

4. Optimizing Fertilizer Use within an Integrated Soil Fertility Management Framework in Burkina Faso

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4.1 Introduction

Nutrient application is important to increase crop productivity in Burkina Faso. While fertilizer use has increased by 50% during recent decades, the mean total of N, P₂O and K₂O applied was just 15.3 kg/ha/yr in 2013 (World Bank 2013). Only 8 to 35 % of farmers use fertilizer, depending on the region, in spite of government supported subsidies.

Increased crop production has depended on increased cropland area rather than on intensification. Soil nutrients are removed in harvests without replenishment through fertilizer application resulting in soil nutrient depletion and decreased soil productivity and crop yield (Bationo et al., 1998; Ouattara et al., 2006 and 2011; Mason et al., 2014 and 2015). More fertilizer is used where farmers have support from government and non-government extension services. Fertilizer use for food crop production is often constrained because farmers are inadequately informed and have little financial capacity for fertilizer use. Also, the fertilizer supply system is inefficient with untimely delivery.

Farmers wish to profit from fertilizer use. They are more likely to apply fertilizer to cash compared with food crops. If finance is adequate, farmers may apply fertilizer to maximize net returns per hectare resulting from fertilizer use. However, for those living in ongoing financial peril with little opportunity for improvement and much vulnerability, investment in fertilizer use competes with other pressing needs. Therefore, fertilizer use must give high returns with little risk. To reduce risk in fertilizer use, the recommendation should take into consideration the farmers' cropping system and financial conditions. Aspects of farmer profitability and risk were not adequately accounted for when developing fertilizer recommendations in Burkina Faso.

Fertilizer recommendations have been developed since 1974, first for commercial peanut and cotton production. The extension service applied the cotton recommendations to cereals. However, during the 1980s, with the support of a World Bank project known as Fertilizer for Food Crops, research was conducted to develop fertilizer recommendations for maize, sorghum and pearl millet in three main agro-ecological zones (AEZ) to account for annual rainfall differences. These recommendations are still general and do not account for variation in soil type, labour capacity and climate risk. Worse, most farmers are not informed of the recommendations.

The Optimizing Fertilizer Recommendation in Africa (OFRA) project worked to improve the basis for more profitable fertilizer use decisions without increased financial risks for the major crop producing AEZ. Based on multi-location experiments for two main soil types in each agro-ecological zone and for the main crops in Burkina Faso, OFRA has improved the information basis for fertilizer use optimization. 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 small investments in fertilizer use by the financially constrained.

This chapter describes the general agricultural context of Burkina Faso, the characteristics of the AEZ, the soil types, and the main cropping. It addresses fertilizer use optimization in Burkina Faso and factors that affect profitability of fertilizer. Computer-run and paper-based decision tools are introduced for optimizing fertilizer use giving choices expected to maximize profit to fertilizer use. Also, a tool for adjusting fertilizer rates according to practices such as manure use and according to soil test information is provided. A comparison is made

of current fertilizer rate recommendations with the rates that are expected to maximize net returns per hectare due to fertilizer use, called in this chapter the economically optimal rates (EOR) of nutrient application.

4.2 Agricultural systems of the agro-ecological zones (AEZ) in Burkina Faso

The AEZ of Burkina Faso include the Sahel, the North Sudan Savanna and the South Sudan Savanna (Figure 4.1).

The Sahel is semi-arid. Mean annual rainfall in Dori, which is in this zone, is 485 mm, of which 47% falls in July, August and September (Table 4.1). Monthly mean maximum and minimum temperatures range from 32 to 42°C and from 16 to 29°C, respectively. The generally high sand content of upland soils combined with low and erratic rainfall makes the occurrence of drought a major constraint to crop production; the best adapted crops are pearl millet, cowpea and sesame. The main soils are: (i) tropical ferruginous

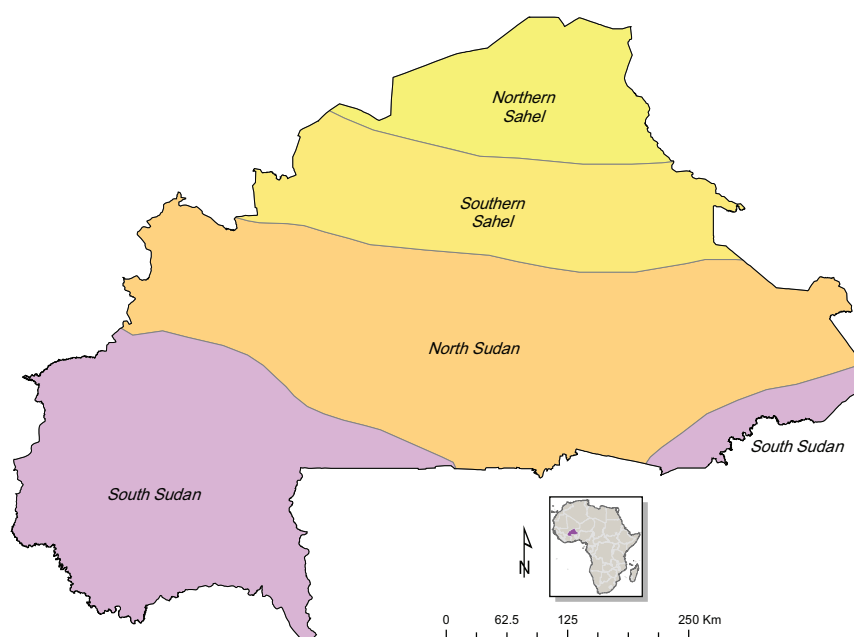


Figure 4.1: Map of the agro-ecological zones of Burkina Faso derived from the map of natural vegetation and land cover of Fontès and Guinko (1995).

Table 4.1: Mean monthly rainfall (mm) and maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of AEZ of Burkina Faso

	J	F	M	A	M	J	J	A	S	O	N	D
South Sudan Savanna, Farakoba												
Rainfall	6.8	0.0	26.1	41.5	59.7	175.0	201.5	304.4	327.7	61.2	17.3	0.3
Tmax	33.0	35.6	37.2	37.6	36.1	33.0	31.5	30.2	30.7	33.4	34.6	32.1
Tmin	19.3	22.1	24.3	25.7	25.2	23.2	22.5	22.0	21.5	22.6	22.1	18.8
North Sudan Savanna, Boni												
Rainfall	0.0	3.3	0.0	0.5	38.5	65.9	204.5	234.6	238.8	43.7	11.8	0.0
Tmax	33.0	35.6	37.2	37.6	36.1	33.0	31.5	30.2	30.7	33.4	34.6	32.1
Tmin	19.3	22.1	24.3	25.7	25.2	23.2	22.5	22.0	21.5	22.6	22.1	18.8
Sahel, Dori												
Rainfall	4.3	0.0	13.6	0.0	6.1	54.8	124.4	160.8	106.6	15.1	0.0	0.0
Tmax	32.6	34.4	38.9	41.6	42.0	39.2	36.0	33.4	35.1	39.0	37.8	32.1
Tmin	16.5	18.9	22.2	25.3	29.3	27.0	25.5	24.3	24.8	25.4	20.6	16.0

Sources: General Direction of National Agro-meteorology, Burkina Faso.

types, poorly to fully leached overlying sandy, clayey-sand and sandy-clay material; (ii) degraded holomorphic soils comprising solonetz overlying sandy-clay material; and (iii) tropical eutrophic brown soils overlying high clay parent material and poorly evolved erosional soil overlying gravelly material (CILSS and OMM, 2001). Crop and livestock production are both important and transhumance is practised. The livestock produce manure which is important to soil fertility management but also denude cropland of plant residue and expose the soil to erosion. The vegetation is characterized by Saharan and Sahelian species which are uncommon in higher rainfall areas including the woody species *Acacia ehrenbergiana*, *Acacia nilotica* variety *tomentosa*, *Acacia raddiana*, *Grewia tenax*, *Leptadenia pyrotechnica*, *Maerua crassifolia* and *Salvadora persica*. The thin riparian zones are dominated by *Anogeissus leiocarpus*, *Mitragyna inermis*, *Acacia ataxacantha* and *Acacia seyal*. The southern Sahel is a transition to the Sudan savanna and the composition of woody species changes with an increase in *Acacia laeta*, *Acacia nilotica* variety *adansonii*, *Acacia senegal*, *Boscia salicifolia*, *Commiphora africana*, *Dalbergia melanoxylon*, *Pterocarpus lucens* and *Grewia flavescens*. Sudan savanna species common in the southern Sahel are *Acacia macrostachya*, *Combretum glutinosum*, *Combretum nigricans* var. *elliottii* and form the composition of the bushes associated with *Pterocarpus lucens* and *Dalbergia melanoxylon* (Fontès and Guinka, 1995).

Mean annual rainfall in Boni, which is in the Northern Sudan Savanna, is 840 mm and 56% falls in July, August and September (Table 4.1). The rainfall season is wetter and begins earlier compared with the Sahel. Monthly mean maximum and minimum temperatures range from 30 to 38°C and from 19 to 26°C, respectively. The soils include tropical ferruginous soils, poorly evolved erosional soils and hydromorphic mineral to pseudogley soils overlying material of varied texture. The crops produced are sorghum, maize, groundnut, cotton and pearl millet, and also rice close to some seasonal streams. The Sudan Savanna becomes wetter moving south and the physiognomy is a succession of herbaceous, shrubby and bushy species, tending to a clear forest in the extreme south-west. The savanna landscape can be park-like with many big

trees including *Faidherbia albida* (known for its reverse phenology bearing leaves during the dry season but shedding leaves with the start of the rains), *Adansonia digitata*, *Butyrospermum paradoxum* subsp. *parkii*, *Lannea microcarpa* and *Tamarindus indica*. In the shrubby stratum, combretaceae are well represented. The most regular species are: *Acacia dudgeoni*, *Acacia gourmaensis*, *Acacia seyal*, *Bombax costatum*, *Combretum micranthum*, *Combretum glutinosum*, *Combretum nigricans*, *Grewia bicolore*, *Guiera senegalensis* and *Sterculia setigera*.

The South Sudan Savanna is the more humid zone. Farakoba, which is in this zone, has an annual mean rainfall of 1220 mm (Table 4.1). The wettest period is July to September when 68% of the rainfall occurs. Monthly mean maximum and minimum temperatures range from 30 to 37°C and from 19 to 26°C, respectively. The main soil types are tropical ferruginous soils poorly to fully leached, hydromorphic mineral to pseudogley soils and ferralitic soils; partly desaturated overlying variable textured material (CILSS and OMM 2001). The cropping systems are cereal- and cotton-based. The crops produced are maize, sorghum, cotton, groundnut, pearl millet and irrigated and rainfed rice.

The 'General Population and Housing Census' (GPHC) in 2006 estimated Burkina Faso's population at 13.7 million, was 52% female and had a mean population density of 40 inhabitants per sq km. The mean rate of population increase between 1996 and 2006 was 2.5% per year. The population was unevenly distributed. The Center Region, in the North Sudan Savanna, accounted for 11% of the population. The Boucle du Mouhoun Region (10.5%) and the Hauts-Bassins Region (10.3%) in the South Sudan Savanna were the next two most populous regions. Conversely, the Cascades, Southwest, and Center South regions accommodated 3.8%, 4.6%, and 4.7% of the population, respectively. More than 80% of the population lived in rural areas. The population of Center Region was 77.5% urban, followed by Hauts-Bassins Region with 34.7% of its population living in towns. In the Sahel and East Regions, only 6.5% and 6.3% of the population, respectively, lived in urban areas. The largest sociolinguistic groups were the Mossi (about 48% of the total

population) and Fulani (10%). Other ethnic groups were the Lobi, Bobo, Mande, Senoufo, Gourounsi, Gourmantche and Kel Tamasheq (Tuareg).

4.3 Soil nutrient management, including fertilizer use, in Burkina Faso

Traditional fallowing practices had various important ecological and sociological functions including restoration of soil fertility and biodiversity, hunting and supplies of medicinal plants. However, fallowing is less common than in the past due to demographic pressure and more intensive land use (Ouattara et al., 2006).

In Burkina Faso, estimates indicate that nutrient mining from 6.6 million hectares of cultivated land amounted to a total loss of 95,000 tonnes of N, 28,000 tonnes of P_2O_5 and 79,000 tonnes of K_2O , equivalent to US\$ 159 million of NPK fertilizer (Bationo et al., 1998; MAHRH 1999). Arable lands are increasingly degraded in terms of soil productivity, biodiversity and ground water recharge due to shortening fallow periods, over-grazing and animal traffic. Other traditional soil fertility management practices include land application of organic resources such as manure and household wastes. The contracting of herdsman to keep livestock overnight in the field during the dry season for excretion of urine and faeces has a strong tradition.

Fertilizer recommendations developed in the 1970s and 1980s differ by rainfall regime but do not consider other aspects of the farmer's situation. The application of organic fertilizer (OM) is recommended at 5 t/ha every two years for integration with fertilizer use. Evidence for adjusting fertilizer for soil test results is weak. OFRA activities have improved the information basis for fertilizer use decisions.

The soils in Sub-Saharan Africa are known for their low nutrient contents. Fertilizer use has resulted in crop yield increases. In on-station and on-farm trials conducted in 2014-15 in the three AEZ of Burkina Faso, nitrogen (N) application compared to the control gave mean grain yield increases of 27% for rice, 40% for sorghum, 53% for pearl millet and 181% for maize. For legume crops, P application resulted in mean yield increases of

43% for cowpea and 17% for groundnut. The diagnostic treatment containing N-P-K-S-Zn-Mg-B responded differently relative to the comparable N+P+K treatment by crop and AEZ. The percent yield increase was greater than the standard error of the mean for cowpea, maize, sorghum and rice, but the effect on pearl millet was inconsistent and groundnut was negatively affected (Figure 4.2a). The mean yield changes by AEZ, with and without manure applied, were less than the standard error except for a significant yield increase with the diagnostic treatment with no manure applied in the Sahel (Figure 4.2b). More information is needed to verify these observations and to determine which of the four nutrients of the diagnostic package accounts for these effects.

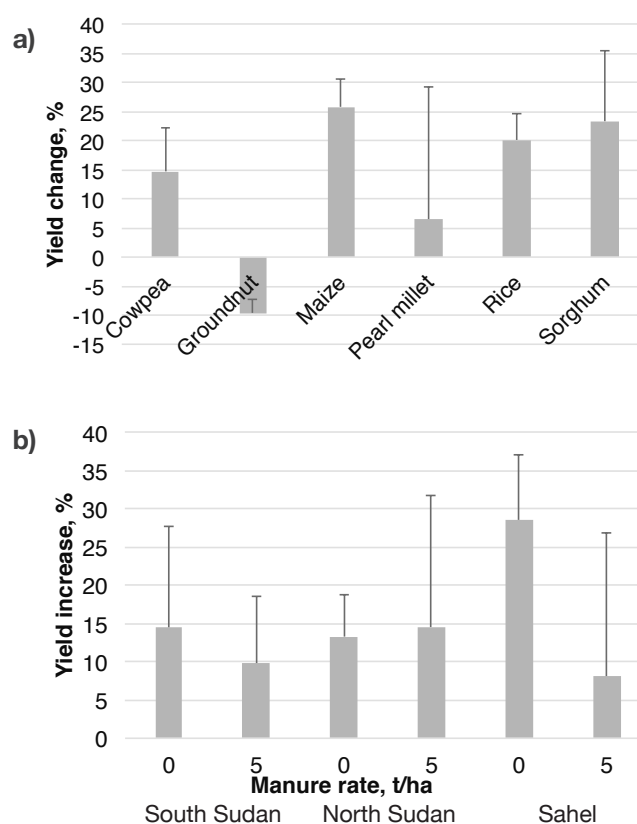


Figure 4.2: Percent yield change due to a diagnostic treatment (N+P+K+Mg+S+Zn+B) compared with N+P+K for a) several cereal and legume crops and b) by agro-ecological zone with and without 5 t/ha compost applied in Burkina Faso.

4.4 Optimizing fertilizer use in Burkina Faso

Field research under the OFRA project was conducted in 2014 and 2015 to improve the information base for fertilizer use decisions for sorghum, maize, pearl millet, rice, cowpea

and groundnut. The research was conducted on the major agricultural soil types of the three AEZ described above for determination of crop nutrient response functions for N, P and K.

Data were analyzed to determine curvilinear to plateau responses as represented by maize response to N in the South Sudan Savanna (Figure 4.3). The response curve is represented by the equation $Y = a - bc^r$ where Y = yield, a and b = maximum yield (yield at plateau) and maximum yield increase achievable, respectively,

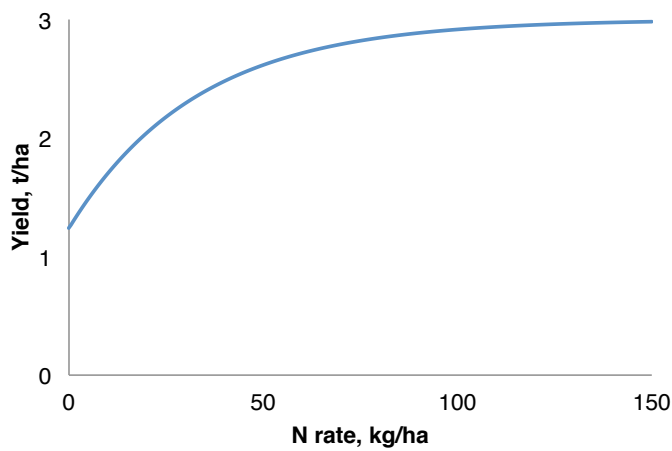


Figure 4.3: Maize response to N in the South-Sudan Savanna of Burkina Faso.

with application of this nutrient; c , together with exponent r (nutrient rate), determine the shape of the curve.

Maize yield was near the plateau with 90 kg/ha N applied but most of the yield gain was with 40 kg/ha N applied after which the rate of yield increase with more N diminished. Once the maize N response curve for yield has been determined for an AEZ, it is possible to determine net financial returns to N application at any rate, depending on fertilizer N cost and the value of maize grain, and to determine the N rate for maximizing profit per hectare from fertilizer application.

Most smallholders in Burkina Faso are financially constrained farmers who need to achieve high profit from fertilizer use. Some nutrients applied to some crops have much more profit potential than for other nutrients applied to the same or other crops (Figure 4.4). The amount of money invested in one nutrient applied to one crop is shown on the x-axis, that is, on the horizontal axis. The y-axis shows net returns to investment in one nutrient applied to one crop as the rate of nutrient application changes. Each curve represents the profit potential of one nutrient applied to one crop.

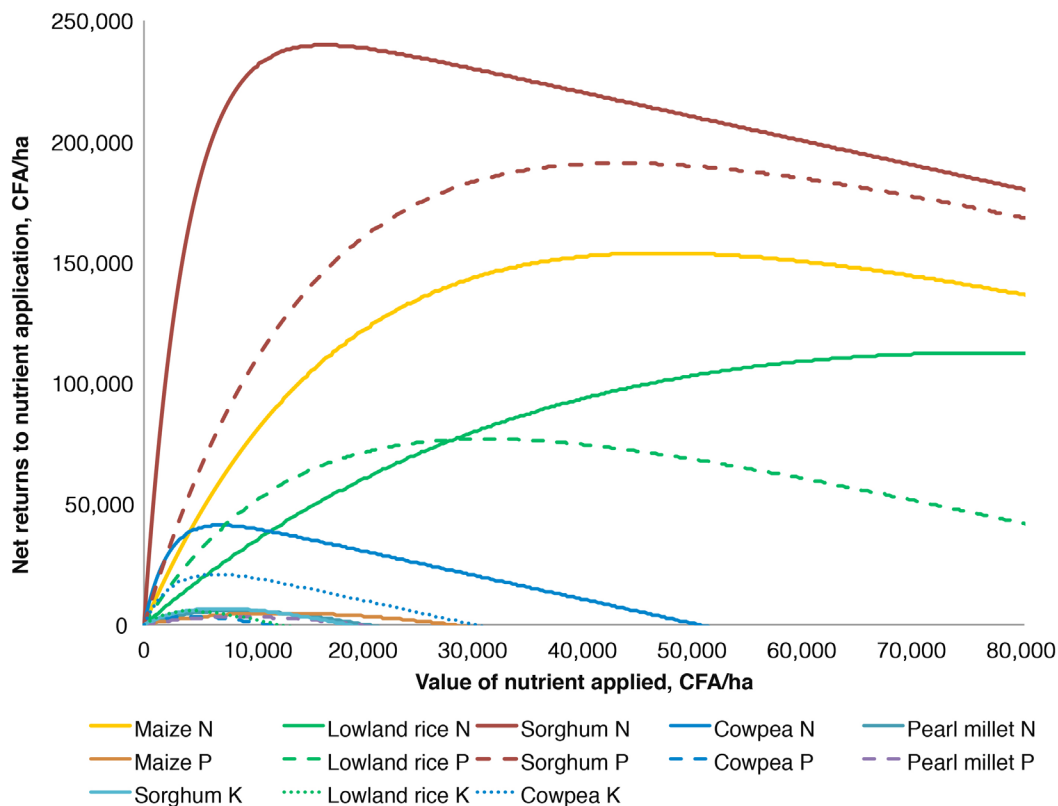


Figure 4.4: Net returns to investment in crop-nutrient for the South Sudan Savanna of Burkina Faso. The fertilizer use costs per 50-kg bag were FCFA 19000, 22500, 23000, 20750 and 23000 for urea, TSP, DAP, KCl and NPK, respectively. The crops values used were FCFA 125 per kg of maize and rice, and 150, 300, 400 and 500 per kg of sorghum, groundnut, pearl millet and cowpea respectively.

When the slope of the curve is steep, net returns to investment are very high. As the amount invested (the x-axis) increases the slope decreases but if still upward, profit is increasing. The curves reach a peak at the EOR, that is, the rate of maximum profit per hectare. When slopes decline with increased nutrient rate, profit is declining. The financially constrained farmer wants first to take advantage of the crop-nutrient combinations that will give the most net returns.

In the South Sudan Savanna, sorghum with N and P applied, and maize and lowland rice with N applied, have high profit potential with small investment (Figure 4.4). The highest rate of returns on investment is with a small amount of N applied to sorghum, up to about FCFA 5000/ha worth of N, but EOR is soon reached after which profit declines. The next steepest slope is with N applied to maize with a high rate of return up to FCFA 20,000/ha of N applied after which applying more N reduces profit. Nitrogen and P applied to rice has profit potential with the maximum return with FCFA 20,000/ha investment in P while the required investment to reach EOR for rice N is around FCFA 60,000/ha. Nitrogen and K applied to cowpea have moderate profit potential while other options with low lying curves have relatively little profit potential.

As for other AEZ of Burkina Faso, profit potential varies with crop-nutrient-rates. The financially constrained farmer needs to first take advantage of the high profit opportunities such as with N and P applied to sorghum and N applied to maize and lowland rice, if the farmer produces any of these crops. The rates of application should be less than EOR for P applied to sorghum and N applied to maize or rice as other fertilizer use options become competitive for profit potential, such as low rates of P applied to lowland rice or to maize.

The financially able farmer striving to maximize profit per hectare due to fertilizer use should not invest more than FCFA 30,000 per ha in an applied nutrient given the assumed fertilizer costs and grain values. The exception is with N applied to lowland rice in this AEZ; profit can increase by applying up to 60,000 FCFA per ha worth of N to lowland rice.

4.5 Fertilizer use optimization tools (FOT) for AEZ of Burkina Faso

Making decisions on choice of crop to fertilize and the amount of each nutrient to apply to maximize profit from fertilizer use is complex for the farmer producing several different crops. Not only the agronomy of the responses to applied nutrients by the different crops is important, but the farmer's choice of crops, expected crop values, fertilizer use costs and available money for fertilizer use need to be considered.

A computer program using linear optimization was developed for each AEZ to aid in the choice of fertilizer use options to maximize profit potential (<https://agronomy.unl.edu/OFRA>). The program is a Microsoft Excel Solver[®] (Frontline Systems Inc.) tool and is referred to as a Fertilizer Optimization Tool (FOT). The FOT uses complex mathematics in integrating the numerous crop nutrient responses functions with economic and agronomic information.

4.5.1 The Excel FOT

Use of the FOT requires the Excel add-in Solver and also for macros to be enabled. Step-by-step instructions are provided for this in the 'Help and Instructions' worksheet of the FOT. More detailed instructions are in Extension Materials and FOT Manual (<https://agronomy.unl.edu/OFRA>).

The FOT data input screen (Figure 4.5) allows for entry of how much land the farmer plans to plant for each crop of interest (under **Area planted, ha**) and the estimated commodity value on-farm at harvest time considering that some will be for home consumption (the most valuable) and that the surplus will be marketed (under **Expected grain value/kg**). The costs of using different available fertilizers are entered (under **Costs per 50 kg bag**). An additional fertilizer can be added below the four fertilizers where the fertilizer name and concentration of N-P₂O₅-K₂O-Zn can be entered (occupied by NPK 14-23-14-0 in the image at FCFA 20,000 for a 50 kg bag). Finally, the farmer's available money for fertilizer use is entered (under **Budget constraint**, 200,000 is entered). When data entry is complete, the below 'Optimize' cell is left-clicked to run the optimization.



AEZ South Sudan Savanna

Producer Name:
 Prepared By:
 Date Prepared:

Crop Selection and Prices		
Crop	Area Planted (Ha)*	Expected Grain Value/kg †
Maize	1	125
Rice Upland	1	400
Sorghum	1	150
Rice Lowland	1	400
Cowpea	1	500
Groundnut	1	300
Pearl millet	1	400
Total	7	

Fertilizer Selection and Prices					
Fertilizer Product	N	P2O5	K2O	Zn	Costs/50 kg bag ††*
Urea	46%	0%	0%	0%	19000
Triple super phosphate, TSP	0%	0%	0%	0%	22500
Diammonium phosphate, DAP	18%	46%	0%	0%	23000
Murate of potash, KCL	0%	0%	60%	0%	20750
NPK	14%	23%	14%	0%	23000

Budget Constraint	
Amount available to invest in fertilizer	200000

Figure 4.5: The input screen image of the fertilizer optimization tool for the South Sudan Savanna of Burkina Faso.

Fertilizer Optimization					
Crop	Application Rate - kg/Ha				
	Urea	TSP	DAP	KCL	NPK
Maize	54	0	0	0	0
Rice Upland	116	0	94	28	0
Sorghum	9	0	66	0	0
Rice Lowland	36	0	0	8	0
Cowpea	15	0	3	11	0
Groundnut	0	0	34	6	0
Pearl millet	0	0	0	0	0
Total fertilizer needed	229	0	197	54	0
Expected Average Effects per Ha					
Crop	Yield Increases	Net Returns			
Maize	930	95,910			
Rice Upland	2,723	990,522			
Sorghum	2,443	332,620			
Rice Lowland	225	72,681			
Cowpea	222	99,476			
Groundnut	332	81,332			
Pearl millet	1	344			
Total Expected Net Returns to Fertilizer					
Total net returns to investment in fertilizer	1,672,886				

Figure 4.6: The output screen image for the fertilizer optimization tool for the South Sudan Savanna of Burkina Faso.

The output results are displayed (Figure 4.6), including the amount of each fertilizer to apply to each crop in the upper table, the expected average yield increases and net returns per hectare for each crop in the middle table, and the total net returns to fertilizer use for the farm. Some recommended rates are too low to be feasible and it is suggest when the recommended rates are less than 20 kg/ha, the fertilizer or money be allocated elsewhere, such as the money for 9 kg/ha urea for sorghum be used to increase the DAP rate. Before such adjustments, the FOT has recommended that the available money for fertilizer use be for 229, 187 and 54 kg of urea, DAP and KCl, respectively.

In this South Sudan Savanna scenario of input data, the single nutrient fertilizers and diammonium phosphate (DAP) were found to have the greatest profit potential and the

optimized solution does not include any application of the fertilizer NPK blend. This is expected as most crops do not have an economic response to all three nutrients and use of NPK often means paying for one or more nutrient that does not result in profit to the farmer. If fertilizer type availability is limited to urea and NPK, the expected average total net returns is 1,463,156 rather than 1,672,886 as shown in Figure 4.6 with several common fertilizers available, an expected profit loss to the farmer of about 210,000.

The yield increases are greater for upland rice, maize and sorghum compared with the other crops and the greatest profit per hectare from fertilizer use is with upland rice followed by sorghum; this implies that whole farm profits from fertilizer use may be increased by allocating more land to one or both of these crops.

Table 4.2: Example paper fertilizer optimization tool

BURKINA FASO SOUTH SUDAN SAVANNA FERTILIZER USE OPTIMIZER

The below assumes:

Calibration measurement is with a Lafti water bottle lip that holds 7.5 ml and about 5.25 g urea and 8.25 g DAP, TSP or KCl, or with a Gino tomato cup of 70 ml bottle to hold 50 g urea and 77 DAP, TSP or KCl.

Row spacing: maize and sorghum at 80 cm; soybean, cowpea, and groundnut at 40 cm; and rice 20 at cm.

Grain prices per kg: 126 maize; 142 sorghum; 119 rice; 310 groundnut; 290 cowpea; 143 soybean.

Costs for use of 50 kg of fertilizer: 25,000 CFA urea and KCl; 26,000 CFA TSP and 42,000 CFA.

Broadcast width: 4 m; WAP = Week after planting.

Level 1 financial ability.

Maize	band apply 54kg/ha urea (water bottle lid for 1.2 m) at 6 WAP
Sorghum	band apply 67 kg/ha of DAP (water bottle lid for 1.1 m) at 2 WAP.
Rice, lowland	broadcast apply 36 kg/ha of urea (water bottle lid for 7 m) at panicle initiation
Groundnut	band apply 36 kg/ha of TSP (water bottle lid for 2.9 m) at 2 WAP

Level 2 financial ability.

Rice, lowland	broadcast 44 kg/ha urea (water bottle lid for 5.8 m) at 2 WAP and 44 kg/ha at panicle initiation (water bottle lid for 5.8 m)
Maize	band apply 53 kg/ha of urea (water bottle lid for 1.2 m) at 2 WAP and again at 6 WAP
Sorghum	band apply 100 kg/ha of DAP (water bottle lid for 0.8 m) at 2 WAP
Groundnut	band apply 32 kg/ha of DAP (water bottle lid for 2.4 m) and 39 kg/ha TSP (water bottle lid for 2.7 m) at 2 WAP

Level 3 financial ability (maximize profit per ha).

Rice, lowland	broadcast 50 kg/ha urea (water bottle lid for 7.6 m) and 21kg/ha KCl (water bottle lid for 17.9 m) 2 WAP; broadcast 81 kg/ha urea at panicle initiation (water bottle lid for 4.7 m)
Maize	band apply 50 kg/ha of urea (water bottle lid for 1.3 m) at 2 WAP and 39 kg/ha of DAP (water bottle lid for 0.6 m) at 6 WAP; band apply 81 kg/ha urea at 6 WAP (water bottle lid for 0.8 m)
Sorghum	band apply 100 kg/ha of DAP (water bottle lid for 0.8 m) at 2 WAP
Groundnut	band apply 100 kg/ha of TSP (water bottle lid for 1.1 m) at 2 WAP

4.5.2 Paper versions of the FOT

Very often smallholder farmers and their advisors do not have access to a computer. Therefore, a paper version of the Excel FOT was developed for each AEZ (Table 4.2). The farmer's financial ability for fertilizer use is accounted for in three levels where the budget constraint is not more than one-third or two-thirds the amount required to apply fertilizer at EOR (the rate to maximize profit per ha) to all cropland for financial level 1 and 2, respectively. With level 3, the farmer can apply at EOR to at least some of the cropland.

The paper tool makes several assumptions as listed in Table 4.2. The recommendations are given for each financial level and address the 4 Rs of fertilizer use, that is, advice is given on the product, rate, time and method of application.

Guidelines are also provided for helping the farmer to calibrate his or her eye and feel for the rate of application. For example, under

“Level 3 financial ability (maximizes profit per ha)”, the recommendation for maize is

Maize: band apply 50 kg/ha of urea (water bottle lid for 1.3 m) at 2 WAP and 39 kg/ha of DAP (water bottle lid for 0.6 m) at 6 WAP; band apply 81 kg/ha urea at 6 WAP (water bottle lid for 0.8 m). Therefore, 50 kg/ha urea and 39 kg/ha DAP are applied to maize in a band at least 5 cm from the plants and covered with soil at two weeks after planting. The farmer calibrates his or her perception of the rates by applying one Lafti brand water bottle lid of urea for 1.3 m and one Lafti lid of DAP for 0.6 m of band. A topdressing application of 81 kg/ha urea is made at six weeks after planting in a band and covering with soil. The calibration for this application is for one Lafti lid of urea to 0.8 m of band.

4.5.3 The fertilizer substitution value of other practices

Manure application and other practices can improve soil nutrient availability. After the farmer

Table 4.3: A fertilizer substitution guide for the effects of alternative crop and soil management practices.



**FERTILIZER USE WITHIN
AN INTEGRATED SOIL FERTILITY MANAGEMENT
FERTILIZER SUBSTITUTION**



ISFM practice	Urea	TSP/DAP	KCI
	Fertilizer reduction, % or kg/ha		
Previous crop was a green manure crop	100%	70%	70%
Farmyard manure per 1 t of dry material	4 kg	3 kg	2 kg
Residual value of FYM applied for the previous crop, per 1 t	2 kg	1 kg	1 kg
Poultry manure, per 1 t dry material	20 kg	13 kg	15 kg
Residual value of poultry manure applied for the previous crop, per 1 t	10 kg	6 kg	7 kg
Cattle manure, per 1 t dry material	5 kg	2 kg	3 kg
Residual value of cattle manure applied for the previous crop, per 1 t	2 kg	1 kg	2 kg
Sheep manure, per 1 t dry material	10 kg	6 kg	3 kg
Residual value of sheep manure applied for the previous crop, per 1 t	4 kg	3 kg	1 kg
Compost, per 1 t	10 kg	2 kg	2 kg
Residual value of compost applied for the previous crop, per 1 t	6 kg	1 kg	1 kg
Rotation	0% reduction but more yield expected		
Cereal-legume intercropping	Increase TSP by 7 kg/ha, but no change in N and K compared with sole cereal fertilizer		

or advisor has the FOT recommendation, consideration of the effects of other practices that may have been applied to a land parcel is suggested using Table 4.3. For example, if 2 t/ha of farmyard manure dry weight is applied, fertilizer rate reductions can be 8 kg/ha of urea, 6 kg/ha of DAP or TSP, and 4 kg/ha of KCl. Such practices are generally not applied each year to all, if any, land parcels and therefore the recommendations for most cropland are not likely to need adjustment.

4.6 Targeted crops by AEZ

Crop nutrient response functions were developed for the crops listed under AEZ in Table 4.4 a-c using results of past and recent nutrient response research. In the Sahel, crop yield response to applied P was determined to be greater compared with applied N and K (Table 4.4a). The EOR for N and K were less than the recommended rates (REC) but EOR of P was greater than REC for sorghum and pearl millet but EOR of P for cowpea and groundnut was less than REC.

Crop responses were greater with applied N compared with P for the North Sudan Savanna (Table 4.4b). The large increase in sorghum yield with just 30 kg/ha N applied is especially noteworthy suggesting a great profit opportunity but also efficient use of the applied N. There

was no evidence of response to applied K for the crops considered. The EOR and REC were similar for lowland rice N. In all other cases, EOR was less than the currently recommended application rates.

Crop responses for the South Sudan Savanna were greater for applied N compared with P, and least with applied K except for cowpea (Table 4.4c). There were large yield increases with P applied to sorghum and upland rice. Comparing EOR and REC, these were similar for maize N, cowpea N, pearl millet P and cowpea K. The EOR was more than REC for P applied to lowland rice and sorghum, both otherwise EOR was less than REC. Generally, the EOR determined from relatively recently conducted field research was less than REC. In four of the 25 crop nutrient response functions considered, the EOR was higher than REC, but the REC was on average 25% more than EOR. Therefore, the financially capable farmer loses profit opportunity by applying fertilizer at REC. The financially constrained farmer should normally be applying at rates less than EOR to gain the advantage of the greater profit potential associated with steep crop yield response to increasing nutrient rates.

Only in the South Sudan Savanna were there crops that had an economic response to each of N, P and K and these were sorghum, cowpea

Table 4.4a: The Sahel. Response functions (col. 3-5), expected yield increases (t/ha) for different increases in nutrient application rate (col 6-9), and OFRA economically optimal rate (EOR) to maximize profit per hectare (col. 10) compared to current or recent (REC) recommendations (col. 11) by agro-ecological zones in Mali. $P_2O_5 = P \times 2.29$; $K_2O = K \times 1.2$. Crop nutrient combinations not included have a lack of evidence for profitable response

Crop	Nutrient	Response coefficients, Yield = a - bc [†] ; r = elemental nutrient rate			Elemental nutrient rate change, kg/ha				Elemental nutrient rate change, kg/ha	
		A	B	C	0-30	30-60	60-90	90-120	EOR†	REC
		t/ha			t/ha				t/ha	
Pearl millet	N	0.742	0.223	0.93	0.198	0.022	0.003	0.000	21	37
Sorghum	N	1.098	0.273	0.97	0.164	0.066	0.026	0.011	18	37
					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	23	10
Sorghum	P	0.975	0.548	0.908	0.210	0.129	0.080	0.049	18	10
Groundnut	K	1.093	0.104	0.800	0.070	0.023	0.008	0.002	7	12
Cowpea	K	0.477	0.063	0.650	0.056	0.006	0.001	0.000	4	12

† EOR was determined with the cost of using 50 kg urea and TSP at CFA 13,500 and 18,000, respectively. Commodity values (CFA/kg) used were: rice 125; maize 125; sorghum 170; cowpea 200; groundnut 300; and pearl millet 200.

Table 4.4b: The North Sudan Savanna of Burkina Faso

Crop	Nutrient	Response coefficients, Yield = a - bc ^r ; r = elemental nutrient rate			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				t/ha	
Rice, lowland	N	2.483	0.429	0.974	0.234	0.106	0.048	0.022	73	74
Maize	N	2.290	1.619	0.960	1.143	0.336	0.099	0.029	56	67
Sorghum	N	4.068	1.534	0.860	1.517	0.016	0.000	0.000	22	37
					0-5	5-10	10-15	15-20		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	8	15
Cowpea	P	1.095	0.075	0.700	0.062	0.010	0.002	0.000	0	10
Groundnut	P	1.320	0.141	0.855	0.077	0.035	0.016	0.007	7	10

Table 4.4c: The South Sudan Savanna of Burkina Faso

Crop	Nutrient	Response coefficients, Yield = a - bc ^r ; r = elemental nutrient rate			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				t/ha	
Maize	N	3.000	1.760	0.970	1.054	0.423	0.170	0.068	69	67
Rice, lowland	N	4.655	1.908	0.988	0.580	0.404	0.281	0.196	61	74
Sorghum	N	4.067	1.530	0.860	1.513	0.016	0.000	0.000	25	37
Cowpea	N	1.860	0.168	0.770	0.168	0.000	0.000	0.000	13	14
Pearl millet	N	1.111	0.110	0.930	0.098	0.011	0.001	0.000	19	37
					0-5	5-10	10-15	15-20		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	8	15
Rice, lowland	P	3.633	0.979	0.904	0.388	0.234	0.141	0.085	30	20
Sorghum	P	2.770	1.470	0.910	0.553	0.345	0.215	0.134	24	10
Cowpea	P	0.929	0.040	0.700	0.033	0.006	0.001	0.000	4	10
Pearl millet	P	1.520	0.129	0.900	0.053	0.031	0.018	0.011	12	10
Sorghum	K	2.016	0.114	0.900	0.047	0.028	0.016	0.010	7	11
Rice, lowland	K	0.871	0.100	0.800	0.067	0.022	0.007	0.002	10	23
Cowpea	K	0.871	0.100	0.800	0.067	0.022	0.007	0.002	12	12

and lowland rice. For all other crop/AEZ options, the response to at least one of these nutrients was not economical. Therefore, farmers need access to single nutrient fertilizers to maximize profit from fertilizer use. An NPK blended fertilizer may supply one or two nutrients that have an economical response, but paying for the unneeded nutrients reduces the farmers' financial ability to use more fertilizer nutrients that have high profit potential. Therefore, the farmer suffers financial loss not only by paying

for unneeded nutrients but missing a profit opportunity of applying more fertilizer for crop-nutrients that have high profit potential.

4.7 References

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