

8. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Mali

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8.1 Agricultural systems of Mali

Mali is a vast country of 1,241,000 km² in the semi-arid zone of West Africa (10 ° to 25 °N and 4 °E to 12 °W; Diarra 1993; MEATEU 2000). Agriculture is the principal occupation of about 80% of the population. It accounts for 34% of GDP and 23% of exported products.

Subsistence farming dominates with agricultural produce largely consumed locally by the producers. Cropland has increased while fallow has decreased and crop mean yields, except for rice, have not increased.

Generally, smallholders readily adopt new good agricultural practices (GAP), including new varieties, use of fertilizers and good husbandry methods. Where appropriate, double cropping is practised and fertilizer use varies according to farmers' financial capacity. In the south and west of the country, inputs may be provided for cotton

and maize production and fertilizers are used more in the cereal-cotton rotation than cropping systems that do not include cotton. The value of complementing fertilizer use by manure application is recognized. Farmers welcome herdsmen to 'overnight-park' livestock on their fields during the dry season to gain the excreted urine and faeces.

A law called 'Loi d'Orientation Agricole' (LOA: Agricultural Orientation Law), enacted in 2006, has enabled government subsidies on seeds and fertilizers, mechanization of agriculture, structuring and strengthening the technical capabilities of producers and their organizations, and the establishment of an institutional framework called the High Council of Agriculture.

Mali has a dry tropical climate with an annual rainfall ranging from less than 100 mm to about 1200 mm (Table 8.1). Mali has four bioclimatic based agro-ecological zones (AEZ): Sahara,

Table 8.1: Mean monthly rainfall (mm) and maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of AEZ of Mali

	J	F	M	A	M	J	J	A	S	O	N	D
Sahara, Kidal												
Rainfall	1	0	0	1	5	12	37	46	23	3	0	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
Sahel, Niono												
Rainfall	2	0	1	4	20	56	131	171	76	17	0	0
Tmax	30	34	38	41	43	40	37	34	35	35	32	29
Tmin	15	20	24	28	30	27	25	24	24	23	18	14
Northern Sudan Savanna, Kolombada, Samanko												
Rainfall	2	1	3	22	52	119	215	268	169	55	2	0
Tmax	33	37	38	40	39	36	33	32	33	34	34	32
Tmin	15	20	22	25	26	24	24	22	22	23	18	14
Southern Sudan Savanna, Bougouni, Longorola, Finkolo												
Rainfall	2	1	7	39	98	144	242	292	206	77	9	1
Tmax	31	33	35	35	33	31	28	28	29	31	33	30
Tmin	18	24	27	28	27	25	24	23	24	24	23	21

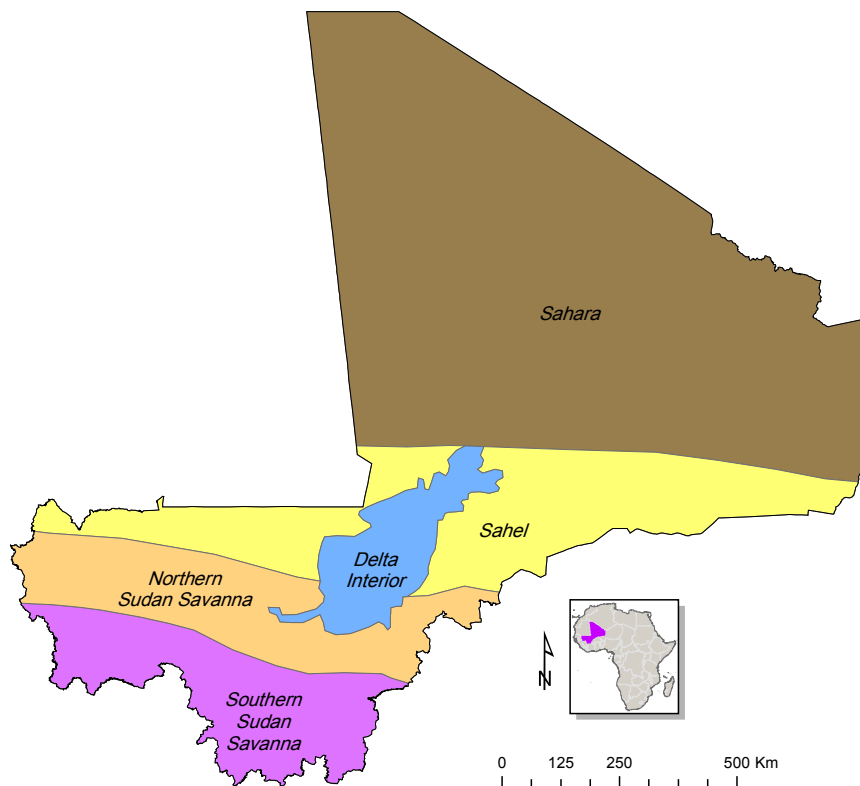


Figure 8.1: Natural regions of Mali.

Sahel, Northern Sudan Savanna, pre-Guinean zone considered here as Southern Sudan Savanna and a transverse area called the Niger River Delta (Figure 8.1).

The Sahara covers more than 50% of the country. It has an extreme spatial and temporal variability of precipitation. The annual rainfall is less than 200 mm and the temperature ranges from less than 14 to more than 42°C. The soils are sandy with low water retention capacity and much wind erosion occurs. Livestock can complement crops as the manure produced is a valuable resource if well used for crop production.

In the Sahel, the average annual rainfall is 200 to 600 mm with a rainy season from July to September during which 79% of the rainfall is received (Table 8.1). Soils are generally low in organic matter and available nutrients. Soil erosion, especially by wind is of major concern. Cereals production is hampered by frequent drought occurrence. Cattle are the main livestock but sheep and goats are also important in the northern Sahel. Manure is important for soil fertility management in this zone, but the amounts produced are insufficient for farmers' needs.

The North Sudan Savanna is characterized by annual rainfall of 600 mm to 1100 mm. The rainy season ranges from about 3 months in the north to 4 months in the south during which 90% of the rainfall is received (Table 8.1). Heavy rainfall causes leaching of nutrients. The most fertile soils are alluvial soils found in the lowlands (Soumaré 2004). This AEZ has the most agricultural potential in Mali. In addition to a relatively long rainy season and high rainfall, good soil water holding capacity in the lowlands allow for adaptation of many crops.

The South Sudan Savanna corresponds to ecosystems of open forests and woodlands. This is the most humid climatic AEZ in Mali with an annual rainfall ranging from 1100 to 1200 mm (Table 8.1). The rainy season is of 5 to 7 months duration and has some torrential rains which are major soil erosion factors. The soils consist of loam and sandy loam in the lowlands and there are areas of ferralitic soil. The wooded land covers 40 to 90% of the AEZ . Furthermore, favourable natural conditions allow the cultivation of several crop types including tubers, citrus, cereals and pulses. Major biotic constraints of this AEZ for agricultural productivity include insects, mites and birds.

8.2 Current soil fertility management

Extensive and unsustainable exploitation of natural resources has resulted in soil degradation in Mali (Koné and Doumbia 1997). Each cropping system is experiencing intensification and sustainability challenges. Increased crop yields on soils of low natural fertility requires a more intensive and effective use of fertilizer combined with manure. Most fertilizer used in Mali is imported.

Crop production is mostly rainfed and crops are grown from June to October and harvested between November and December. Over the years, farmers have adopted GAP for soil fertility management that fit their production systems. Some examples of GAP are:

- **Fallowing to restore soil fertility:** although traditionally very important (Wane 2009) fallows are becoming shorter and disappearing in some places (Dixon et al., 2001) because of population growth of 3% per year and a high pressure on lands.
- **Intercropping:** sorghum-cowpea and sorghum-peanut in the North Sudan Savanna and lowlands of the Sahel; pearl millet-cowpea in the Sahel; and annual crops with trees such as shea tree in the North Sudan Savanna and *Acacia albida* in the Sahel add to land productivity while the trees contribute to the maintenance of soil fertility.
- **Application of manure on the fields by three traditional manure delivery systems:** (a) the 'overnight-parking' arrangement with nomads with consequent deposition of faeces and urine in the fields, (b) moving

night pens from one point to another in which the deposition and trampling of faeces by animals contribute to their incorporation into the soil, and (c) fixed night pens from which the manure is transported and applied to fields (Landais and Lhoste 1993). Dry season feeding of crop residues is common with the unconsumed residue serving as bedding and eventually absorbing urine and entering into manure.

To achieve fertilizer use efficiency, recommendations should be adapted to cropping systems and rainfall amounts and distribution with rates decreasing from south to north. Good fertilizer nutrient management is referred to as the 4Rs of Nutrient Stewardship implying application of the right source of nutrients at the right rate, at the right time for efficient uptake by the crop, and with the right placement to be accessible to plant roots (Johnston and Bruulsema 2014).

Fertilizer use in Mali has increased from 84,800 tons in 1994 to 175,000 tons in 2009 and 250,000 tons in 2011, despite the unusually high fertilizer costs, or fertilizer price inflation, of 2007 and 2008. In 2012, fertilizer sales reached about 300,000 tons. This increase in imports and sales of fertilizer is mainly due to subsidies and more efficient fertilizer distribution with about 2000 input shops supplying quality fertilizers to farmers (CNFA 2010). Fertilizer blending facilities, which include Toguna Agro-Industry, Sogefert and ADP, respectively, in Bamako, Sikasso and Ségou, attempt to match blends with crop needs.

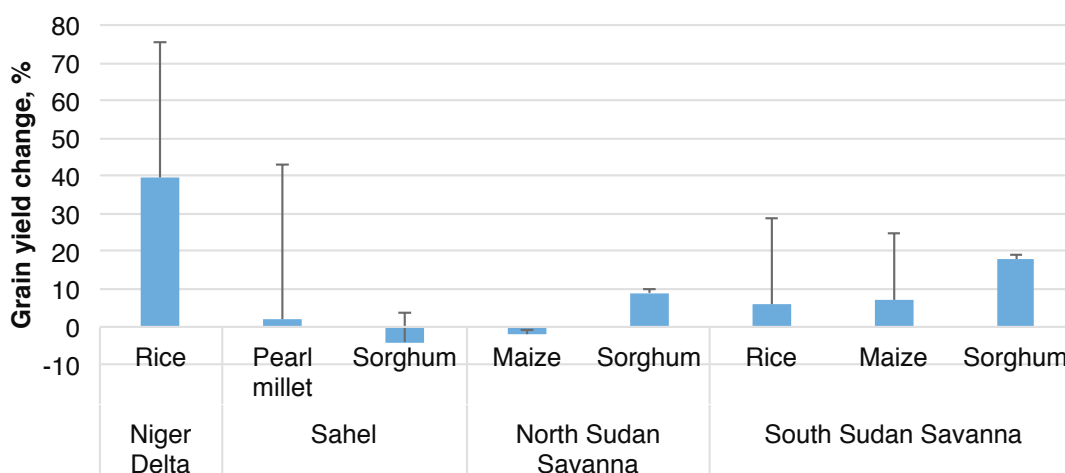


Figure 8.2: Crop response to added secondary and micronutrients (Mg, S, Zn, B) at field research sites of 2014-15 in Mali.

A concern with fertilizer supply is the low availability to farmers of single nutrient and two-nutrient compound fertilizers, with the exception of urea and DAP, although the same are imported and used to create blends. Limiting the fertilizer choice and emphasis on blends is expected to add to fertilizer cost and reduce the farmers' profit potential.

There has been some commercialization of organic resources. Companies such as Profeba, Orgafert and Elephant Vert produce municipal and industrial compost but the supply is small relative to farmer demand.

The combined use of fertilizer, organic resources and soil and water conservation techniques (Mason et al., 2014) are needed to restore and improve soil fertility (AGRA 2013). Examples of GAP integration include use of manure, micro-dose fertilizer application, improved sorghum and maize varieties, the basin tillage practice of zai and reducing runoff and erosion with stone barriers or earthen bunds. Micro-dose fertilizer use with improved cereal varieties is practised, often complemented by application of manure. Other encouraged GAP include mulching, crop rotation, managed fallow, simple and tied ridging and intercropping. In valleys, dams are sometimes used to store water for irrigation of rice and vegetable crops.

8.3 Diagnosis of nutrient deficiencies in Mali

Trials conducted in 2014-2015 included a diagnostic treatment to determine the importance of secondary and micronutrients to crop performance. This treatment contained Mg, S, Zn and B in addition to N, P and K and was compared with a treatment of the same N, P and K rates. The diagnostic treatment resulted in a mean yield increase of 39% for irrigated rice yield. However, there was not a consistent yield increase with other crops in the Sahel, North Sudan and South Sudan Savannas indicating that other biotic or abiotic factors are more constraining to yield than any of these secondary or micro-nutrients (Figure 8.2). Further investigation is needed to determine which of these nutrients are most important to irrigated rice production.

8.4 Optimizing fertilizer use in Mali

In spite of the government subsidy programme for fertilizer many poor farmers cannot afford

fertilizer use or apply inconsistently at low levels. To overcome this pitfall, optimization of fertilizer use is aimed at maximizing farmer profit from fertilizer use. Determining the economics of fertilizer use requires crop nutrient response functions. Results of numerous studies from different AEZ were used to capture crop responses to applied nutrients with a curvilinear to plateau relationship of nutrient rate with yield. This response is represented mathematically as: $Yield = a - bc^r$, where a is near maximum yield for application of that nutrient, b is the gain in yield due to application of that nutrient, and c^r determines the shape of the curvilinear response where c is a curvature coefficient and r is the nutrient rate. A response function has been established for each targeted crop-nutrient combination of three AEZ. Once such a response function has been determined, economics can be applied to estimate the profit potential for different nutrients applied to different crops.

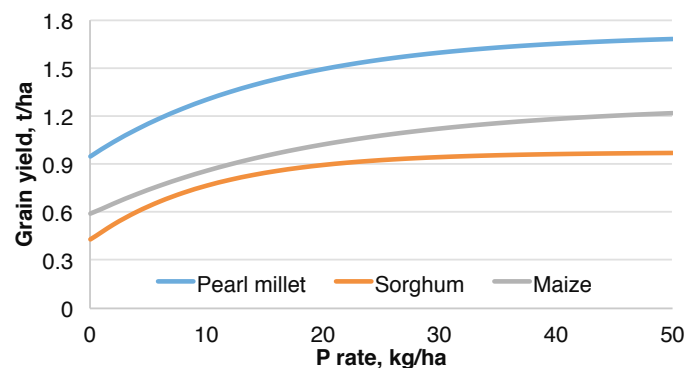


Figure 8.3: Crop responses to fertilizer P in the Sahel.

The fertilizer P response curves of maize, sorghum and pearl millet in Figure 8.3 illustrate how rate of application is important to profitability. With all curves, there is a higher rate of yield gain per kg/ha of P applied at lower compared with higher rates, especially for sorghum. Sorghum yield has a steep rate of increase as P is increased from 0 to 10 kg/ha and therefore potential for a relatively high rate of return on investment, a lesser rate for 10 to 20 kg/ha, eventually reaching a point of insufficient yield value increase to justify the cost of applying additional P. The financially constrained farmer can obtain the best returns on a limited investment in fertilizer use by applying at a rate where the response curve is relatively steep.

Another important economic consideration in fertilizer use, especially for the financially

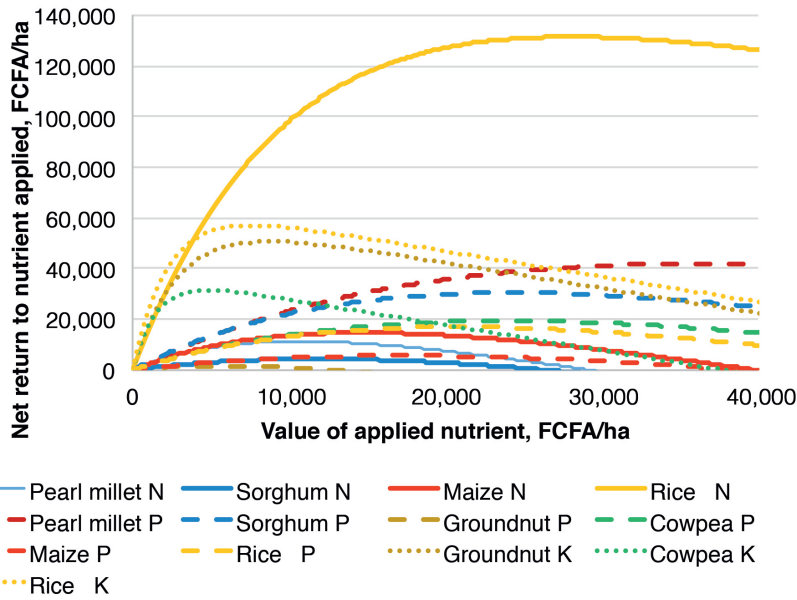


Figure 8.4a: Net return from fertilizer use in the Sahel Zone of Mali. This graphic assumes that grain values used were (in XOF) 330 for rice, 80 for maize, 130 for sorghum, 135 for pearl millet, 600 for cowpea and groundnut. Fertilizer use costs were: 13,500 for urea, 20,000 for DAP, 16,000 for TSP, 16,000 for KCl, and 13,500 for 15-15-15.

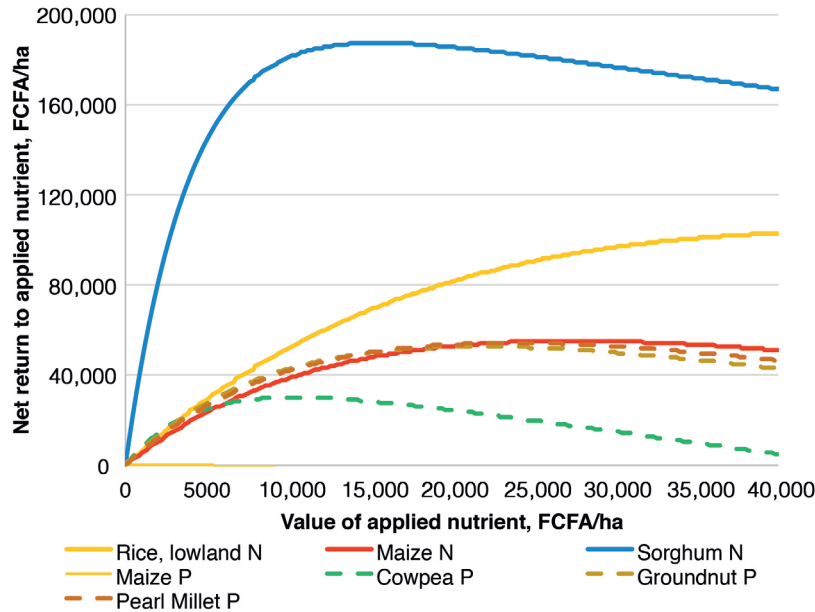


Figure 8.4b: Net return from fertilizer use in the North Sudan Savanna of Mali.

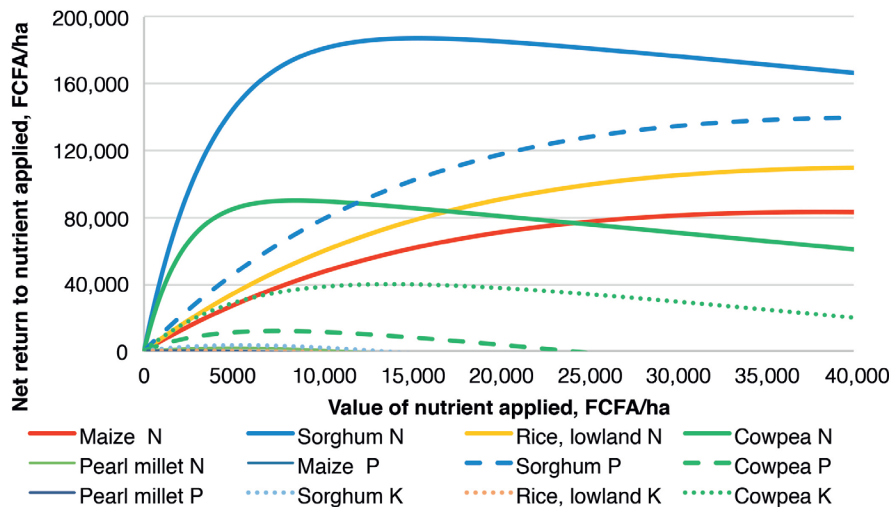


Figure 8.4c: Net return from fertilizer use in the South Sudan Savanna of Mali.

constrained farmer, is that not all nutrients applied to the same or different crops have the same profit potential. In Figures 8.4a-c, each curve represents the profit for a nutrient applied to a particular crop. The horizontal axis shows the amount invested in a nutrient applied to a crop. The vertical axis shows the net revenue resulting from the application of each nutrient to a crop. The net income tends to increase as one invests more in an applied nutrient until a peak before net income begins to decrease. The rate at the peak is referred to in this chapter as the economically optimal rate (EOR), that is the rate to maximize net returns per hectare and the targeted rate of the farmer with adequate financing. With the optimization of fertilizer use approach, the farmer's financial constraint affects the choices of fertilizer amounts to apply to different crops as the farmer wants to apply fertilizer to maximize net returns on the limited investment. When the curves are steep, the expected net returns to application of that nutrient to the crop are high.

In the Sahel region, there is high profit potential, at least at low rates of application, for N and P applied to rice, P applied to groundnut and K applied to cowpea (Figure 8.4a). The point where the yield gain is insufficient to pay for the cost of additional nutrient is at the peak of the curve and the EOR, after which profit is lost with more nutrient application. There the value of P applied to rice and of K applied to cowpea should be less than 7000 and 5000 CFCA/ha, respectively. There is good profit potential, however, with applying more P to groundnut and more N to rice. The lower lying curves also have the potential for profit, but much less potential compared with the steeper curves.

In the North Sudan Savanna, the big profit opportunity is with N applied to sorghum (Figure 8.4b). Below that, with good but less profit potential are with N applied to maize and rice, and P applied to cowpea and pearl millet. The relatively low grain price for maize reduces its profit potential. In the South Sudan Savanna, the better profit opportunities are with N applied to sorghum, P applied to rice and sorghum, and K applied to cowpea (Figure 8.3c). Therefore, the financially constrained farmer needs to choose crop-nutrient-rate

combinations appropriate to the choice of crops that have the greatest potential to maximize net returns per hectare.

8.5 Fertilizer use optimization tools for Mali

Decisions on investing in fertilizer use to optimize profit on the investment must consider a great deal of information and is potentially overwhelming, especially if the decisions are finance constrained. A farmer in the South Sudan Savanna has the implications of 14 crop-nutrient response functions to consider while accounting for their choice of crops, land allocation, expected value of commodities, the fertilizer use costs, and the amount of money to invest in fertilizer use. Therefore, fertilizer optimization tools (FOTs) were developed that work with macros created in Excel with the add-on Solver[®] (Frontline Systems Inc., Incline Village, NV, USA). These Excel FOTs use complex mathematics of linear programming which integrate crop-nutrient response information with other agronomic and economic information relevant to the farmer's specific situation (agronomy.unl.edu/OFRA). In spite of this mathematical complexity, use of the FOTs is easy. Before the FOTs can be used, the add-on Solver needs to be activated and macros need to be enabled; the steps to doing this are given in the 'Help and Instructions' worksheet of the FOT. The FOTs and instructional materials are available at (<https://agronomy.unl.edu/OFRA>).

In the input panels (Figure 8.5a), the user enters the land area allocated to each crop and expected value of the harvest, accounting for the value of that which will be kept for home consumption and the surplus to be marketed. He/she then enters the cost of using, considering purchase costs and the costs of transport and application, 50 kg bags of each fertilizer likely to be available. If a fertilizer is not available, its cost is replaced by zero. He/she finally enters the amount available for use of fertilizers; this is the budget or financial constraint. After fully informing the tool, the user left-clicks on the optimize button to launch the calculation.

The amount of each fertilizer to be applied to each crop to maximize profit is reported in the upper panel of the output (Figure 8.5b). Sometimes the recommended rates are too

AEZ_SAHEL

Producer Name:	xxx
Prepared By:	xxx
Date Prepared:	July 6, 2016

Crop Selection and Prices		
Crop	Area Planted (Ha)*	Expected Grain Value/kg †
Pearl millet	3	135
Sorghum	2	130
Groundnuts, unshelled	0.5	600
Cowpea	0.5	600
Maize	0.5	80
Rice	0.25	300
Total	6.75	

Fertilizer Selection and Prices					
Fertilizer Product	N	P2O5	K2O	xx	Costs/50 kg bag ¶*
Urea	46%	0%	0%	0%	13500
Triple super phosphate, TSP	0%	46%	0%	0%	16000
Diammonium phosphate, DAP	18%	46%	0%	0%	20000
Murate of potash, KCL	0%	0%	60%	0%	16000
NPK	15%	15%	15%	0%	13500

Budget Constraint	
Amount available to invest in fertilizer	100000

Figure 8.5a: Input panel for the Excel FOT.

Fertilizer Optimization					
Crop	Application Rate - kg/Ha				
	Urea	TSP	DAP	KCI	NPK
Pearl millet	0	0	48	0	0
Sorghum	0	22	10	0	0
Groundnuts, unshelled	0	0	0	20	0
Cowpea	0	18	0	11	0
Maize	31	0	0	0	0
Rice	65	0	21	18	0
0	0	0	0	0	0
Total fertilizer needed	32	53	170	20	0
Expected Average Effects per Ha					
Crop	Yield Increases	Net Returns			
Pearl millet	449	41,439			
Sorghum	271	24,032			
Groundnuts, unshelled	93	49,319			
Cowpea	82	40,053			
Maize	351	19,733			
Rice	751	193,591			
0	0	0			
Total Expected Net Returns to Fertilizer					
Total net returns to investment in fertilizer	275,331				

Figure 8.5b: Excel FOT output panel after optimization showing fertilizers needed and the expected returns.

Table 8.2: The paper fertilizer optimization tool for the South Sudan Savanna



MALI-South Sudan-AEZ Fertilizer Use Optimizer

The below assumes:

Calibration measurement is with: Diago water bottle lid that holds about 8 ml, 5.6 g urea, 8.8 g DAP, 8.8 g of TSP, 8.0 g NPK and 8.8 g KCl; Gino tomato can of 70 ml to hold 49 g urea, 77 g DAP, 77 g TSP, and 77 g KCl.

Planting: It is assumed maize and cowpea: 0.8 x 0.4 m; sorghum 0.8 x 0.8 m; pearl millet 1 x 0.8 m; groundnut 0.4 x 0.4 m; rice 20 cm.

Crop values: It is assumed grain prices per kg (CFA): 80 maize; 130 sorghum; 300 rice; 135 pearl millet; 600 Groundnut; 600 cowpea.

Fertilizer use costs for 50 kg: It is assumed 50 kg of fertilizer use costs (CFA): 13,500 urea; 20,000 DAP; 13,500 NPK; 16,000 TSP; 16,000 KCl.

Broadcast width: 3 m; WAP=weeks after planting, WAT=weeks after transplanting. Application rate is kg/ha.

Level 1 financial ability.

Cowpea	Point apply 35 kg NPK (1 Diago lid for 7 plants) at emergence
Maize	Point apply 11 kg urea (1 Diago lid for 20 plants) at 6 WAP
Rice, lowland	Broadcast 78 kg urea in 2 applications : 28 kg urea (1 Gino can for 7.5 m) at transplanting and 50 kg urea (1 Gino can for 4.1 m) at panicle initiation and 106 kg NPK (1 Gino can for 2 m) at transplanting, and 106 kg NPK at transplanting (1 Gino can of 70 ml for 2 m)
Sorghum	Point apply 66 kg NPK (1 Diago lid for 2 plants) at emergence

Level 2 financial ability.

Maize	Point apply 32 kg urea (1 Diago lid for 6.8 plants) at emergence and 50 kg urea (1 Diago lid for 4.8 plants) 6 WAP
Cowpea	Point apply 50 kg NPK at emergence (1 Diago lid for 5 plants)
Rice, upland	Broadcast 49 kg urea (1 Gino can for 3.3 m) at transplanting and 50 kg urea (1 Gino can lid for 7 plants) at panicle initiation and broadcast 162 kg NPK at emerging or transplanting (1 Gino can for 1 m)
Sorghum	Point apply 135 kg of NPK (1 Diago lid for 1 plant) at emergence
Rice, lowland	Broadcast 26 kg urea (1 Gino can for 6.3 m) at transplanting and 50 kg urea (1 Gino can for 3.3 m) at panicle initiation

Level 3 financial ability (maximize profit per acre).

Millet	Point apply 10 kg urea at emergence (1 Diago lid for 14 plants) and 26 kg NPK at emergence (1 Diago lid for 4 plants)
Maize	Point apply 31 kg urea (1 Diago lid for 7.5 plants) at emergence and 100 kg urea (1 Diago lid for 2 plants) 6 WAP and 33 kg NPK (1 Diago lid for 8 plants) at emergence and point apply 33 kg NPK at emergence (1 Diago lid for 8 plants)
Cowpea	Point apply 66 kg NPK at emergence (1 Diago lid for 9 plants) and 12 kg KCl at emergence (1 Diago lid for 23 plants)
Rice, upland	Broadcast 200 kg NPK at transplanting (1 Gino can for 1 m) and 50 kg at panicle initiation (1 Gino can for 3.3 m)
Sorghum	Point apply 187 kg of NPK (1 Diago lid for 1 plant) at emergence
Rice, lowland	Broadcast 35 kg Urea at transplanting (1 Gino can for 4.7 m and 100 kg urea at panicle initiation (1 Gino can for 1.6 m), and broadcast 26 kg KCl at land preparation (1 Gino can for 9.9 m)

small to be feasible, such as 10 kg/ha DAP applied to sorghum or 11 kg/ha KCl applied to cowpea. For such small rates, the money or fertilizer should be allocated to another option. The second panel shows the expected average increases in yield and net profits due

to the recommended fertilizer application for each crop. The very high net return to fertilizer applied on rice might cause the farmer to allocate more land to rice production. Finally, the total expected net return due to fertilizer use is reported.

Note that the budget constraint was FCFA 100,000 which was allocated to 32, 53, 170, 20 and 0 kg of urea, TSP, DAP, KCl and NPK 15-15-15 (Figure 8.5b). The NPK blended fertilizer is likely the most expensive to produce, but has the lowest price because of unbalanced subsidies on fertilizer types. Even though it has a low price, it was not found to be economically competitive with other fertilizers because farmers would have to pay for the three nutrients even if the crop does not have an economic response to all nutrients. The added cost would mean profit lost. It would be even more harmful to the financially constrained farmer as purchase of the NPK would mean less money available for purchase of a fertilizer that has high profit potential. In some situations where the crop has an economic response to all three nutrients, the NPK blend may be economically competitive if adequately subsidized. When the scenario of Figure 8.4 is optimized with only urea and NPK available, the expected average total net returns are only CFA 184,524 compared with CFA 275,331, and only 67% of expected profit to the farmer who has the wider choice of fertilizer. The results illustrate the importance of enabling farmer access to a choice of fertilizers if the intent is to maximize farmer profit potential.

For each Excel FOT, a companion paper FOT is developed realizing that farmers and extension workers often will not have a readily available computer (Table 8.2). The paper FOT has three financial capacity levels. Financial level 1 is the most constrained for a farmer who cannot invest more than one-third of the total amount required to apply fertilizer to all cropland at EOR. Farmers in financial level 2 have less than two-thirds the money needed to apply to all cropland at EOR. Farmers in financial level 3 have enough money to apply to at least some cropland at EOR.

The paper FOT makes assumptions about the measuring units that the farmer can use to calibrate the visual and hand-feel perception of the correct rate. It is assumed that the farmer will plant as recommended. Assumptions are made about fertilizer costs and expected grain values on-farm at harvest. The paper FOT addresses the 4Rs of fertilizer use and recommends the right product, the

right rate, the right time and the right method of application. It also informs the user on calibration of application.

Consider the paper FOT for South Sudan Savanna (Table 8.2). One of the three recommendations for the financial level 1 is "Rice lowland: Broadcast 28 kg urea (Gino for 11 m) at 0 WAT and 50 kg urea (Gino for 6 m) at panicle initiation, and 106 kg NPK (Gino for 2 m) at 0 WAT." Therefore, the farmer will broadcast apply 28 kg/ha of urea and 106 kg/ha NPK 15-15-15 to lowland rice, including irrigated rice, at transplanting time and another 50 kg/ha urea at panicle initiation. When broadcasting, he/she will broadcast with a 3 m width. He/she should use a Gino brand tomato sauce can of 70 ml for calibration of his/her sense of application to achieve the correct rate. One Gino can is enough to broadcast to an area of 3 m wide and 11 m long for the transplant application of 28 kg/ha of urea. For the transplant application of 106 kg NPK, one Gino is sufficient to broadcast an area of 3 m wide and 2 m long. For the application at panicle initiation of 50 kg urea, one Gino is enough for an area 3 m wide and 6 m long.

A constraint of the paper FOTs is that it may need to be revised yearly if there are significant changes in fertilizer costs relative to grain values. This is to be done at the national level with redistribution such as publication in newspapers as well as with on-line access. The steps to paper FOT development and revision are described in Chapter 1.

Smallholder farmers typically farm small areas of land but numerous parcels of land that differ in crop history and management. The FOTs more or less work on a whole farm basis to optimize profit for the farm enterprise. The FOTs (Excel and paper versions) give optimized recommendations for fertilizer use within the farmer's context and in situations of important agricultural land typical to an AEZ. However, optimization of fertilizer use needs to consider other practices that might affect nutrient availability on one or more of their land parcels (Table 8.3). Soil test results may indicate an adjustment in the fertilizer recommendation. Some practices, such as manure application, affect the optimal fertilizer use rate. For example, it is recommended that if farmyard manure is applied

Table 8.3: Fertilizer rate adjustments within an integrated soil fertility management framework

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT CONTEXT

FERTILIZER SUBSTITUTION AND SOIL TEST IMPLICATIONS



ISFM practice	Urea	DAP/TSP	KCl	NPK 17-17-17
	Fertilizer reduction, % or kg/ha			
Previous crop was a green manure crop (Sesbania and dolichos)	Incorporation at the end of the rainy season increase cereal grain and stover yields by 27% and 49% compared to cereal monoculture without organic amendment (Kouyaté, 2000).			
Farmyard manure per 1 t of dry material in the Sudan Savanna	11 kg	7 kg	13 kg	73 kg
Dairy or poultry manure, per 1 t dry material	53 kg	27 kg	27 kg	
Compost, per 1 t	38 kg	12 kg	14 kg	
Rotation	0% reduction in fertilizer rate but an average of 18 and 23% more cereal yield expected following cowpea compared with a cereal on loamy sand and loam respectively (Kouyaté et al., 2000).			
Cereal-other legume (effective in N fixation) intercropping	Increase DAP/TSP by 11 kg/ha, reduce urea by 9 kg/ha and no change in K compared with sole cereal fertilizer			
If soil P > 15 ppm by Bray 1	Apply no P			

in the Sudan Savanna, then urea, TSP/DAP, KCl, or NPK can be allocated elsewhere by 11, 7, 13 and 73 kg/ha per 1 t/ha manure applied (dry weight), respectively; this does not apply to the Sahel, however, as farmyard manure application commonly results in increased response to fertilizer.

8.6 Targeted crops and cropping systems by AEZ

Mali has four major AEZ for crop production. The OFRA project was implemented in areas of 450 to 1200 mm annual rainfall for the major staple cereals including maize, sorghum, millet and rice in the regions of Koulikoro (Samanko and Kolombada), Kayes (Bema), Sikasso (Bougouni, Kebila, Longorola and Finkolo) and Segou (Cinzana and Niono). Other crops were addressed using results of past research including data from neighbouring countries.

Crop nutrient response functions for N, P and K were developed (Tables 8.4a-c). The coefficients a, b and c of the response functions (column 3-5), the expected yield increase due to increments of nutrient application (column 6-9) and the EOR compared with the recommended rates are reported (column 10-11).

In the Sahel, rice and maize had more response to N compared with sorghum and pearl millet but all of the upland cereals had big responses to P (Table 8.4a). Rice and groundnut did not have economic responses to P. Only rice and cowpea had economic responses to K. EOR of N is less than half the recommended rate (REC) for maize and rice, but also less for sorghum and pearl millet. The EOR is sometimes more for P than the REC. The rice EOR for K was about 25% the REC.

In the North Sudan Savanna, maize and sorghum had greater response to N compared with rice and most of the grain yield increase occurred with 30 kg/ha applied (Table 8.4b). Responses to P were relatively small except for with pearl millet. Evidence of response to K was lacking. The N REC for rice was low compared with the rate of the Sahel and similar to the EOR for N. The EOR for N applied to rice was greater than for maize and sorghum because of the higher value for rice grain. The EOR of N were less than the REC for maize and sorghum. The EOR of P varied inconsistently with the REC.

In the South Sudan Savanna (Table 8.4c) upland rice, maize and sorghum have the best response

Table 8.4a: Sahel Zone in Mali (200-600mm). Response functions (col 3-5), expected yield increases (t/ha) for crop-nutrients (col 6-9), and OFRA economically optimal rate (EOR) to maximize profit per hectare compared to current or recent (REC) recommendations by AEZ in Mali. $P_2O_5 = P \times 2.29$; $K_2O = K \times 1.2$

Crop	Nutrient	Response coefficients, Yield = a - bc [†] ; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR†	REC
		t/ha			t/ha				kg/ha	
Pearl millet	N	0.742	0.223	0.930	0.198	0.022	0.003	0.000	21	32
Sorghum	N	1.098	0.273	0.970	0.164	0.066	0.026	0.011	20	32
Maize	N	1.275	0.687	0.951	0.535	0.118	0.026	0.006	31	84
Rice (irrigated)	N	4.461	0.564	0.942	0.470	0.078	0.013	0.002	48	120
					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	16	10
Groundnut	P	0.254	0.032	0.870	0.016	0.008	0.004	0.002	0	9
Cowpea	P	0.605	0.109	0.930	0.033	0.023	0.016	0.011	15	10
Maize	P	1.275	0.687	0.951	0.153	0.119	0.092	0.072	0	7
Rice (Irrigated)	P	5.190	0.189	0.919	0.065	0.043	0.028	0.018	14	20
Groundnut	K	1.093	0.104	0.800	0.070	0.023	0.008	0.002	0	0
Cowpea	K	0.477	0.063	0.650	0.056	0.006	0.001	0.000	8	0
Rice (irrigated)	K	6.036	0.223	0.750	0.170	0.040	0.010	0.002	12	50

†EOR was determined with grain values (in CFA) of 330 for rice, 80 for maize, 130 for sorghum, 135 for pearl millet, 600 for cowpea. Fertilizer use costs in CFA per 50 kg bag were: 13,500 for urea; 20,000 for DAP; 16,000 for TSP; 16,000 for KCl; and 13,500 for NPK 15-15-15.

Table 8.4b: North Sudan Savanna of Mali (600-1200 mm)

Crop	Nutrient	Response coefficients, Yield = a - bc [†] ; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR†	REC
		t/ha			t/ha				kg/ha	
Rice, lowland	N	2.483	0.429	0.974	0.234	0.106	0.048	0.022	67	60-80
Maize	N	2.290	1.619	0.960	1.143	0.336	0.099	0.029	54	84
Sorghum	N	4.068	1.534	0.860	1.517	0.016	0.000	0.000	26	32
					0-5	5-10	10-15	15-20		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	3	7
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	6	9
Pearl millet	P	2.010	0.662	0.870	0.332	0.165	0.082	0.041	13	10

to N and the best increase with the 0-30 kg/ha N increment. Application of P to sorghum and upland rice and of K to upland rice resulted in good yield increases. Application of N, P and K resulted in small cowpea yield increases that were economical because of the high value given to cowpea grain.

The EORs were similar to the REC for lowland and upland rice but less for maize, sorghum and pearl millet. The EOR for P was low compared to the REC for all crops except for sorghum. The EOR for K were determined for upland and lowland rice, sorghum and cowpea while REC are lacking.

Table 8.4c: South Sudan Savanna of Mali (1000-1200mm)

Crop	Nutrient	Response coefficients, Yield = a – bc; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				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	65	84
Rice, upland	N	4.655	1.908	0.988	0.580	0.404	0.281	0.196	70	60-80
Sorghum	N	4.067	1.530	0.860	1.513	0.016	0.000	0.000	28	32
Rice, lowland	N	2.482	0.428	0.970	0.256	0.103	0.041	0.017	62	60-80
Cowpea	N	1.860	0.168	0.770	0.168	0.000	0.000	0.000	15	0
Pearl millet	N	1.111	0.110	0.930	0.098	0.011	0.001	0.000	8	32
					0-5	5-10	10-15	15-20		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	2	7
Rice, upland	P	3.633	0.979	0.904	0.388	0.234	0.141	0.085	13	20
Sorghum	P	2.770	1.470	0.910	0.553	0.345	0.215	0.134	12	10
Cowpea	P	0.929	0.040	0.700	0.033	0.006	0.001	0.000	3	10
Pearl millet	P	1.520	0.129	0.900	0.053	0.031	0.018	0.011	2	10
Rice, upland	K	4.439	0.838	0.800	0.563	0.185	0.060	0.020	25	20
Sorghum	K	2.016	0.114	0.900	0.047	0.028	0.016	0.010	23	12
Rice, lowland	K	1.950	0.091	0.961	0.016	0.013	0.011	0.009	14	20
Cowpea	K	0.871	0.100	0.800	0.067	0.022	0.007	0.002	13	0

The EOR determined from field research results were more than 20% less or more than the REC for 61 and 27%, respectively, of 33 comparisons (Table 8.4a,b,c). This implies that farmers, overall, who apply fertilizer at the REC are losing profit potential due to over-application. One exception is for N applied to upland and lowland, including irrigated, rice where the EOR and REC were generally similar. However, farmers who are financially constrained in fertilizer use need to benefit from the typical curvilinear to plateau response of crops to applied nutrients and generally apply at less than EOR where yield gain for kg/ha of applied nutrient is high.

8.7 Conclusion

Fertilizer use profitability can be improved for all AEZ of Mali. Recommended rates for farmers who are not financially constrained in fertilizer use need to be adjusted to reflect EOR. Farmers who are financially constrained in fertilizer use need to have the capacity to choose the crop-nutrient-rate options that are most likely to maximize returns on their investment. Computer

run and paper-based fertilizer optimization tools have been developed to enable determination of current EOR, depending on fertilizer costs and commodity values, and to determine the combination of crop-nutrient-rates for maximizing returns on investment. The fertilizer rate adjustment in an ISFM framework is important to optimizing fertilizer use to give credit to alternative nutrient supply practices, to apply additional fertilizer when justified (such as for intercropping) and to consider soil test values. If farmer profitability is the objective of fertilizer use optimization, it is essential that farmers have an adequate choice of single nutrient or two-nutrient compound fertilizers.

8.8 Acknowledgements

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