant rotation effect has been demonstrated where soybean residues were returned to the soil.

In general farmers are aware of the beneficial effects of maize-legume rotation but in most cases, farmers tend to keep cereals or maize for the best soils under continuous cropping as maize is the major staple. Farmers have not developed the confidence of routine rotation with reliance on legumes as cash crop to purchase the cereals that they need in the years they will keep a legume crop in place of a cereal. Intercropping has always been the closest compromise.

The main limitation to the widespread adoption of maize-legume rotation/intercropping systems is lack of financial and physical access to fertilizer and availability of high-yielding legume varieties that are also well adapted to intercrop conditions. Under the Challenge Program on Water and Food (CPWF), the Savanna Agricultural Research Institute (SARI) developed a number of cowpea varieties that are high yielding under intercrop conditions.

There are inefficiencies and bottlenecks in the fertilizer distribution network which limit access

and add to the cost of fertilizer in the farming communities. Farmer-based organizations (FBO) are few and weak and therefore unable to acquire credit, fertilizer and other inputs in bulk to reduce cost. SARI, the Ministry of Food and Agriculture (MoFA) and NGOs have promoted the formation of FBOs, but these need to be strengthened and trained. Agro-dealerships are rudimentary in Ghana and lack the skills to support a vibrant agricultural growth.

6.5 Diagnosis of nutrient deficiencies in Ghana

In 2015, five trials were conducted on maize, cowpea, sorghum and groundnut in two agro-ecological zones in Ghana to compare the effect of micronutrients on yields. The diagnostic treatment (N+P+K+Mg+S+Zn+B) was compared with the treatment of the same N+P+K rate to determine if one or more of the secondary or micro nutrients resulted in increased yield. The initial results obtained from the Navrongo location showed an inconsistent but mean increase of 4.8% in maize yield due to the diagnostic package of nutrients. More diagnostic research is needed to verify this increase, to better determine the conditions under which a response is likely to occur, and to better determine which of the four secondary and micro nutrients are most deficient.

6.6 Optimizing fertilizer use in Ghana

Fertilizer use in Ghana is low and the recommended rates are usually blanket and out-moded. Even when fertilizers are subsidized they are still expensive to the smallholder farmer.

The typical crop response to applied nutrient is curvilinear to plateau. Such a yield response (vertical axis or y-axis) of maize to applied N (horizontal axis or x-axis) is displayed in Figure

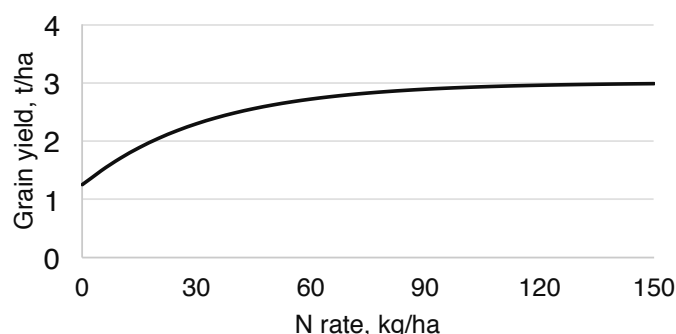


Figure 6.2: Response of maize to N application in South Sudan Savanna of Ghana.

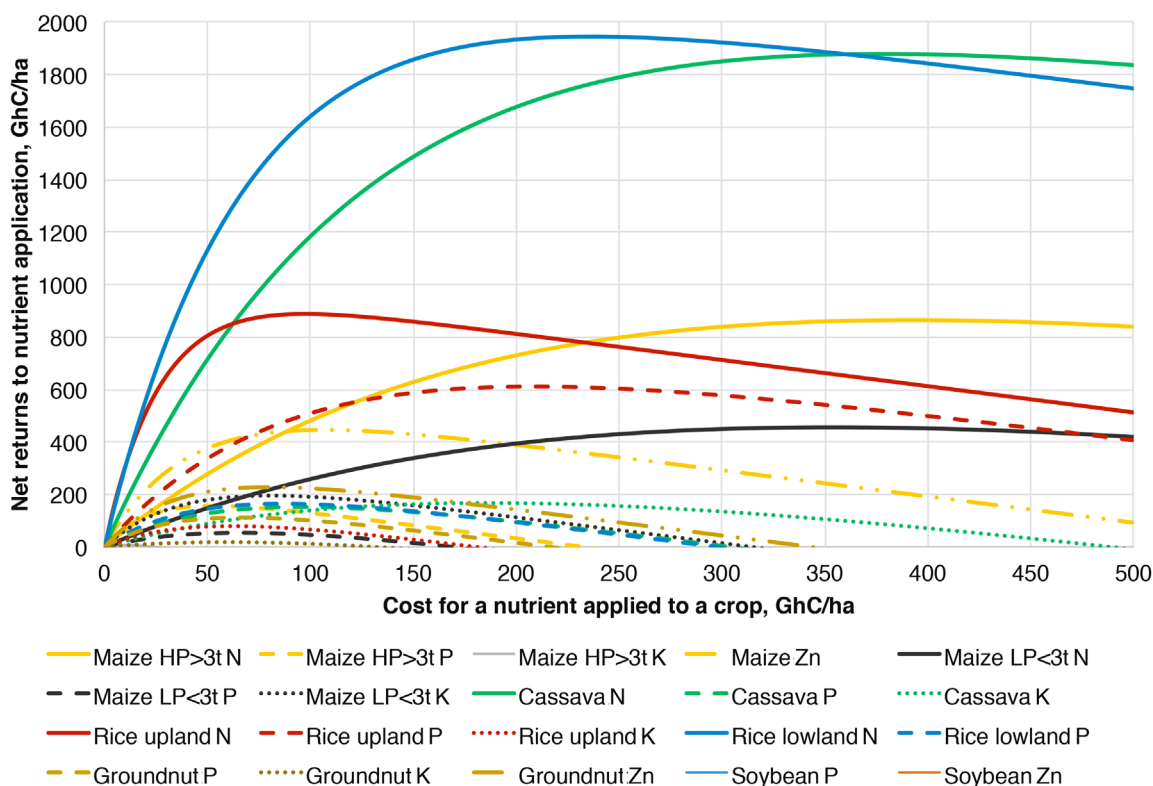


Figure 6.3: Net return from fertilizer use in the Derived Savanna Transitional Zone of Ghana. Less profitable and unprofitable nutrient applications were excluded from the figure. This graphic is dependent on grain values and fertilizer use costs. Grain and tuber values used were: 0.75, 1.52, 1.22, 2.78, 1.77 and 0.20 for maize, sorghum, rice, groundnut, soybean and cassava respectively. Fertilizer use costs were: urea = 100; TSP = 150; KCl = 150 and ZnSO₄ = GH¢ 600 per 50 kg.

6.2 with a large yield increase with increasing N at low rates, a lower rate of yield increase at higher N rates, until yield reaches a plateau with no more yield increase. This tells us that the net returns to low rates of nitrogen application are greater than with higher rates. Such response curves are typical for most crops and nutrients and are essential to determining the profitability of fertilizer use. These show that the financially constrained farmer will make more profit on a limited amount of fertilizer by applying at lower nutrient rates to more land than by applying higher rates over less land.

Another important aspect of achieving high profit from fertilizer use for financially constrained farmers is that profit potential varies with nutrients and the crops to which these are applied (Figure 6.3). In this figure, each curve represents the profit potential of a nutrient applied to a crop. When the slope of the curve is steep, net returns to investment are very high. As the amount invested increases (the x-axis) the slope decreases but if still upward, profit is increasing. The steepest slope for the Derived Savanna Transitional Zone is with about

GH¢ 20/ha (x-axis) of K applied to cassava with an expected net return of approximately GH¢ 1230/ha (y-axis). When the same amount (GH¢ 20) is invested in P applied to groundnut (on x-axis), the expected mean net return is approximately GH¢ 950 (on the y-axis) to farmers in the Derived Transitional Zone. The peak of the curves is the point of maximum profit per hectare for that nutrient applied to that crop. When slopes decline, profit is declining. The financially constrained farmer wants first to take advantage of the most profitable crop-nutrient combinations for crops in the cropping system. Making decisions in consideration of these curves for the amount of nutrient to apply to each crop is, however, very complex. Not only the agronomy of the responses to applied nutrients of the different crops of interest to farmers, but also the farmer's land allocation to different crops, the value of the commodity, the costs of fertilizer use and the money available for fertilizer use need to be considered in optimizing fertilizer use for high profit. Therefore, fertilizer optimization tools were developed using Excel Solver® (Frontline Systems Inc.) that use complex mathematics to integrate economic

and agronomic information, but which are easy to use (<https://agronomy.unl.edu>).

6.7 Fertilizer use optimization tools (FOT) for Ghana

Fertilizer Optimization Tools (FOTs) were developed to integrate the economic and agronomic aspects of the farmer's situation with the crop nutrient response functions determined from field research trials through complex calculations involving linear optimization. Fertilizer use optimization as mentioned here refers to maximizing profit from fertilizer use, including profit per hectare for the farmer with adequate finance and also profit on the small investment in fertilizer use by the financially constrained farmer. These easy to use tools were designed to make decisions to maximize profits from fertilizer use.

The FOTs were developed for four zones in Ghana as shown in the FOT input screen (Figure 6.4) for the Derived Savanna Transitional Zone. It considers high and low potential maize, cassava, upland and lowland rice, groundnut and soybean. To use the FOT, the Excel add-in Solver needs to be activated and macros need to be enabled; see the step-by-step instructions in the 'Help and Instructions' worksheet of the FOTs and more detailed instructions (Extension Materials and FOT Manual) are available at <http://agronomy.unl.edu/OFRA>.

Once Solver has been activated and macros enabled, the user enters the land areas in hectares 'Area Planted, ha' for each crop to be planted. The expected on-farm value of the commodity considering the expected value of that kept for home consumption and that to be marketed is entered 'Expected Grain Value/kg'. If a crop is not planted, '0' is entered for hectares. Next, the cost of using available fertilizers are entered considering the purchase price, and transport and application costs under 'Cost/50 kg bag'; if the fertilizer is not available, '0' is entered for the cost. An optional fertilizer can be added under the KCl row with the nutrient concentrations. Finally, the amount of money that the farmer has for fertilizer use is entered 'Budget Constraint'; in the example, GH¢ 500 is entered, an affordable budget for many smallholders. A left click on 'Optimize' runs the optimization.

The FOT output is in three tables (Figure 6.5). The upper table 'Application rate - kg/ha' gives the recommended fertilizer rates for each crop. Some recommended rates are less than 20 kg/ha and too low for feasible application; that fertilizer or money can be allocated by the user to another fertilizer application. Total fertilizer amounts recommended are 256 kg/ha of urea, 33 of kg/ha of TSP, 0 kg/ha DAP as this was not selected in the Input screen, 56 kg/ha of KCl, and just 6 kg of NPK which was generally not economically competitive with the single nutrient fertilizers.

The next table 'Expected Average Effects per ha' addresses expected average yield increases and net return per acre due to the recommended fertilizer use (Figure 6.5). This table indicates the relative profitability associated with fertilizer applied to the different crops; in the table the most profitable fertilizer use is with cassava suggesting that the farmer may want to increase area planted to cassava; this high profit potential with cassava is consistent with information in Figure 6.3.

The third table 'Total Expected Net Returns to Fertilizer' is an average estimate, adjusted for land allocated to each crop, but expecting that the net returns will be more in some years and less in other years. These results can only be expected if the farmer adheres to good agronomic practices of variety selection, planting and control of weeds, disease and pests.

Crop options are to a large extent determined by physiographic and climatic conditions, such as with sorghum and cowpea generally in drier areas and maize and beans in more humid areas. The choice of crops is done by the farmer considering crop suitability, home consumption needs, local market opportunities, credit availability and market access.

The FOTs help the farmers make decisions to maximize profit from fertilizer use. The FOTs can be used in decision making at district level so as to ensure the fertilizers that are most cost effective for the farmer are adequately available on a timely basis. For example, the results in Figure 6.5 indicate the strong need for timely availability of urea but also that TSP and KCl supply should have priority over supply of NPK.

AEZ Derived Savanna/Transitional

Producer Name: XXX
Prepared By: _____
Date Prepared: August 3, 2016

Crop Selection and Prices		
Crop	Area Planted (Ha)*	Expected Grain Value/kg †
Maize HP>3t	1	0.75
Maize LP<3t	0.5	0.75
Cassava	0.5	0.2
Rice upland	0.5	1.22
Rice lowland	0.5	1.22
Groundnut	1	2.71
Soybean	0.3	1.77
Total	4.3	

Fertilizer Selection and Prices					
Fertilizer Product	N	P2O5	K2O	Zn	Costs/50 kg bag †*
Urea	46%	0%	0%	0%	100
Triple super phosphate, TSP	0%	46%	0%	0%	150
Diammonium phosphate, DAP	18%	46%	0%	0%	0
Murate of potash, KCL	0%	0%	60%	0%	150
NPK	15%	15%	15%	0%	120

Budget Constraint	
Amount available to invest in fertilizer	500

Figure 6.4: Input data options for the computer generated FOT.

Fertilizer Optimization					
Crop	Application Rate - kg/Ha				
	Urea	TSP	DAP	KCL	NPK
Maize HP>3t	45	9	0	0	0
Maize LP<3t	0	0	0	7	0
Cassava	87	0	0	20	6
Rice upland	90	0	0	19	0
Rice lowland	35	0	0	5	0
Groundnut	0	24	0	5	0
Soybean	0	0	0	0	0
Total fertilizer needed	151	33	0	30	3
Expected Average Effects per Ha					
Crop	Yield Increases	Net Returns			
Maize HP>3t	916	571			
Maize LP<3t	177	112			
Cassava	14,952	2,740			
Rice upland	1,800	1,961			
Rice lowland	739	816			
Groundnut	297	717			
Soybean	0	0			
Total Expected Net Returns to Fertilizer					
Total net returns to investment in fertilizer	4,101				

Figure 6.5: Output after optimizing the tool showing fertilizers needed and the expected returns.

Table 6.2: An example paper Fertilizer Optimization

GHANA SOUTH GUINEA AEZ FERTILIZER USE OPTIMIZER:

Paper Version: March 2016



The below assumes:

Calibration measurement is with a: Voltic water bottle cap (cap) of 8 ml, 5.6 g urea, 8.8 g DAP, TSP, or KCl, or 8 g NPK; and with a Gino tomato can (Gino) of 70 ml to hold 49 g urea and 77 g DAP, TSP, or KCl and 70 g NPK.

Plant spacing: maize and sorghum, 75 x 40 cm; pearl millet, 100 x 40 cm; cowpea, groundnut and soybean, 40 x 20 cm and rice, 20 x 20 cm.

Grain values per kg (GH¢): Pearl millet 3; sorghum 1.52; maize 0.75; rice 1.22; groundnut unshelled 2.71; cowpea 2.43; soybean 1.77.

50 kg of fertilizer costs in GH¢: urea 100; TSP 150; KCl 150; NPK (15-15-15) 120.

Broadcast width: 2.0 m; WAP = Weeks After Planting, WAT = Weeks After Transplanting. Application rate is kg/ha. Point apply at least 5 cm from plants.

Level 1 financial ability.

Maize	point apply and cover 33 kg/ha TSP (cap for 9 hills) at 2 WAP; point apply and cover 60 kg/ha urea at 6 WAP (cap for 3.1 hills)
Lowland rice	broadcast 50 kg/ha urea at panicle initiation (Gino for 4.6 m)
Cowpea	82 kg/ha TSP 2 WAP point apply and cover (cap for 13 hills)
Sorghum	45 kg/ha TSP (cap for 7 hills) at 2 WAP
Soybean	29 kg/ha TSP at 2 WAP point apply and cover (cap for 38 hills)
Groundnut	31 kg/ha TSP (cap for 36 hills)

Level 2 financial ability.

Maize	point apply and cover 65 kg/ha urea (cap for 3 hills) and 9 kg/ha ZnSO ₄ (cap for 50 hills) at 2 WAP; point apply and cover 65 kg/ha urea at 6 WAP (cap for 3 hills). Or mix 5 Gino urea and 1 Gino ZnSO ₄ (a cap of mix for 4.5 hills)
Lowland rice	broadcast 39 kg/ha urea at 2 WAT and 39 kg/ha urea at panicle initiation (Gino for 6 m each time)
Upland rice	broadcast 38 kg/ha urea at panicle initiation (Gino for 1.2 m). Broadcast 28 kg/ha KCl at 2 WAT (cap for 1.6 m)
Cowpea	point apply and cover 110 kg/ha TSP at 2 WAP (cap for 10 hills)
Sorghum	point apply and cover 45 kg/ha urea (cap for 4 hills) and 73 kg/ha TSP (cap for 4.5 hills) at 2 WAP; point apply 45 kg/ha urea at panicle initiation (cap for 4 hills)
Soybean	point apply and cover 83 kg/ha TSP at 2 WAP (cap for 13 hills)
Groundnut	apply 43 TSP kg/ha at 2 WAP (cap for 26 hills)

Level 3 financial ability (maximize profit per hectare).

Maize	point apply and cover 75 kg/ha urea (cap for 2.5 hills) and 30 kg/ha TSP (cap for 10 hills) and 15 kg/ha ZnSO ₄ (1 cap for 32 hills) at 2 WAP; point apply and cover 75 kg/ha urea at 6 WAP (cap for 25 hills). Or mix 6 Gino TSP and 5 Gino ZnSO ₄ (cap for 6 hills)
Lowland rice	broadcast 50 kg/ha urea at 2 WAT (Gino for 94.6 m). Broadcast 50 kg/ha urea at panicle initiation (Gino for 3.2 m)
Upland rice	broadcast 64 kg/ha urea at panicle initiation (Gino for 3.5 m). Broadcast 106 kg/ha TSP (cap for 0.4 m) and 33 kg/ha KCl at 2 WAT (cap for 1.3 m)
Groundnut	point apply and cover 53 kg/ha TSP at 2 WAP (cap for 21 hills)
Cowpea	point apply and cover 133 kg/ha TSP at 2 WAP (cap for 8 hills)
Sorghum	point apply and cover 93 kg/ha TSP (cap for 3.5 hills) at 2 WAP
Soybean	point apply and cover 121 kg/ha TSP (cap for 9 hills) and 9 kg/ha ZnSO ₄ at 2 WAP (cap for 200 hills). Or mix 8 Gino TSP and 1 Gino ZnSO ₄ (cap for 7.3 m)

Optimizing fertilizer use implies that other good agronomic practices are applied and therefore adequate availability of other agricultural inputs. Therefore, for the district the FOT does not stop at making decisions for fertilizer use but decisions at a broader scale of agricultural production.

Each Excel Solver® FOT has a corresponding paper FOT to be used when a computer is not available and directly by farmers themselves (Table 6.2). These are available at <http://agronomy.unl.edu/OFRA>. The paper FOT is designed for three financial ability levels. Financial ability level 1 is for the farmer who has not more than one-third the amount required to apply fertilizer to all cropland at the rate to maximize profit per ha. Financial ability level 2 is for farmers with not more than two-thirds the amount required to apply fertilizer to all cropland at rates to maximize profit per hectare. Financial ability level 3 is for farmers with enough money to apply fertilizer at rates to maximize profit per hectare.

The paper tool makes assumptions about:

- measuring units to be used by farmers in adjusting their eyes and feel for applying the right rate of fertilizer as in Table 6.2 where the measuring units are the Voltic brand water bottle lid with a volume of 7 ml and the Gino brand tomato sauce can giving a volume of 70 ml
- crop row and plant spacing
- fertilizer use costs per 50-kg bag
- expected grain values on-farm at harvest, considering the value both for home consumption and for market
- application guidelines.

The paper FOTs address the 4Rs, advising on the right product, rate, time and method of application (Table 6.2). It also advises on calibration, that is the length of band or the number of plants/planting hills for the recommended fertilizer rate with one measuring unit.

Consider as an example from the South Guinea Savanna paper FOT the level 2 financial ability recommendation “Sorghum point apply 45 kg urea (1 lid per 8 hills) and TSP 73 kg (1 lid per

Table 6.3: Fertilizer substitution value of good agronomic practices and soil test implications

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT CONTEXT

FERTILIZER SUBSTITUTION AND SOIL TEST IMPLICATIONS



ISFM practice	Urea	DAP or TSP	KCl	NPK 15-15-15
	Fertilizer reduction, % or kg/ha			
Previous crop was a green manure crop (mucuna for maize)	100%	70%	70%	70%
Farmyard manure per 1 t of dry material (low quality)	22 kg	10 kg	10 kg	70 kg
Residual value of FYM applied for the previous crop, per 1 t	10 kg	5 kg	5 kg	35 kg
Poultry manure, per 1 t dry material	65 kg	22 kg	17 kg	200kg
Residue value of poultry manure, per 1 t dry material	32 kg	10 kg	8 kg	100 kg
Compost, per 1 t	11 kg	1 kg	1 kg	33 kg
Maize-cowpea intercropping	TSP by 22 kg/ha, but no change in N and K compared with sole maize rates			
Maize-groundnut intercropping	Increase DAP/TSP by 52 kg/ha, no change in N and K compared with maize rates			
Maize-cowpea rotation	0% reduction but more yield expected			
Rice-cowpea rotation	0% reduction but more yield expected			
If Bray-Kurtz I P > 20 ppm, or Olsen P > 30 ppm	Apply no P			
If soil test K < 100 ppm	Band apply 15 kg/ha KCl			

Table 6.4a: Derived Savanna Transitional Zone. 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 agro-ecological zones in Ghana. $P_2O_5 = P \times 2.29$; $K_2O = K \times 1.2$. Some functions have zero response because of lack of response or lack of information

Crop	Nutrient	Response coefficients, Yield = a - bc [‡] ; Elemental nutrient rate change, kg/ha			r = elemental nutrient rate, kg/ha				Recommended nutrient rate	
		A	b	c	0-30	30-60	60-90	90-120	EOR†	REC ‡
		t/ha			t/ha				kg/ha	
Maize HP>3t	N	3.787	1.936	0.978	0.955	0.484	0.245	0.124	89	90
Maize LP<3t	N	2.526	1.399	0.982	0.588	0.341	0.198	0.115	72	60
Cassava	N	44.810	11.935	0.967	7.573	2.676	1.011	0.370	98	60
Rice, upland	N	4.650	1.900	0.980	0.864	0.471	0.257	0.140	72	60
Rice, lowland	N	3.104	0.746	0.953	0.570	0.135	0.032	0.007	50	90
					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	24	26
Maize LP<3t	P	0.910	0.240	0.780	0.171	0.049	0.014	0.004	0	17
Cassava	P	28.790	1.527	0.770	1.114	0.301	0.082	0.022	12	26
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	26
Groundnut	P	4.430	0.830	0.800	0.270	0.069	0.017	0.004	23	13
Soybean	P	1.740	0.110	0.880	0.153	0.098	0.063	0.040	37	13
Maize HP>3t	K	3.759	0.036	0.550	0.035	0.002	0.000	0.000	0	50
Maize LP<3t	K	2.565	0.419	0.855	0.227	0.104	0.047	0.022	0	33
Cassava	K	34.000	6.966	0.813	4.234	1.504	0.534	0.190	23	50
Rice, upland	K	4.430	0.830	0.800	0.558	0.183	0.060	0.020	0	33
Groundnut	K	1.740	0.110	0.880	0.052	0.027	0.014	0.008	0	17
					0-1	1-2	2-3	3-4		
Maize	Zn	4.010	0.790	0.310	0.545	0.169	0.052	0.016	1.7	ND
Groundnut	Zn	1.060	0.080	0.300	0.056	0.017	0.005	0.002	0.8	ND
Soybean	Zn	1.774	0.194	0.270	0.142	0.038	0.010	0.003	1.2	ND

† EOR was determined with the cost of using 50 kg: urea 100 Gh cedis; TSP and KCl at GH cedis 150; and zinc sulphate at 600. Commodity values (GH cedis/kg) used were: rice 1.22; maize 0.75; cassava 0.20; cowpea 2.43; groundnut 2.71; soybean 1.77; and pearl millet 1.69.

‡CSIR-Soil Research Institute (SRI)

9 hills) at 2 WAP; urea 45 kg (1 lid per 8 hills) at panicle initiation.” Therefore, urea and TSP are to be applied at least 5 cm to the side of planting hills of sorghum at rates of 45 and 73 kg/ha, respectively. One Voltic bottle lid is sufficient for 8 planting hills with urea and 9 planting hills with TSP. Another 45 kg/ha urea is to be topdress applied at panicle initiation by point applying at least 5 cm away from the plant; one bottle lid is sufficient for 8 planting hills.

6.8 Adjusting fertilizer rates for other practices and soil test information

Fertilizer use decisions need to consider the effects of other practices that supply soil nutrients as well as soil test information (Table 6.3). Manure application to a field calls for adjustment in the fertilizer rate applied according to the fertilizer substitution value of the manure, which varies with the quality of manure. Manure of confined poultry, dairy, sheep and goats manure has greater fertilizer substitution value than farmyard manure.

Other practices with fertilizer substitution value considered in Table 6.3 include having a green manure crop and a cereal following a legume in rotation. Intercropping may require more fertilizer than the sole crop. Soil test values are considered. Soil test P is commonly low for smallholder fields not near the household and P should be applied according to the FOT unless the soil test P value is above 20 mg/kg by Bray 1 for soils with pH of less than 7 or above 30 mg/kg by Olsen for soils with pH greater than 7. Fertilizer K should be applied as recommended by the FOT unless the soil test K is less than 100 ppm when 15 kg/ha muriate of potash or potassium sulphate should be applied.

6.9 Targeted crops and cropping systems by AEZ

Crop responses to nutrients were determined for important food crops in each agro-ecological zone using results of past and recent field research trials (Tables 6.4 a - d). The first two columns are for crop and nutrient. Columns 3-5 have the a, b, c coefficients for the curvilinear to plateau response function, $Y = a - bc^r$. The next four columns report the expected yield increase with increased nutrient rates compared with the lower rate and the right-most columns report the optimized nutrient rate for maximizing profit per hectare due to fertilizer use (EOR) compared with the current recommended rate (REC). The commodity values and fertilizer

Table 6.4b: South Guinea Savanna, Ghana

Crop	Nutrient	Response coefficients, Yield = $a - bc^r$; Elemental nutrient rate change, kg/ha r = elemental nutrient rate, kg/ha				Recommended nutrient rate				
		a	b	c	0-30	30-60	60-90	90-120	EOR†	REC ‡
		t/ha			t/ha				kg/ha	
Maize	N	3.130	1.680	0.980	0.955	0.484	0.245	0.124	69	90
Rice, lowland	N	3.100	0.750	0.950	0.588	0.341	0.198	0.115	46	90
Rice, upland	N	2.500	0.300	0.955	0.225	0.056	0.014	0.004	29	60
Sorghum	N	1.720	0.570	0.980	0.259	0.141	0.077	0.042	46	60
					0-5	5-10	10-15	15-20		
Maize	P	3.160	0.340	0.880	0.161	0.085	0.045	0.024	6	26
Rice, upland	P	3.160	0.770	0.970	0.109	0.093	0.080	0.069	21	17
Groundnut, unshelled	P	1.580	0.360	0.760	0.269	0.068	0.017	0.004	11	13
Cowpea	P	1.060	0.185	0.890	0.082	0.046	0.025	0.014	27	13
Sorghum	P	2.190	0.800	0.890	0.353	0.197	0.110	0.062	19	17
Soybean	P	2.010	0.680	0.930	0.207	0.144	0.100	0.070	24	13
Rice, lowland	K	1.950	0.090	0.810	0.059	0.020	0.007	0.002	6	50
Rice, upland	K	4.430	0.840	0.800	0.565	0.185	0.061	0.020	16	33
Groundnut, unshelled	K	1.770	0.100	0.750	0.076	0.018	0.004	0.001	9	17
Cowpea	K	0.820	0.130	0.800	0.087	0.029	0.009	0.003	11	17
Cassava	K	34.000	6.966	0.813	4.234	1.504	0.534	0.190	23	50
Rice, upland	K	4.430	0.830	0.800	0.558	0.183	0.060	0.020	0	33
Groundnut	K	1.740	0.110	0.880	0.052	0.027	0.014	0.008	0	17
					0-1	1-2	2-3	3-4		
Maize	Zn	4.010	0.790	0.310	0.545	0.169	0.052	0.016	1.7	ND
Groundnut	Zn	1.060	0.080	0.300	0.056	0.017	0.005	0.002	0.8	ND
Soybean	Zn	1.774	0.194	0.270	0.142	0.038	0.010	0.003	1.2	ND

costs used in determining EOR are given in the footnote of Table 6.4.

Nutrient applications exceeding the field research based EOR is expected to result in loss of profit. Any nutrient application at less than EOR means less than maximum potential profit per acre to fertilizer use but lower rates are typically most profitable with financially constrained fertilizer use.

The greatest yield increase, the b value, occurred in the Derived Savanna Transitional Zone with cassava for N application (Table 6.4 a). High potential maize (HP>3t) and upland rice also had a large response to N. High potential maize, cassava, groundnut and soybean had profitable responses to applied P. Only cassava had a profitable response to K. Maize, soybean and groundnut responded well to 1 kg/ha Zn applied. The field research based EOR was: similar to the REC N for high potential maize; more than the REC for low potential maize, cassava, and upland rice; and less than the REC

for lowland rice. The EOR for P was less than the REC for most crops but higher for groundnut and soybean. The EOR for K was less than the REC for all crops and zero for most crops.

For the South Guinea Savanna, maize, upland and lowland rice, sorghum, cowpea, groundnut and soybean were considered (Table 6.4 b). Maize responded especially well to applied N but all cereals had a profitable response to N. All crops had an economical response to applied P. Upland and lowland rice, groundnut and cowpea had profitable responses to K but maize, sorghum and soybean did not. The EOR for N was always less than the REC N rates. The EOR of P for maize was less than REC rate but otherwise EOR of P was similar to REC for groundnut and sorghum, and greater than REC for the remaining crops. The EOR for K was always less than the REC.

Maize, upland rice and sorghum were especially responsive to applied N in the North Guinea Savanna (Table 6.4 c). All crops had an

Table 6.4c: North Guinea Savanna, Ghana

Crop	Nutrient	Response coefficients, Yield = a - bc; r = elemental nutrient rate, kg/ha			Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR†	REC ‡
		t/ha			t/ha				kg/ha	
Cowpea	N	0.963	0.357	0.762	0.357	0.000	0.000	0.000	9	20
Maize LP <3t	N	2.493	1.601	0.972	0.918	0.392	0.167	0.071	73	60
Maize HP >3t	N	3.513	1.808	0.981	0.791	0.445	0.250	0.141	92	90
Rice, lowland	N	2.729	0.214	0.963	0.145	0.047	0.015	0.005	22	90
Rice, upland	N	4.665	1.908	0.988	0.580	0.404	0.281	0.196	92	60
Sorghum	N	4.154	1.338	0.906	1.269	0.066	0.003	0.000	40	13
					0-5	5-10	10-15	15-20		
Cowpea	P	0.961	0.052	0.600	0.048	0.004	0.000	0.000	3	13
Groundnut	P	1.589	0.362	0.760	0.270	0.069	0.017	0.004	11	13
Maize LP <3t	P	2.678	1.653	0.980	0.159	0.144	0.130	0.117	25	17
Maize HP >3t	P	3.541	1.799	0.978	0.189	0.169	0.152	0.136	24	26
Rice, lowland	P	3.058	0.738	0.969	0.108	0.092	0.078	0.067	20	26
Rice, upland	P	3.165	0.770	0.908	0.295	0.182	0.112	0.069	19	17
Sorghum	P	1.721	0.576	0.980	0.055	0.050	0.045	0.041	14	17
Cowpea	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	7	17
Rice, lowland	K	1.951	0.091	0.810	0.059	0.021	0.007	0.003	6	50
Rice, upland	K	2.500	0.300	0.945	0.074	0.056	0.042	0.032	20	33

Table 6.4d: South Sudan Savanna, Ghana

Crop	Nutrient	Response coefficients, Yield = a – bc ² ; r = elemental nutrient rate, kg/ha			Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR†	REC ‡
		t/ha			t/ha				kg/ha	
Maize	N	3.000	1.760	0.970	1.054	0.423	0.170	0.068	69	90
Rice, upland	N	4.655	1.908	0.988	0.580	0.404	0.281	0.196	69	90
Sorghum	N	4.067	1.530	0.860	1.513	0.016	0.000	0.000	23	60
Rice, lowland	N	2.482	0.428	0.970	0.256	0.103	0.041	0.017	42	90
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	16	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	16	26
Rice, upland	P	3.633	0.979	0.904	0.388	0.234	0.141	0.085	20	26
Sorghum	P	2.770	1.470	0.910	0.553	0.345	0.215	0.134	10	26
Cowpea	P	0.929	0.040	0.700	0.033	0.006	0.001	0.000	0	9
Soybean	P	1.319	0.141	0.855	0.077	0.035	0.016	0.007	5	9
Pearl millet	P	1.520	0.129	0.900	0.053	0.031	0.018	0.011	13	17
Rice, upland	K	4.439	0.838	0.800	0.563	0.185	0.060	0.020	16	33
Sorghum	K	2.016	0.114	0.900	0.047	0.028	0.016	0.010	10	33
Rice, lowland	K	1.950	0.091	0.961	0.016	0.013	0.011	0.009	6	50
Cowpea	K	0.871	0.100	0.800	0.067	0.022	0.007	0.002	10	17
					0-1	1-2	2-3	3-4		
Maize	Zn	3.590	0.560	0.250	0.420	0.105	0.026	0.007	1.7	ND
Sorghum	Zn	4.300	0.100	0.500	0.050	0.025	0.013	0.006	1.3	ND
Soybean	Zn	1.614	0.348	0.397	0.210	0.083	0.033	0.013	0.8	ND

economical response to P and all but maize and sorghum had a profitable response to applied K. The EOR N rate was often high compared with the REC with exceptions for lowland rice and cowpea. The EOR and REC for P were similar except that EOR was much lower for cowpea. The EORs of K were always less compared with REC.

In South Sudan Savanna Zone, all crops including cowpea but excluding soybean had an economic response to applied N. All crops had a profitable response to applied P and K application was profitable for upland and lowland rice, sorghum and cowpea but not for maize, pearl millet or soybean. Recommended rates were also higher than EOR for N, P and K. The EOR of Zn was determined for maize,

sorghum and soybean but there was a lack of evidence for response to Zn by pearl millet, upland and lowland rice, and cowpea.

With the exception of N in the Derived Savanna and the North Guinea Savanna where the relationship was inconsistent, the REC compared to the field research derived EOR were on average 44 to 130% higher, and more so for K than for N and P. In 54 of the 69 crop nutrient responses considered across the four agro-ecological zones, the REC is high compared with EOR. Therefore, farmers applying fertilizer at REC are generally over-applying fertilizer with loss in profit potential. Finance-constrained farmers should generally be applying fertilizer at rates well below the EOR, gaining the profit potential typically associated

with relatively steep crop yield increases with lower rates of nutrient application. The results demonstrate the importance of providing farmers with a choice of fertilizers as the most profit potential typically lies with wise use of single nutrient fertilizers.

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