13. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Rwanda

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13.1 Agricultural systems of Rwanda

An agro-ecological zone is a land resource mapping unit, defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use (FAO 1996). An agro-ecological zones (AEZ) map is an essential tool for agricultural planning. There are three regional classification schemes of AEZ commonly used in Rwanda. These were defined based on differences in soils, altitude and rainfall, and as such also show marked differences in cropping patterns, farm size, livestock ownership and other important household and regional characteristics. The most used in Rwanda is that of Clay and Dejaegher (1987), who defined five AEZ with emphasis on agronomic and socio-economic homogeneity within AEZ among farmers and their farming systems (Figure 13.1).

The Northwest AEZ includes parts of Western and Northern Provinces and has both temperate highlands (>1800 m above sea level (masl)) that are dominated by fertile volcanic soils and the well-watered lowlands of Lake Kivu. Temperature varies little by month but is affected by altitude with mean minimum and maximum annual temperatures of 14 and 20°C at Gisenyi, respectively, and 2°C less at Musanze. Rainfall is bimodal with mean annual totals of 1170 and 1320 mm at Gisenyi and Musanze, respectively. Major cash crops are coffee, Irish potato and pyrethrum. Major food crops are maize, sweet

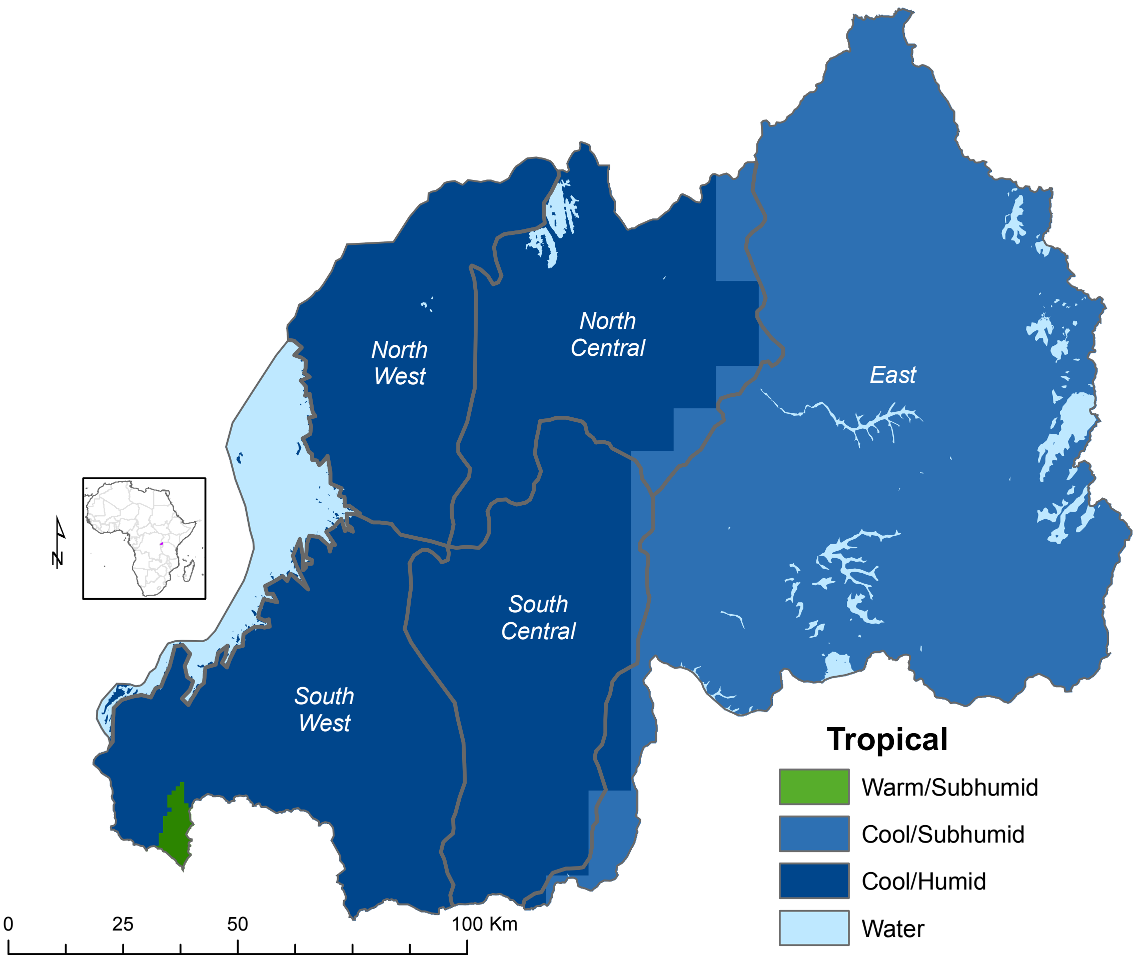

Figure 13.1: Agro-ecological zones of Rwanda.

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

Table 13.1: Rwanda farming systems

Farming system	Principal livelihoods
Cereal, root/legumes intercropping	Maize, sorghum, cassava, legumes
Banana mixed crops	Banana, common bean, maize, fodder for livestock
Cereal/root crop-legumes rotation	Maize, sorghum, potato, cassava, legumes
Sole cropping	Banana, coffee, cassava, tea, sweet potato, maize, bean, soybean, cassava, wheat and rice in marshland
Pastoral	Cattle in Eastern Rwanda
Tree crop integration	Maize, bean, Irish potato, agroforestry species (*Alnus acuminata, Calliandra callothyrsus*, etc.), green manure incorporated

potato, wheat and bean. The zone is very densely populated with 4,197,609 inhabitants (NISR, 2014).

The Southwest AEZ includes Nyamagabe District in Southern Province and the districts of Karongi, Nyamasheke and Rusizi in Western province. It is mostly high altitude with steep slopes and high rainfall, with concomitant soil erosion and soil acidity problems. A substantial but diminishing part of the Southwest AEZ is covered by the natural, protected Nyungwe Forest. Major cash crops are tea and coffee. The major food crops are bean, sweet potato, taro and cassava. Soils have a high proportion of clay, are often degraded and range from poorly to moderately suitable for agriculture. Acid soil prevails on the steep slopes of the Congo-Nile Divide and soils are fertile on the coast of Lake Kivu.

The North Central AEZ covers parts of Ruhengeri, Byumba and Kigali. It has high mountains, steep slopes and soils are susceptible to erosion. Major cash crops are bananas and coffee, with some highland areas specializing in potato and wheat. Food staples include sweet potato, bean and maize. Agro-climatically, it is quite similar to the South-Central zone.

The South Central AEZ comprises the districts from Kamonyi to Huye and part of Nyamagabe in Southern Province. The soils are acidic and require lime application. Major cash crops are banana and coffee, while the staples are bean, sweet potato, cassava, sorghum and rice in the wetlands.

The Eastern AEZ corresponds to current Eastern Province and is characterized by gentle slopes and relatively low altitude. Rainfall is less than in other AEZ. Because it is drier, livestock are important. The main staple crops are banana, sorghum, bean and cassava with coffee as an export crop.

13.2 Soil fertility management in Rwanda

Soils of Rwanda have a high clay content. Suitability classification for agriculture ranges from poor to moderate. Farming is principally by smallholders. The government supported Crop Intensification Program is based on consolidation of farmland use and facilitation of inputs access, including improved seeds and fertilizers by farmers at subsidized costs. This has resulted in increased fertilizer use from 4 to 32 kg/ha from 2007 to 2015 (NISR 2014).

Recommended rates of fertilizers (RECs) include: 41 kg N and 46 kg P_2O_5/ha for maize and wheat; 18 kg N and 46 kg P_2O_5/ha for bean and soybean; 50 kg/ha DAP for cassava; and 80 kg N, 34kg P_2O_5 and 34 kg K_2O/ha for rice. However more specific fertilizer use guidelines are needed.

The 4Rs of nutrient stewardship including the right product, rate, method and time of application needs to be applied for more fertilizer use efficiency. The ‘right’ combination of these factors needs to be location and cropping system specific.

Amendment of soil acidity and aluminium (Al) toxicity is essential for crop response to fertilizers with some soils. Deficiencies of nutrients other than macro nutrients can also limit response to N-P fertilizer. Lime application and planting of green manure crops are proven good agronomic practices although not much adopted. Minjingu rock phosphate from northern Tanzania is especially reactive on acid soils with some liming effect.

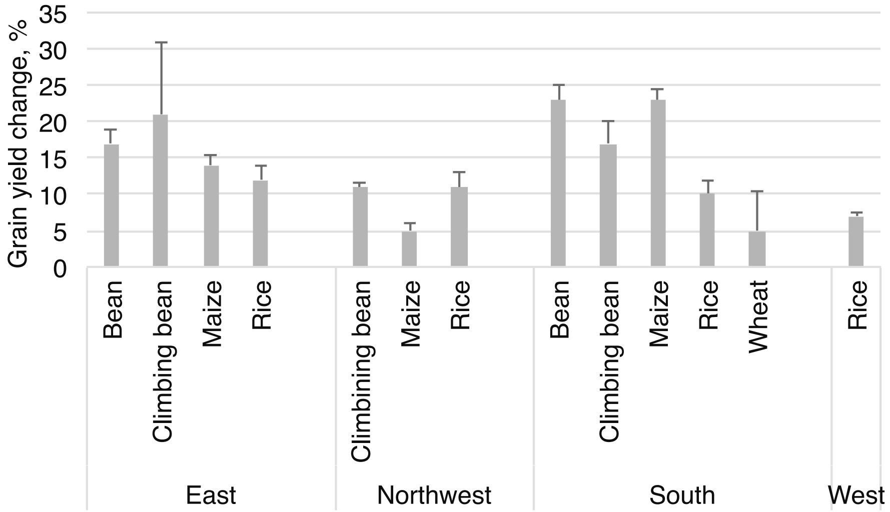

Figure 13.2: Yield change due to secondary and micronutrient application.

Nitrogen-fixing legumes are important in cropping systems; most are food crops but some farmers maintain leguminous trees. Land use and management by smallholders is very site specific in Rwanda with much crop production as diverse mixtures that vary with soil type, topographical position and distance from the household compound. The most common farming systems are summarized in Table 13.1.

13.3 Diagnosis of nutrient deficiencies in Rwanda

About 47% of soils in Rwanda are acidic, often with a pH below 5.2 and with high exchangeable Al (Beenart 1999). Plant growth and production on these soils are not only limited by low pH but also by increasing depletion of N, P, Ca and Mg, low cation exchange capacity and Al toxicity. Soil organic carbon is often low. In the volcanic highlands, crop production is highly constrained by P deficiency with high P sorption capacities (Cyamweshi et al., 2013). Research on the status of secondary and micronutrient availability is still in early stages in Rwanda.

Nutrient response trials were conducted in five AEZ during 2013-15, mostly on farmers' fields. The mean yield increases range from: 50% for bean to 94% for rice in response to applied N; 18% for rice to 59% for bean in response to applied P; and 18% for rice and 25% for bean in response to applied K. The mean responses of maize and wheat were within the same range.

These trials also included a diagnostic treatment of N+P+K+Mg+S+Zn+B that was compared to N+P+K alone. The crops were maize, rice, wheat, bush bean and climbing bean. There was a yield increase due to the diagnostic treatment of 12 to 21% in the East, 5 to 23% in the South, 5 to 11% in the Northwest and 7% in the West (Figure 13.2). This reveals that at least one of S, Mg, B and Zn are yield limiting in these AEZ.

In 2015, four levels of a secondary and micronutrient package were included in the wheat and rice trials. The mean yield increase was 10% with 5, 15, 1.25, 0.25 and 0.5 kg/ha of Mg, S, Zn, B and Cu, respectively, applied in addition to N, P and K. Doubling these rates of secondary and micronutrients increased yield by another 1%. Therefore, substantial yield increase can be achieved with low rates of application for these nutrients although the responses to N, P and K are much greater. More research is

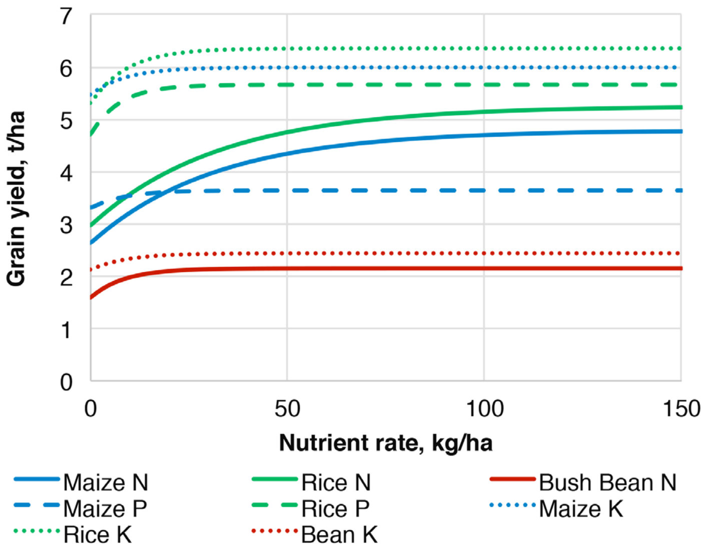

Figure 13.3: Crop response to nutrient application in Eastern AEZ.

needed to determine which of these secondary and micronutrients are most limiting.

13.4 Optimizing fertilizer use in Rwanda

Optimization of fertilizer use in this chapter refers to maximizing net return to application of nutrients as a means to improved production, food security and financial growth as well as improved profits from fertilizer application. Farming is a business and fertilizer use is one component of that business.

Fertilizer use can only be efficient and very profitable if crops are well managed; this implies investment in good quality seed of adapted varieties and control of weeds, diseases and insects as well as supplying or adding soil nutrients. Smallholder farmers, however, typically have severe financial constraints and investment in fertilizer use competes with other uses of available finance. Therefore, for the farmer with adequate access to finance, optimization of fertilizer use may mean applying fertilizer nutrients at rates to maximize profit per hectare from fertilizer which in this chapter is referred to as the economically optimal rate (EOR). For the financially constrained, however, optimization of fertilizer use is applying according to the crop-nutrient-rate combinations that will give the highest return on their limited investment.

Crop response to applied nutrients varies in magnitude and nature. The response can be negative, no response, or positive. Results from numerous trials indicated that the shape of the response is commonly curvilinear until a yield plateau is reached.

Figure 13.3 illustrates curvilinear to plateau responses of maize, rice and bush bean to applied N, P or K in eastern Rwanda with nutrient rate on the x-axis and yield on the y-axis. The magnitude of the response can be great as with N applied to maize and rice or small such as for P applied to bean. The shape of the responses differ with some being abrupt and with the yield increase occurring at low nutrient rates, such as with 10 kg/ha P applied to rice and 10 kg/ha N applied to bean. Other shapes have a more gradual curvature as with maize and rice response to N. In all cases, the yield increase per kg/ha of nutrient applied is greater at low rates as compared with higher rates of application until yield reaches a plateau beyond which increased rates of nutrient application will not result in increased yield. At some point before yield reaches the plateau, the value of yield increase per unit of applied nutrient is less than the added cost. The rate where added value equals added cost is the EOR. Therefore,

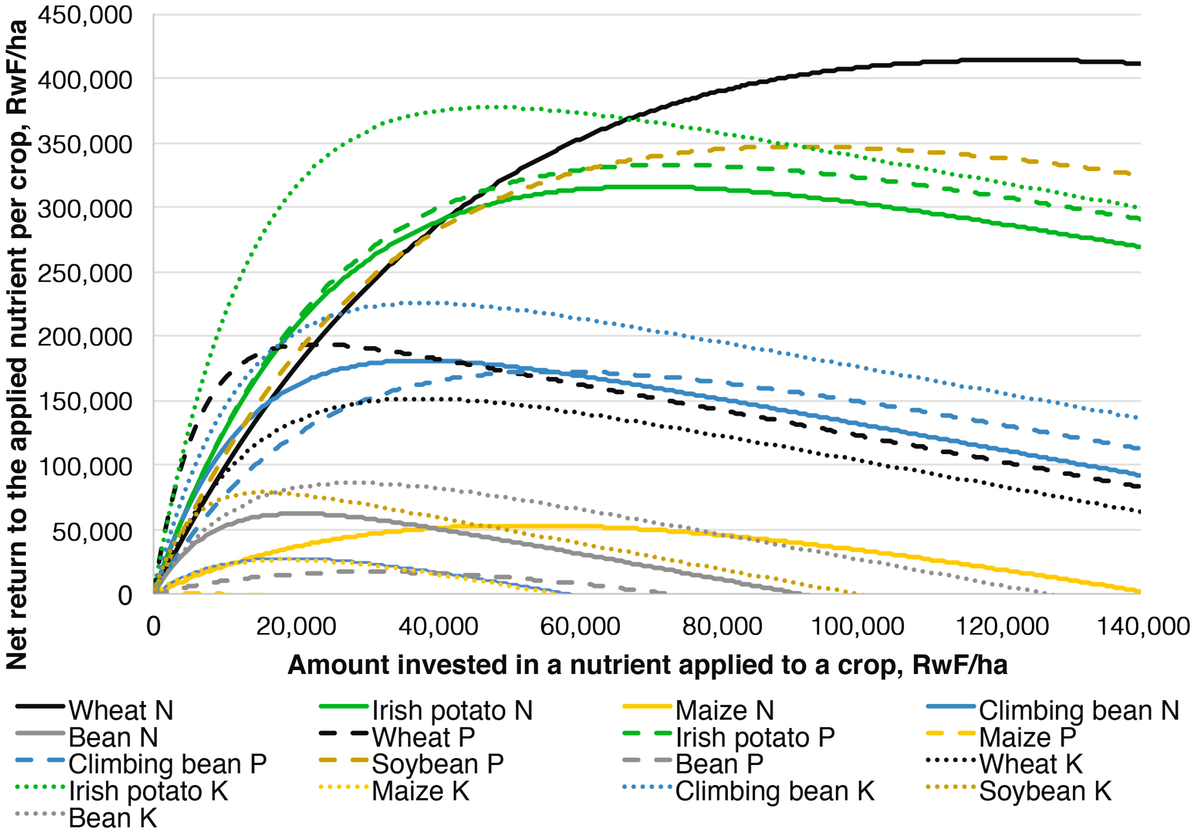

Figure 13.4: Net return to investment in the application of a nutrient to a crop in the Northwest AEZ.

Producer Name:	xxx
Prepared By:	xxx
Date Prepared:	**September 5, 2016**

Crop Selection and Prices		
Crop	**Area Planted (Are)***	**Expected Grain Value/kg †**
Banana > 0.4 t/Are	10	200
Maize	35	110
Sorghum	10	130
Lowland rice, paddy	0	400
Beans	15	400
Soybeans	10	400
Sweet potato	10	150
Total	**90**	

Fertilizer Selection and Prices					
Fertilizer Product	**N**	**P2O5**	**K2O**	**xx**	**Costs/50 kg bag ¶***
Urea	46%	0%	0%	0%	30,000
Triple super phosphate, TSP	0%	46%	0%	0%	40,000
Diammonium phosphate, DAP	18%	46%	0%	0%	40,000
Murate of potash, KCL	0%	0%	60%	0%	34,000
NPK	17%	17%	17%	0%	40,000

Budget Constraint	
Amount available to invest in fertilizer	50000

Figure 13.5: The input screen of the fertilizer optimization tool for Eastern Rwanda.

Fertilizer Optimization					
	Application Rate - kg/Are				
Crop	**Urea**	**TSP**	**DAP**	**KCL**	**NPK**
Banana > 0.4 t/Are	0.78	0.00	0.00	1.00	0.00
Maize	0.38	0.00	0.11	0.10	0.00
Sorghum	0.42	0.00	0.06	0.00	0.00
Lowland rice, paddy	0.00	0.00	0.00	0.00	0.00
Beans	0.13	0.00	0.45	0.25	0.00
Soybeans	0.00	0.00	0.96	0.19	0.00
Sweet potato	0.65	0.00	0.00	0.00	0.00
Total fertilizer needed	34	0	21	19	0

Expected Average Effects per Are		
Crop	**Yield Increases**	**Net Returns**
Banana > 0.4 t/Are	90	16,918
Maize	11	848
Sorghum	13	1,367
Lowland rice, paddy	0	0
Beans	11	3,612
Soybeans	14	7,516
Sweet potato	28	3,777

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer	379,622

Figure 13.6: Output screen for the fertilizer optimization tool of Eastern Rwanda.

the farmer whose ability to use fertilizer is limited by financial constraints can expect to get more yield increase for a small investment by applying at a low rate to more land compared with applying at a higher rate to less land.

Application of a nutrient to a crop has different profit potential compared with other nutrients applied to the same or other crops (Figure 13.4). The net returns (RwF/ha; y-axis) resulting from investment in a nutrient applied to a crop (x-axis) are shown with each curve representing the economic response to a single nutrient applied to a crop. When the curves have a steep slope, as with N applied to high potential banana or N applied to climbing bean, the potential mean returns on investment are very high. As more nutrient is applied, the slopes decrease and other crop-nutrient combinations become equally or more competitive. The peak of the curves represent the EOR; application of nutrient beyond EOR results in a decline in profit from fertilizer use due to other factors. Therefore, the financially constrained farmer needs to take advantage of the most profitable options if he/she produces these crops. In the northwest AEZ, low rates of K applied to Irish potato and P applied to wheat have high profit potential followed by low application rates of K for climbing bean and N and P for Irish potato. Application of N for climbing bean and wheat and P for soybean also has high profit potential. Other options have less profit potential. It is hoped that the high profits from optimizing fertilizer use will result in increased financial ability so that eventually fertilizer use can be EOR for all cropland.

Consideration of available information for optimizing fertilizer use by choosing the crop-nutrient-rate combinations that are expected to result in the most profit for a farmer's situation is very complex. The agronomic response of each crop to each nutrient needs to be considered but also the farmer's choice of crops, land allocation, expected commodity values, fertilizer use costs and the farmer's financial ability. Therefore, fertilizer use optimization tools (FOTs) have been developed for each AEZ in Microsoft Excel Solver© (Frontline Systems Inc., Incline Village, NV, USA). The FOTs are easy to use but involve complex mathematics of linear optimization to generate crop-nutrient-rate combinations expected to optimize returns on investment (Jansen et al., 2013).

13.5 Fertilizer use optimization tools for AEZ of Rwanda

For Rwanda, FOT have been developed for the East, Northwest and South Central AEZ. The FOT for the East AEZ is used for illustration. The FOT for the East considers banana, maize, sorghum, rice, bush bean, soybean and sweet potato (Figure 13.5). Data input for the FOT include the farmer's choice of crops and land allocation to these crops, the expected on-farm value per kg of these crops at harvest time (considers the value of the kept harvest for home consumption and the surplus to be marketed), the choice of available fertilizers, the cost of a 50-kg bag for each fertilizer and the farmer's budget constraint to fertilizer use. In this example, the farmer has 90 are of upland cropland and opts to grow all crops except for lowland rice. The budget constraint is RwF 40,000. After completing data input, a left-click on the 'Optimize' cell runs the linear optimization.

The FOT provides the fertilizer recommendations for each crop, expected average effect per acre on yield and net returns to fertilizer use for each crop, and the average expected total net return on investment (Fig. 13.6). Very low rates of application, such as the 0.13 kg/are of urea for bean, may not be feasible and that fertilizer or money might be allocated elsewhere. Consideration of the net returns per crop may prompt the farmer to change the land allocation, e.g. the net returns to fertilizer use on soybean are high compared to that for maize and sorghum and the farmer might try allocating more land to soybean and less to maize or sorghum to increase expected average total net returns to fertilizer use. As it is, the expected average returns to fertilizer use for this example are RwF 7.6 for each RwF 1 invested.

Very often, farmers and their advisors do not have ready access to a computer. Therefore, a paper FOT has been developed for each Excel FOT (Table 13.2). The paper FOTs are constructed with 3 levels of financial ability. Level 1 financial ability is for the poor farmer who has no more money than one-third the amount required to apply fertilizer to all crop land at EOR. Level 2 financial ability farmers have less than two-thirds the amount required to apply fertilizer to all cropland at EOR, while level 3 financial ability is for farmers with enough

Table 13.2: The paper version of the Fertilizer Use Optimizer for Eastern Rwanda

RWANDA (EASTERN) FERTILIZER USE OPTIMIZER: paper version

The below assumes:
Measurement is with a Inyange water bottle cap of 8.4 ml that holds about 5.9 g urea and 9.2 g of DAP, KCl and TSP, or with Inyange bottle cut at 2 cm (89 ml) to hold 62 g urea and 98 g of DAP, KCl and TSP.
It is assumed maize and sorghum are planted with 75 cm row spacing (30 cm plant spacing) and the legumes (bean, soybean, groundnuts) are planted with 50 cm row spacing. Sweet potato 80 x 30 cm. Banana 300 x 300 cm.
Fertilizer costs per 50 kg bags are: FRW 30,000 for urea; 40,000 each for TSP and DAP; 34,000 for KCl.
Commodity values per kg are: 110 for maize; 450 wheat; 400 each for sorghum, rice, bean, and soybean; sweet potato 150; and 120 banana.
Broadcast will be done at 1.5m width. Application rates are in kg/are. WAP = weeks after planting.

Level 1 financial ability.	
Banana	Apply in a circle around the plant 0.62 kg/are urea (1 2-cm bottle per 1.1 plant) and 0.62 kg/are KCl (a 2-cm bottle for 1.8 plants)
Lowland rice	Broadcast at planting 0.4 kg/are DAP (CAP for 1.6 m) and 0.45 kg/are KCl (CAP per 1.4 m); sidedress with 0.82 kg/are urea (CAP for 0.5 m) at panicle initiation
Soybean	Band at planting 0.4 kg/are DAP (CAP for 5 m)
Sweet potato	Point apply 0.42 kg/are urea at 6 WAP (CAP for 6 plants)
Level 2 financial ability.	
Banana	Apply in a circle around the plant 0.82 kg/are urea (1 2-cm bottle per 0.8 plant) and 1.0 kg/are KCl (a 2-cm bottle per 1.1 plants)
Maize	Point apply 0.5 kg/are urea at 6 WAP (CAP for 5.3 plants)
Sorghum	Point apply 0.45 kg/are urea 6 WAP (CAP for 6.3 plants)
Lowland rice	Broadcast at planting 0.62 kg/are urea, (CAP per 0.6 m); and 0.95 kg/are DAP (CAP per 0.7 m) and 0.7 kg/are KCl (CAP per 1.5 m); sidedress with 0.77 kg/are urea (CAP for 0.5 m) at panicle initiation
Bean	Band at planting 0.5 kg/are DAP (CAP for 3.7 m) and 0.52 kg/are KCl (CAP for 3.6 m)
Soybean	Band at planting time 0.82 kg/are DAP (CAP for 2.5 m)
Sweet potato	Point apply 0.7 kg/are urea at planting and 0.7 kg/are urea at 6 WAP (CAP for 3.8 plants each time)
Level 3 financial ability (maximize profit per acre).	
Banana	Apply in a circle around the plant 1 kg/are urea (2-cm bottle per 0.7 plant) and 1 kg/are KCl (a 2-cm bottle per 1.1 plants)
Maize	Point apply 0.6 kg/are DAP (CAP for 7 plants) and 0.35 kg/are KCl at planting (CAP for 11 plants). Point apply 1.22 kg/are urea 6 WAP (CAP for 2.2 plants)
Sorghum	Point apply 0.4 kg/are DAP at planting and 0.57 kg/are urea 6 WAP (CAP for 3.9 plants)
Lowland rice	Broadcast at planting 35 kg urea (CAP per 0.5 m); and 58 kg/are DAP (CAP per 0.4 m) and 0.92 kg/are KCl (CAP per 0.7 m); sidedress with 42 kg/are urea (CAP for 0.4 m) at panicle initiation
Bean	Band at planting 30 kg/are DAP (CAP for 2.6 m) and 0.42 kg/ha KCl (CAP for 4.4 m)
Soybean	Band at planting time 1.22 kg/are DAP (CAP for 1.7 m)
Sweet potato	Point apply 0.92 kg/are urea at planting and 0.92 kg/are urea at 6 WAP (CAP for 2.8 plants)

money to exceed level 2 recommendations and apply fertilizer to at least some of their cropland at EOR.

The paper FOTs are developed with some assumptions including: calibration measuring units to be used by farmers to adjust their eye and feel for the correct rate of application; row and plant spacing; commodity values; fertilizer use costs; and broadcasting width. The paper FOTs go beyond the Excel FOTs and include instructions for all 4 Rs of nutrient stewardship including the right product, rate, method and

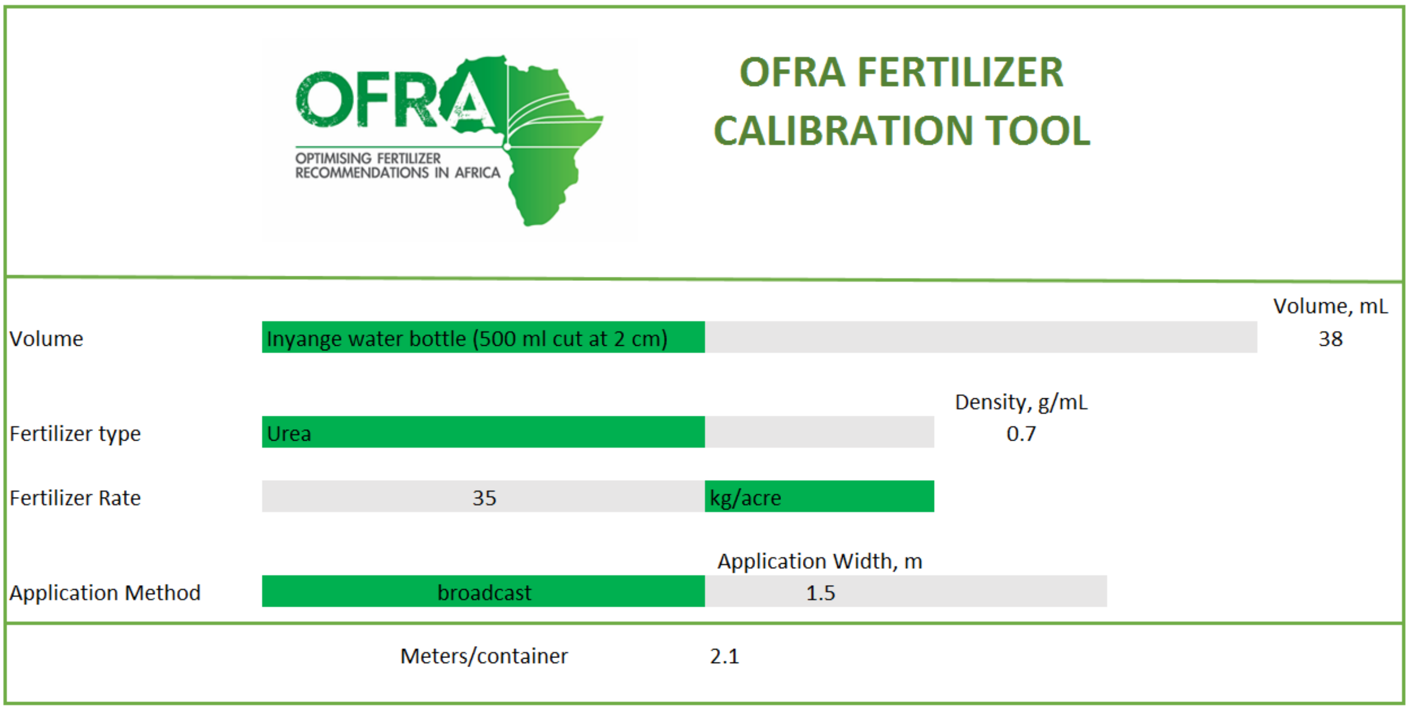

Figure 13.7: The OFRA Fertilizer Calibration Tool.

Table 13.3: Nutrient substitution and soil test implications for adapting fertilizer use rates

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT CONTEXT

ISFM practice	Urea	SSP	KCl	NPK 15-15-15
	Fertilizer reduction, % or kg/ha			
Previous crop was a green manure crop	100%	70%	70%	70%
Fresh vegetative material (e.g. prunings of Lantana or tithonia) applied, per 1 t of fresh material	10 kg	5 kg	5 kg	20 kg
Farmyard manure per 1 t of dry material	12 kg	7 kg	5 kg	20 kg
Residual value of FYM applied for the previous crop, per 1 t	5 kg	2 kg	2 kg	7 kg
Dairy or poultry manure, per 1 t dry material	20 kg	10 kg	12 kg	35 kg
Residual value of dairy and poultry manure applied for the previous crop, per 1 t	5 kg	5 kg	2 kg	7 kg
Compost, per 1 t	20 kg	7 kg	7 kg	35 kg
Residual value of compost applied for the previous crop, per 1 t	7 kg	5 kg	2 kg	12 kg
Rotation	0% reduction but more yield expected			
Cereal-bean intercropping	Increase DAP/TSP by 15 kg/ha, but no change in N and K compared with sole cereal fertilizer			
Cereal-other legume (effective in N fixation) intercropping	Increase DAP/TSP by 25 kg/ha, reduce urea by 20 kg/ha, and no change in K compared with sole cereal fertilizer			
If Mehlich III P > 15 ppm	Apply no P			
If soil test K < 100 ppm	Band apply 40 kg/ha KCl			

time of application. It also includes guidelines for farmer calibration of fertilizer application to achieve the correct rate.

The paper FOTs are easy to use and are intended for use by farmers themselves and their advisors. The farmer's budget constraint is first considered and the financial ability level is determined. Each level has several fertilizer use options, each of similar profit potential.

Consider the lowland rice recommendation under level 2 financial ability "Lowland rice. Broadcast at transplanting 0.62 kg/are urea (CAP for 0.6 m), 0.95 kg/are DAP (CAP per 0.9 m) and 0.7 kg/ha KCl (CAP per 1.3 m); 0.77 kg/are urea (CAP for 1.2 m) at panicle initiation". Therefore 0.62 kg/are of urea, 0.75 kg/are of DAP and 0.5 kg/are KCl are to be broadcast applied in passes 1.5 m wide at transplanting time. The farmer calibrates his/her eye and feel using the Inyange brand bottle lid (CAP) which is sufficient for 0.6 m for urea, 0.9 m for DAP and 1.3 m for KCl. At panicle initiation, 0.65 kg/are of urea are to be broadcast applied (one bottle lid is enough for 1.2 m).

A constraint of the paper FOT is that it requires revision by a team at the national level when there is significant change in fertilizer use costs relative to grain values.

Table 13.4a: Eastern Rwanda. Response functions, expected yield increases (t/ha) for crop-nutrients, and OFRA economically optimal rate (EOR) to maximize profit per hectare compared to current (REC) recommendation. P_2O_5 = P x 2.29; K_2O = K x 1.2. Some functions have zero response because of lack of response or lack of information

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
		t/ha			**t/ha**				**kg/ha**	
Banana >20 t/ha	N	39.250	6.625	0.903	6.315	0.296	0.014	0.001	16	34
Maize	N	5.076	2.291	0.980	1.041	0.568	0.310	0.169	67	41
Sorghum	N	2.270	1.580	0.932	1.389	0.168	0.020	0.002	34	36
Lowland rice	N	5.204	2.292	0.975	1.220	0.571	0.267	0.125	108	80
Bush Bean	N	2.048	0.473	0.860	0.468	0.005	0.000	0.000	20	18
Soybean	N	0.810	0.148	0.899	0.142	0.006	0.000	0.000	15	18
Sweet potato	N	9.500	3.074	0.925	2.778	0.268	0.026	0.002	37	18
					0-5	**5-10**	**0-15**	**15-20**		
Maize	P	5.257	0.859	0.907	0.332	0.204	0.125	0.077	8	20
Sorghum	P	2.018	0.478	0.867	0.244	0.119	0.059	0.029	6	16
Lowland rice	P	5.766	0.937	0.919	0.323	0.212	0.139	0.091	24	15
Bean	P	2.235	0.509	0.833	0.305	0.122	0.049	0.020	12	20
Soybean	P	1.981	1.185	0.893	0.512	0.291	0.165	0.094	23	20
Banana >20 t/ha	K	37.177	3.302	0.970	0.466	0.401	0.344	0.295	66	28
Maize	K	6.226	0.626	0.924	0.204	0.138	0.093	0.062	18	0
Lowland rice	K	6.617	1.351	0.928	0.421	0.290	0.200	0.137	45	28
Bean	K	2.506	0.356	0.930	0.108	0.075	0.052	0.036	28	0
Soybean	K	2.567	0.249	0.775	0.179	0.050	0.014	0.004	11	0

† EOR was determined with the cost of using 50 kg urea at FRW 30,000, KCl at 34,000 FRW, DAP and TSP at 40,000, respectively. Commodity values (FRW/kg) used were: rice 400; maize 110; sorghum 130; soybean 400; common bean 400; banana 100; wheat 400; sweet potato and Irish potato 100. The EOR and REC are as rates of P_2O_5 and K_2O.

Table 13.4b: Southern Rwanda

	Response coefficients, Yield = a –bc^r; r = elemental nutrient rate, kg/ha				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
			t/ha			**t/ha**			**kg/ha**	
Wheat	N	3.555	1.816	0.977	0.912	0.454	0.226	0.112	78	41
Maize	N	4.326	1.459	0.979	0.695	0.364	0.191	0.100	45	41
Climbing bean	N	2.593	0.894	0.902	0.853	0.039	0.002	0.000	33	18
Lowland rice	N	5.216	1.972	0.974	1.077	0.489	0.222	0.101	105	80
Bean	N	1.704	0.433	0.924	0.393	0.037	0.003	0.000	30	18
Soybean	N	0.809	0.148	0.899	0.142	0.006	0.000	0.000	21	18
Sweet potato	N	9.500	3.074	0.925	2.778	0.268	0.026	0.002	21	18
					0-5	**5-10**	**10- 15**	**15-20**		
Wheat	P	1.357	0.312	0.878	0.289	0.101	0.035	0.012	11	20
Maize	P	3.812	1.984	0.906	0.773	0.472	0.288	0.176	17	20
Climbing bean	P	2.446	0.705	0.895	0.300	0.172	0.099	0.057	18	20
Lowland rice	P	5.817	0.815	0.770	0.594	0.161	0.044	0.012	12	15
Bean	P	2.239	0.514	0.845	0.293	0.126	0.054	0.023	13	20
Soybean	P	1.981	1.185	0.893	0.512	0.291	0.165	0.094	16	20
Wheat	K	4.730	0.526	0.863	0.274	0.131	0.063	0.030	12	0
Maize	K	6.029	0.699	0.924	0.228	0.154	0.104	0.070	19	0
Climbing bean	K	3.539	0.799	0.934	0.231	0.164	0.117	0.083	40	0
Lowland rice	K	6.631	1.099	0.935	0.314	0.224	0.160	0.114	46	28
Bean	K	2.439	0.317	0.895	0.135	0.077	0.044	0.026	21	0
Soybean	K	2.567	0.249	0.775	0.179	0.050	0.014	0.004	11	0

The Excel and paper FOTs, along with other tools to aid in fertilizer use decisions are available at http://agronomy.unl.edu/OFRA.

The calibration guidelines for fertilizer application are built into the paper FOTs but the guideline needs to be developed separately when using the Excel FOT. Applying too much or too little fertilizer reduces farmer profit. The Excel OFRA Fertilizer Calibration Tool can be used to advise farmers on application to achieve the correct rates (Figure 13.7). This tool is adapted for each country for measuring units and fertilizer choices. It considers fertilizer density which differs by fertilizer type and allows for a choice between band, point, or broadcast application.

Another aspect of fertilizer use optimization is considering other management practices and soil test information (Table 13.3). Some practices such as manure application justify reducing fertilizer rates. Intercropping calls for an increase in rates relative to that recommended for the cereal sole crop. Soil test P is typically low but when Mehlich III P is above 15 ppm, the recommended P or the money for its use should be allocated elsewhere. When soil test K <100 ppm, KCl should be applied even if not recommended by the FOT. These considerations apply generally for only one or a few of the land parcels of a farm. The intent is that Table 13.3 is back-to-back with the paper FOT for the AEZ to be provided to farmers and their advisors as a single sheet of paper.

13.6 Crop nutrient response functions by AEZ in Rwanda

The crops for which nutrient response functions were determined from past and OFRA research of 2013-15 are presented in column 1 of Table

Table 13.4c: Northwestern AEZ

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
			t/ha			**t/ha**			**kg/ha**	
Wheat	N	3.534	1.465	0.974	0.800	0.363	0.165	0.075	94	41
Irish potato	N	15.100	4.105	0.949	3.251	0.676	0.141	0.029	54	51
Maize	N	4.717	1.337	0.969	0.817	0.318	0.124	0.048	40	41
Climbing bean	N	2.409	0.580	0.906	0.550	0.028	0.001	0.000	29	18
Soybean	N	0.809	0.148	0.899	0.142	0.006	0.000	0.000	15	18
Bean	N	1.118	0.229	0.862	0.544	0.015	0.000	0.000	16	18
					0-5	**5-10**	**10-15**	**15-20**		
Wheat	P	4.000	0.557	0.815	0.357	0.128	0.046	0.017	12	20
Irish potato	P	17.354	4.327	0.859	2.303	1.077	0.504	0.236	18	23
Maize	P	4.686	0.376	0.899	0.155	0.091	0.054	0.031	17	20
Climbing bean	P	2.371	0.633	0.847	0.357	0.156	0.068	0.030	14	20
Soybean	P	1.981	1.185	0.893	0.512	0.291	0.165	0.094	9	20
Bean	P	1.075	0.212	0.898	0.293	0.126	0.054	0.023	7	20
Wheat	K	4.607	0.509	0.909	0.193	0.120	0.074	0.046	28	0
Irish potato	K	24.445	4.393	0.907	1.697	1.041	0.639	0.392	35	24
Maize	K	5.990	0.521	0.893	0.225	0.128	0.073	0.041	14	0
Climbing bean	K	3.458	0.690	0.895	0.294	0.169	0.097	0.056	27	0
Soybean	K	2.567	0.249	0.775	0.179	0.050	0.014	0.004	11	0
Bean	K	2.440	0.317	0.895	0.135	0.078	0.045	0.026	21	0

13.4a-c. The table presents the crop response functions in columns 3-5, the expected yield (t/ha) increases due to increments of applied elemental nutrients in columns 6-9 and a comparison of the EOR with recommended elemental nutrient rates (REC) in columns 10-11. Both RECs and EORs assume the crop will be well managed and that the field does not have abnormally severe constraints to crop growth such as very shallow soil, very low pH, or very low water holding capacity.

All seven crops considered for Eastern AEZ had an economic response to applied N including soybean which occurred primarily with the first 30 kg/ha of N applied (Table 13.4a). All crops except banana and sweet potato had profitable response to P with >50% of response occurring with 5 kg/ha elemental P applied in most cases. All crops except for sorghum and sweet potato were found to have profitable response to applied K.

All seven crops considered for the South Central AEZ had economic responses to applied N, P and K, with the exception of sweet potato for P. Low rates of nutrient application were very effective (Table 13.4b).

All six crops considered for the Northwestern AEZ had economic responses to applied N, P and K with much of the response occurring at low rates of nutrient application (Table 13.4c). The K EORs were determined for several crops which did not have RECs for K application.

The EOR for N was generally more than or similar to the REC. The EOR for P was generally less than the REC. The EOR for K was generally more than the REC. The EOR will change with substantial changes in fertilizer prices relative to grain values.

13.7 Conclusion

Research on optimization of fertilizer use was conducted in the Northwest, South Central and Eastern AEZ of Rwanda in 2013-15. Response functions for N, P and K applied to maize, rice, wheat, bush and climbing bean, soybean, Irish potato, sweet potato and banana were determined using results from past and recent trial results. The response functions were used in the development of FOTs to be used to determine the optimal crop-nutrient-rate combination for maximizing net returns on investment in fertilizer use, especially for finance constrained situations. Paper FOTs were introduced as well as other tools for fertilizer use decisions. The RECs were found to be generally high compared to the EOR determined from results of field research.

13.8 Acknowledgements

The authors acknowledge the financial support of the Alliance for Green Revolution in Africa (AGRA) through the OFRA project, the facilitation of Rwanda Agriculture Board (RAB), and technical support from Professor Charles Wortmann of the University of Nebraska-Lincoln and of Dr. Kaizzi C. Kayuki of the National Agricultural Research Organization of Uganda.

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