15. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility in Uganda

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15.1 Agro-ecological zones (AEZ) of Uganda

Uganda has 14 AEZ (Wortmann and Eledu 1999) (Figure 15.1). An alternative zonation has 10 production zones (MAAIF 2004) (Figure 15.2).

Central Uganda (Lake Victoria Crescent) is an extensive agricultural area receiving over 1200 mm per year of rainfall in a bimodal pattern (Table 15.1). The population density is 280 persons per km^2. The zone is subdivided into three sub-zones: west of the Nile River; east of the Nile; and the eastern section in Bugiri, Busia and Tororo Districts. About 82% of the land is farmed. Wetlands are important for plant products, environmental protection and rice cultivation. The crops are diverse. Banana is important throughout much of the zone, but particularly in the west. Bean, sweet potato, cassava and maize are the main food crops. The cereal and grain legume crops are relatively more important east of the Nile. Rice production is important in parts of Tororo, Busia and northern Iganga districts. Robusta coffee is a major cash crop throughout the zone. West of the Nile, the soils are variable but often have high clay content (Figure 15.3). Sandy clay loam soils are also common. The sub-soil has a clay loam texture in some places, which may interfere with rooting depth. Soils are often acidic and low in K, but contain moderate levels of organic matter. Crop production takes place primarily on the slopes where the soil is generally deep. Murram may limit rooting depth on the lower slopes; ridge tops and swamp fringes are generally not suitable for crop production. Clay loam soils are typical on the hill slopes east of the Nile River, where the soils are less fertile than in the west, and these soils are more often sandy

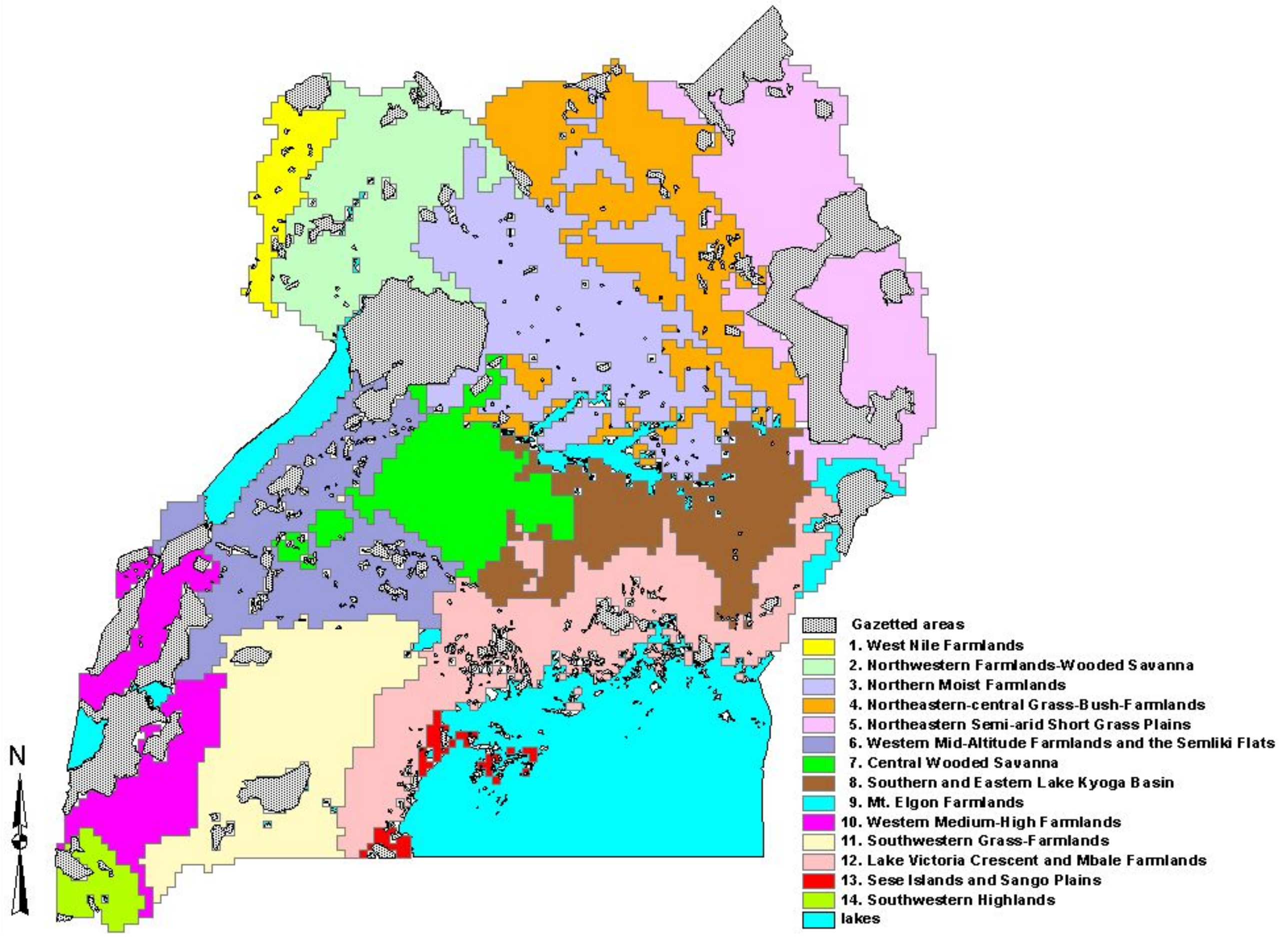

Figure 15.1: Agro-ecological zones of Uganda.

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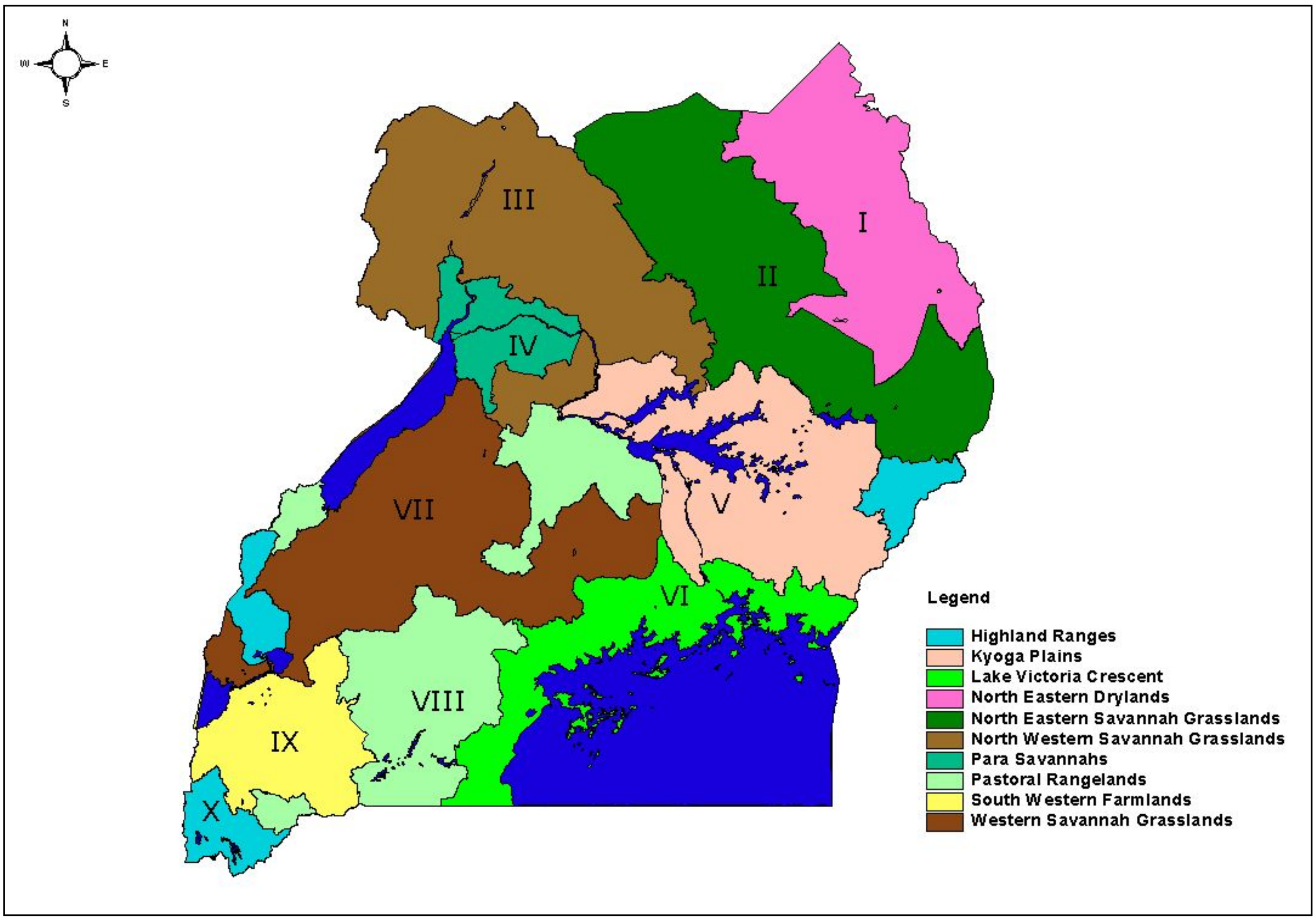

Figure 15.2: Map of agricultural production zones in Uganda.

loam and acidic, especially in the south east, where K is often deficient.

The Eastern Lake Kyoga Basin (Southern and Eastern Lake Kyoga Basin) is sub-humid with two growing seasons of similar rainfall, 560 mm during March-June and 540 mm during July-November (Table 15.1). The mean population density is 129 persons per km^2. Finger millet, banana and maize are major food crops, with more production in the southern part of the zone than in the north. Rice production in low-lying areas is important in Pallisa, northern Iganga and eastern Kamuli. Sorghum is relatively more important in Kumi and Pallisa. Cassava is a common food crop, especially in Kumi and parts of Pallisa. Cotton is the major cash crop. The soils of the western part of this zone are generally loam on the ridges and upper slopes and sandy loam on the lower slopes (Figure 15.3). In the east and north west, sandy soils derived from ancient lake deposits prevail. Soils are occasionally acidic and often have low organic matter and low nutrient supply. South and east of Kumi and near Bukedea, loam soils with good nutrient supply are common. Maize, cotton and other crops are likely to be very responsive to application of moderate amounts of N and P. Crop production is often constrained by water and nutrient deficits.

The Eastern 1400–1800 masl (Mt Elgon High Farmlands) AEZ is a very productive area with fertile soils and more than 1200 mm/yr rainfall in a bimodal pattern (Table 15.1). This AEZ is cool and wet. The southern part is warmer with less rain in July than in the north. Rainfall peaks in April and May but is generally more than 100 mm per month from March to November. The population density is 345 persons per km^2. Bean is the major food crop in terms of area, but banana is also very important. Maize and groundnut are important crops. Arabica coffee is the major cash crop. While important throughout the AEZ, the production of banana, bean and maize is more prevalent in the northern part. In the north, much of the soil is derived from volcanic parent material and the soils are

Table 15.1: Mean monthly rainfall (mm) and maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of AEZ of Uganda

	J	F	M	A	M	J	J	A	S	O	N	D
Lake Victoria Crescent – Central Uganda												
Rainfall	63	57	135	213	137	67	64	88	108	135	107	90
Tmax	29	29	29	28	27	27	27	27	28	28	28	28
Tmin	15	16	16	17	17	16	15	16	16	16	16	16
South and Eastern Lake Kyoga Basin												
Rainfall	30	69	119	170	147	87	103	151	181	179	134	65
Tmax	31	32	31	29	28	28	27	27	28	28	29	29
Tmin	16	17	17	17	17	16	16	16	16	16	16	16
Mt Elgon High Farmlands (Eastern 1400–1800 masl)												
Rainfall	32	53	100	149	167	107	111	132	98	96	86	52
Tmax	31.7	31.4	30.5	29.0	28.3	28.2	27.5	27.9	28.6	28.9	29.4	30.0
Tmin	16.4	17.0	17.2	17.5	17.3	16.7	16.5	16.3	16.2	16.2	16.4	16.3
Kapchorwa Farm – Forest (Eastern >1800 masl)												
Rainfall	40	57	92	173	217	141	197	196	129	171	113	50
Tmax	26.8	27.2	26.7	25.3	24.5	24.3	23.3	23.7	24.6	24.7	25.0	25.6
Tmin	12.1	12.1	12.3	12.4	12.5	11.9	11.8	11.6	11.6	11.8	11.9	12.0
North, Mid-West and Western (Northern Moist Farmlands)												
Rainfall	21	50	98	157	193	115	139	184	170	161	102	39
Tmax	33	33	32	30	29	28	27	28	29	30	31	31
Tmin	16	17	17	17	17	17	16	16	16	16	16	16
North, Mid-West and Western (Western Mid-Altitude Farmlands)												
Rainfall	46	71	113	205	234	165	185	210	163	201	124	56
Tmax	27.2	27.4	26.8	25.5	24.7	24.6	23.8	24.0	24.7	24.8	25.1	25.7
Tmin	12.4	12.3	12.3	12.5	12.6	12.0	11.9	11.7	11.7	11.7	11.9	12.1
South Western Highlands (1400–1800 masl) South-western medium – highlands												
Rainfall	57	71	96	122	84	25	32	53	95	113	137	89
Tmax	26.8	26.9	26.8	25.9	25.9	26.2	26.7	26.8	26.7	26.2	25.8	25.9
Tmin	13.9	14.1	14.3	14.5	14.3	13.2	13.0	13.9	14.0	14.1	14.2	13.8
South Western Highlands (1400–1800 masl) Bushenyi-N.Rukungiri Farmlands												
Rainfall	72	78	113	138	100	40	36	85	128	138	151	118
Tmax	25.6	25.7	25.5	24.7	24.5	24.8	25.2	25.4	25.4	25.0	24.6	24.8
Tmin	12.7	12.9	13.0	13.3	13.3	12.2	12.1	13.0	13.0	13.0	13.0	12.7
South Western Highlands (above 1800 masl) Kabale – Rukungiri Highlands												
Rainfall	62	84	114	150	90	27	23	56	103	105	126	88
Tmax	24	24	24	23	22	23	23	23	24	23	23	23
Tmin	10	10	10	11	11	9	9	10	10	10	10	10
South Western Highlands (above 1800 masl) Kabale – Kisoro Highlands												
Rainfall	90	119	142	173	117	42	29	76	136	158	166	120
Tmax	23.7	23.6	23.3	22.5	22.2	22.9	23.5	23.5	23.7	23.2	22.7	23.0
Tmin	11.2	11.4	11.4	11.7	11.7	10.7	10.6	11.2	11.3	11.3	11.3	11.3

typically red clay loam, well drained, highly leached, often acid, but of good nutrient supply (Figure 15.3). In the south, the surface soils more often have high sand content and lower nutrient supply.

The Eastern above 1800 masl (Kapchorwa Farm-Forest Land) AEZ is on the northern steps of Mount Elgon with above 1200 mm/yr unimodal rainfall (Table 15.1). The climate is cool and sub-humid with a long wet season from April to October and with peak rainfall in April and May. The population density is 206 persons per km^2. Much of this zone is forested; about 40% is used for crop production. Maize and bean are the main crops, with beans produced in association with other crops. Banana is also an important crop. This is the major AEZ for wheat production in Uganda. The soils are generally highly productive. In the forest zone, soils are primarily reddish-brown loam over deep clay loam sub-soil. In the farmland areas, much of the soil is derived from volcanic parent material; clay and clay loam soils are common and often acidic, but are of good nutrient supply (Figure 15.3).

The Northern Moist Farmlands are very important for annual crop production. It receives above 1200 mm/yr of unimodal rainfall (Table 15.1). The zone is sub-humid and relatively warm with rainfall well distributed from April to October, during which mean monthly rainfall exceeds 110 mm. The main dry season is December-March. Population density is 65 persons per km^2. Maize, finger millet and bean are important food crops but are not uniformly distributed. Sweet potato, cassava and sorghum are also important. Cotton, simsim (sesame) and tobacco are major cash crops. This is the major AEZ for pigeonpea and cowpea production in Uganda. Rice is becoming an important cash crop. The soils are variable and often acidic and sandy. In the West Nile, the soils are over a metre deep, sandy and acidic, and often low in nutrient availability. The soils of Gulu, Lira and Apac are generally sandy and sandy clay soils with low organic matter and low nutrient

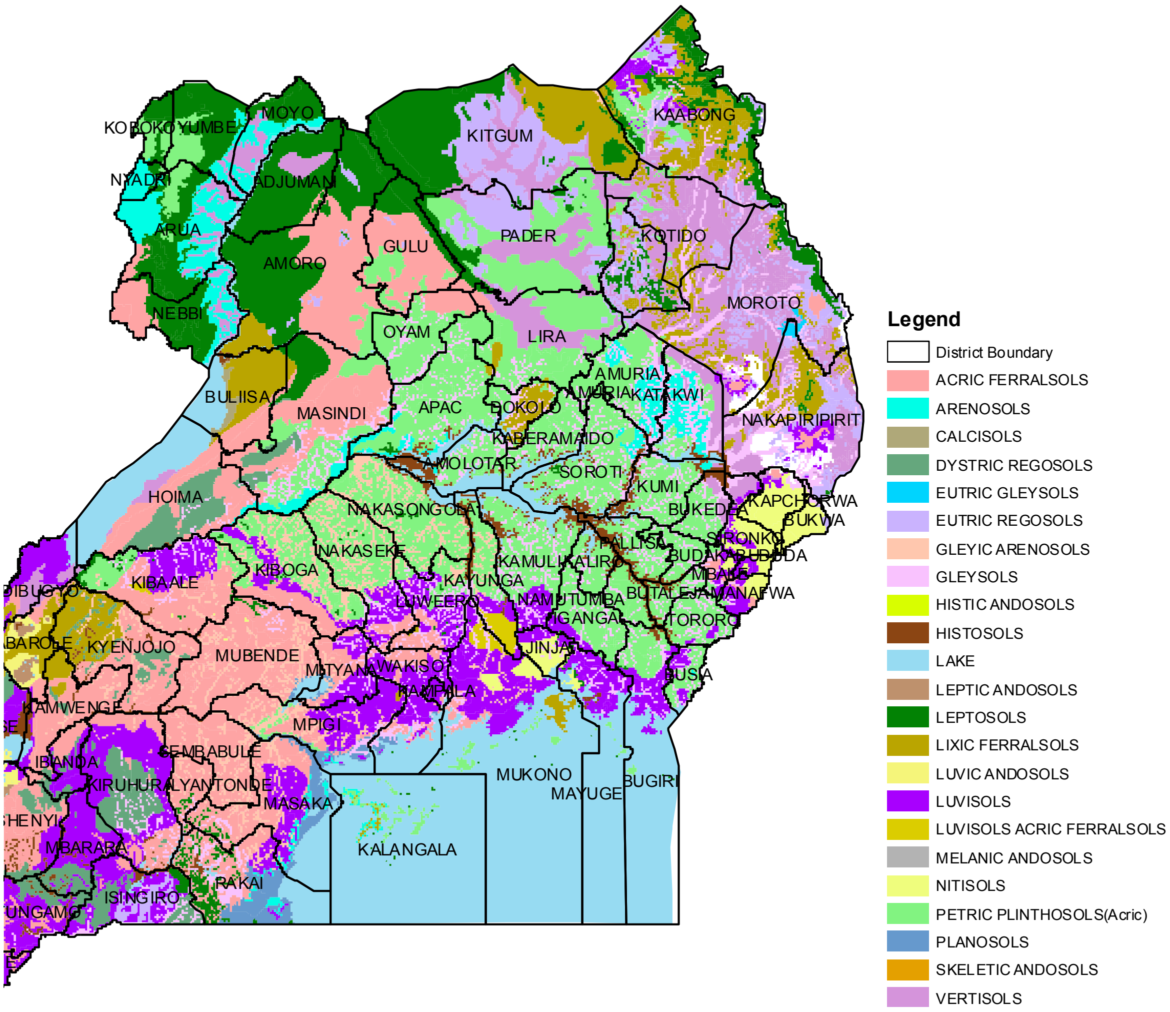

Figure 15.3: Major soil types of Uganda.

availability, but loam soils are common near Gulu town. With loam upland soils and clay valley soils of moderate nutrient supply, the land of Kigumba is of medium productivity and is important for maize and cotton production. In the south-east part, red loam soils are associated with the higher slopes, brown sandy soils are common on the lower slopes, and dark clay soils predominate in the valleys (Figure 15.3). The soils near the Pager and Agaga rivers are high in clay but are often acidic and have low nutrient supply. Throughout this AEZ, maize, cotton and other crops are likely to be very responsive to application of moderate amounts of N and P.

The Western Mid-altitude Farmlands is a large, widely dispersed and variable AEZ, receiving between 1000–1200 mm per year of bimodal rainfall (Table 15.1). The first season is shorter with mean rainfall of 360 mm during March-May and the second season receives mean rainfall of 485 mm during August-November. Population density is 78 persons per km^2. The food crops are diverse with banana the most important, followed by maize, bean and sweet potato. Maize is more important in the eastern part of the AEZ while sweet potato, cassava and groundnut are more important in Kabarole. Livestock keeping is important. The soils in the west are often shallow, coarse-textured and acidic; patches of deeper soil are cultivated (Figure 15.3). Areas in Kibale have loam soils. In northern Mubende and Kiboga, the soils are shallow except on the lower slopes where brown loam, typically a metre deep, occurs. Shallow soils at the base of rock outcrops are often intensively cultivated. In western Mubende, more productive loam and clay loam soils occur on the mid-slopes; productivity is low to medium. Maize, cotton and other crops are likely to be very responsive to application of moderate amounts of N.

South-western Highlands (1400–1800 masl) includes the South-western Medium Highlands and Bushenyi-North Rukungiri which receives 1000–1200 mm/yr of bimodal rainfall (Table 15.1). June and July are the driest and coolest months. Rainfall is sufficient for good crop productivity and is most reliable during the second season. Population density is about 202 persons per km^2. Banana is the major crop and is commercially important. Other important food crops are bean, maize and sweet potato. Cattle and goat production are major activities. The soil is typically dark, deep and often acidic, but nutrient supply is generally good in the Southwestern Medium Highlands (Figure 15.3). In Bushenyi-North Rukungiri, tea and coffee are important cash crops and the soils are commonly sandy loam in the south-west and loam in the north-east and are often acidic.

The South-western Highlands (>1800 masl) includes the Kabale–Rukungiri Highlands and Kabale-Kisoro Highlands with 1000–1200 mm and >1200 mm/yr, respectively, of bimodal rainfall (Table 15.1). June and July are the driest and coolest months. The respective mean population densities are 244 and 309 persons per km^2. Sorghum is sown in December and January and other crops are sown mainly in March for the first season. The second season is from September through December. Rainfall peaks in April and November. The main crops are banana and bean, followed by maize and sweet potato. Sorghum, finger millet and Irish potato are also important. This AEZ is important for Uganda's production of Irish potatoes. In the Kabale-Rukungiri Highlands, much of the soil is acid loam, but nutrient supply is generally good and productivity is medium to high. In the Kabale-Kisoro Highlands, the soils are dark brown, often acid and low in base, and are derived from basalt, lava, ash and, in places, phyllite (Figure 15.3). In the south, the humose brown loam soils are typically of moderate to high productivity. In the north, soils are acidic with low base supply and low productivity. Waterlogged valley soils are often high in sulphur (S), which leads them to become acidified upon aeration following drainage.

15.2 Current soil fertility management

The soils in Uganda are of inherently poor soil fertility with low nitrogen (N) and phosphorus (P) availability. Soil fertility is associated with soil organic matter in the top 20 cm depth which is susceptible to losses through erosion once vegetation cover is removed, resulting in permanent loss of soil fertility and land productivity. Nutrient removal in crop harvests and losses through runoff and soil erosion is not adequately compensated by using crop residue, manure and fertilizer resulting in negative

Table 15.2. Average nutrient depletion rates (kg/ha) in Uganda (Source: Kaizzi et al., 2004)

Agro-ecological Zone	N	P	K
West Nile and North-western	-36	-4	-26
Northern Moist	-56	-3	-37
Mt Elgon	-66	-5	-82
South-western Grassland-Farmland	-97	-4	-172
Lake Victoria Crescent and Mbale	-82	-8	-80

nutrient balances in all AEZ of Uganda (Table 15.2), especially for K in the south-west. The common practices by farmers are tillage using either hand hoes or animal traction and residue removal.

Current soil fertility management practices include the use of farmyard manure, crop residues, compost, fertilizer, plus crop rotation and, in some places and with declining frequency, leaving the land fallow for a few years. Unfortunately, manure and fertilizers are used on only 7 and 1% of the land parcels annually and by 24 and 2% of smallholders, respectively (UBOS 2006, 2010). Some farmers attempt to control runoff and erosion, but are not always successful. Others make little effort. Crop residues for land application are scarce with competing fuel and feeding demands. Manure use requires much animal labour and the nutrient content is low. Green manure production has been proven effective in supplying N to the following crop but requires land that could be used for food or cash crops and is not much practised. Transfer of plant materials from field boundary areas, or nearby fallow or grazing areas, often has potential in sub-humid areas but less potential in semi-arid areas; its practice is mostly limited to banana production.

Current fertilizer recommendations (REC) are not site specific, originate from the 1970s and call for high rates of application for maximizing yield. Examples of the existing recommendations include: for maize, apply 125 kg/ha diammonium phosphate (DAP) at planting and 125 kg/ha urea when maize is approximately 1m tall; for finger millet, broadcast apply 125 kg/ha ammonium sulphate when plants are about 15 cm tall; for sorghum, apply 110 kg/ha of SSP at planting and 110 kg/ha of CAN about 3 weeks after planting (NARO 2001).

Most farmers use little if any fertilizer and are not well informed on proper fertilizer use, time of application and suitability of different products. This also applies to their advisors. Effective fertilizer use requires a well-managed crop, but also proper use of the fertilizer. Farmers and extension advisors need to be aware of 4R Nutrient Stewardship including: applying the right source of nutrients, at the right rate, at the right time, and with the right method. Fertilizer use is very costly in Uganda. Sales and demand are low and the fertilizer supply chain is not well developed. Fertilizer subsidies are needed at least on an interim basis to sufficiently increase demand for fertilizer, so the supply chain can become more efficient (Kaizzi 2012).

15.3 Diagnosis of nutrient deficiencies in Uganda

Trials supported by the Optimizing Fertilizer Recommendations in Africa (OFRA) project were conducted both on farmers' fields (OFT) and at research stations (RMT). The mean response of finger millet was 124, 14 and 3% to N, P and K over 33 site-season-variety comparisons. The trials included treatments to determine if the nutrient package of N+P+K+Mg+S+Zn+B, referred to as a diagnostic treatment, compared with N+P+K resulted in increased yield of finger millet. The results indicate that one or more of Mg, S, Zn and B are limiting yield as observed from yield increases of 39 and 64% in on-farm trials (OFT) in Palissa and Tororo, respectively. The average effects of the diagnostic treatment ranged from negative to a 29% increase with researcher managed trials in Tororo and Apac, respectively (Figure 15.4).

The results of foliar sample analyses are revealing (Table 15.3). Foliar levels of N and P

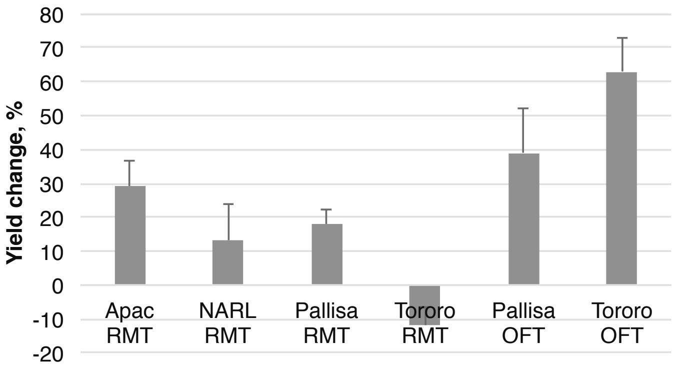

Figure 15.4: Mean increases in finger millet grain yield due to the application of Mg+S+Zn+B in Uganda.

Table 15.3: Foliar nutrient contents for finger millet samples taken from plots with applications of N, P and K at planting plus in-season N application. The critical value for interpretation of foliar results were determined in consideration of other warm season cereals as no values specific for finger millet were found. Means of 18 samples per location

Location	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn	N	Mo
Apac	4.34	0.86	5.57	218	2.13	0.28	256	32.9	0.19	0.17	27.8	1.58	0.74
NARL	5.00	0.91	6.17	836	2.78	0.23	397	46.4	0.33	0.22	50.9	1.64	1.20
Palissa OFT	3.75	0.80	4.85	311	2.17	0.23	262	33.3	0.21	0.13	29.3	1.30	2.05
Tororo OFT	3.86	0.83	5.15	180	2.10	0.24	248	34.2	0.20	0.14	28.6	1.44	1.12
Critical value	3	0.2	3	20	1.2	0.1	15		0.22	0.11	15	2.8	0.1

were most frequently low relative to the critical values used in interpretation of the results, even though N, P and K had been applied to sample plots. The results indicate that boron (B) and S are the most likely nutrients applied in the diagnostic package to have resulted in the large yield increases due to the diagnostic package for the OFT of Tororo and Palissa. The B and S mean levels were low compared with National Agricultural Research Laboratories (NARL) and Apac and because the foliar levels were relatively near the critical levels. Soil organic matter is the major source of S and B; finger millet response to N in these trials was great suggesting that the rate of nutrient mineralization from soil organic matter is low. Both S and B are subject to leaching loss. Another micronutrient of interest is molybdenum (Mo) which is low at some locations relative to the critical value but high for the Palissa OFTs. Further investigation is needed to validate these observations, the extent and conditions of the occurrence of deficiencies, and the economics of application.

15.4 Optimizing fertilizer use in Uganda

Optimization of fertilizer use in this chapter, as developed by OFRA, refers primarily to maximizing farmer profit from fertilizer use, given that most Uganda farmers are severely limited in their management options by poverty. However, the profit needs to be achievable without much risk.

Determination of the profit potential for farmers from their fertilizer use decisions requires information on the typical response of a crop to an applied nutrient in an AEZ. Responses were determined using curvilinear to plateau, or asymptotic quadratic-plateau, functions taking the form of an exponential rise to a maximum or plateau yield as this form of response is most typical when numerous site-years of data are considered (Figure 15.5).

The asymptotic function was $Y = a - bc^r$, where Y was yield (t/ha), a was the maximum or plateau yield (t/ha), b was the maximum gain in yield (t/ha) due to nutrient application, and c^r represented the shape of the quadratic response, where c was a curvature coefficient and r the nutrient application rate (t/ha).

The typical form of crop response to a nutrient has economic implications for the farmer. The curvilinear to plateau yield responses (y-axis) of maize, upland rice, sorghum, finger millet and bean to applied N (x-axis) are displayed in Figure 15.5. The magnitude of response, b, and the shape of the curve differ by crops, but all crop responses have a steep yield increase with increasing N at low rates (i.e. up to 20 kg/ha N applied). The rate of yield increase is less at higher N rates with little yield increase for some crops with >40 kg/ha N; yield eventually reaches a plateau with no more practical yield increase in response to increasing N rates. The levelling off of the curve implies that factors other than N are more limiting to crop yield. The response curves presented are typical for most crops and nutrients. The response implies that the net returns to low rates of N are greater than with higher rates. This has implications for risk as application at lower rates not only has potential

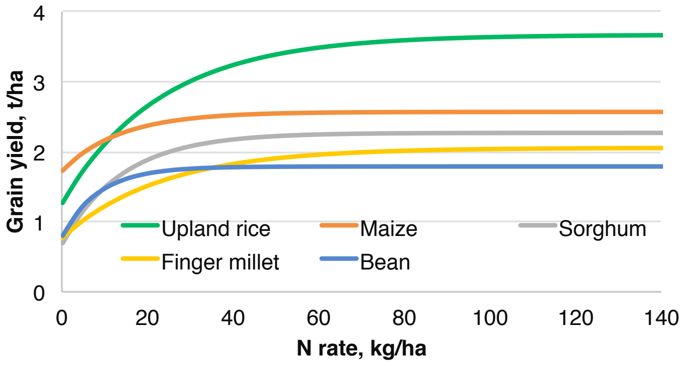

Figure 15.5: Nitrogen response curves for different crops.

for higher returns per unit of investment but the same fertilizer value can be applied over more land and to more crops as compared to applying at higher rates.

Another important aspect of achieving high profit from fertilizer use for financially constrained farmers is the unique specificity of crop response to a particular applied nutrient. This is due to the magnitude and shape of the crop response to a nutrient, but also the value of the produce (revenue) and fertilizer use costs (costs). In Figure 15.6, the amount of money invested in one nutrient applied to one crop is on the x-axis and the y-axis shows net returns to investment in nutrient application. Each curve represents the profit potential of a nutrient applied to a crop. Net returns to investment are very high if the slope of the curve is steep. With increased rates of application, the slope decreases, but profit is increasing if the curve continues upward. The peak of the curve is the point of maximum profit per hectare, referred to in this chapter as the economic optimum rate (EOR). When slopes decline, profit is declining. The financially constrained farmer can maximize profit potential by taking advantage of the crop-nutrient combinations that will give the highest benefit to cost ratio for the limited investment in fertilizer use.

Upland rice response to N has the greatest profit potential, partly due to the high value of the grain. Also very profitable are: P applied to groundnut and a low rate of N applied to bean. The fourth most profitable crop response to specified nutrient is N applied to finger millet. Several other less profitable options have lower lying curves. When a farmer's ability to use fertilizer is finance constrained, it is important to take advantage of the crop-nutrient-rates that have the most profit potential given the farmer's cropping system and financial context. The farmer who can apply fertilizer to all cropland at EOR is less concerned about crop-nutrient choices, but about their EOR.

Decisions of crop-nutrient-rate choices for maximizing a farmer's profit potential is very complex as the nature of the crop-nutrient responses needs to be considered as well as the farmer's land allocation to different crops, the produce value, the costs of fertilizer use and the money available for fertilizer use. Therefore, easy to use fertilizer use optimization tools (FOTs) were developed which use linear programming to consider reiteratively the economic and agronomic information using Excel Solver© (Frontline Systems Inc.). The FOTs are available at http://agronomy.unl.edu/OFRA.

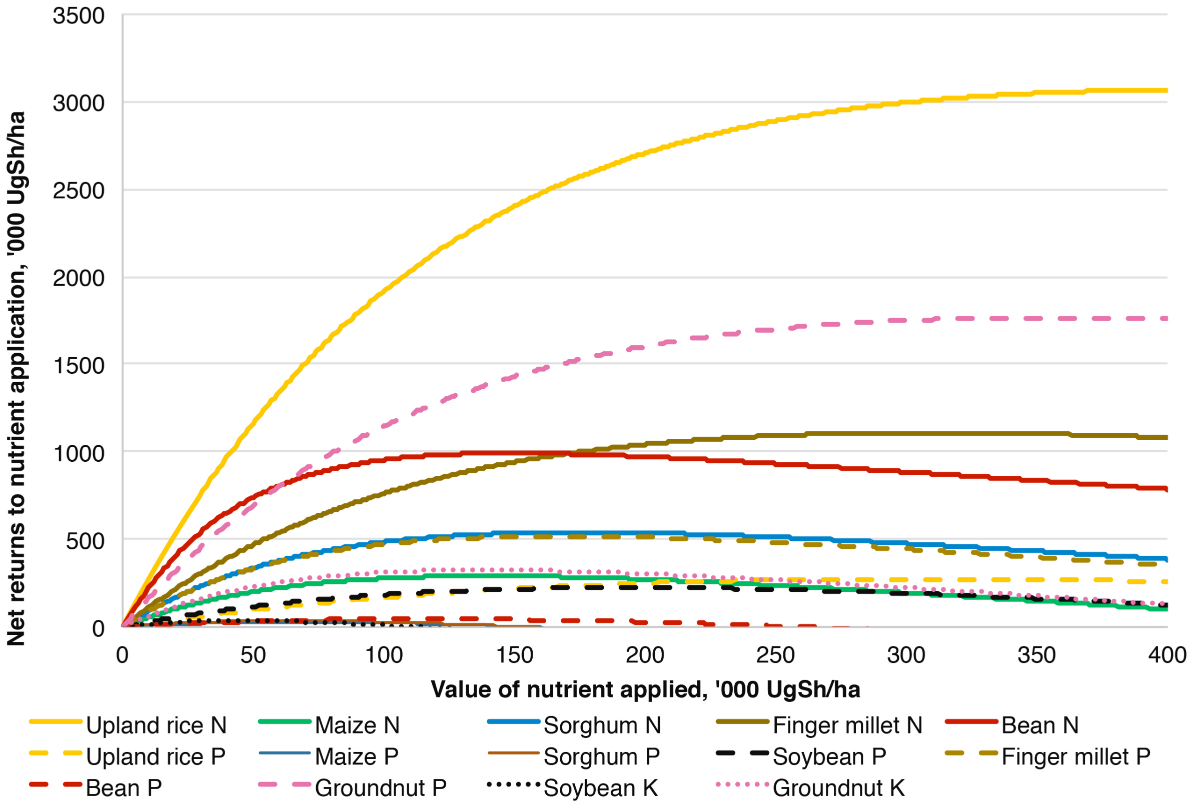

Figure 15.6: Net returns on investment depend on choice of crop-nutrient-rate combinations for eastern Uganda – Lake Kyoga Basin.

The Excel FOT requires that the Solver add-in be enabled. Instructions for enabling the Solver add-in are provided in a worksheet of the FOT 'Help and Instructions'. Instructions are also given for enabling macros, another essential step to using the Excel FOTs. More detailed instructions are available in Extension Training Materials at http://agronomy.unl.edu/OFRA. When enabled the Solver add-in appears under the Data tab on the Quick Access Toolbar.

The data input includes: the farmer's allocation of land to each crop of interest; estimated farm gate value per kg of produce at harvest time, considering that some is for home consumption (the most valuable) and that the surplus will be marketed; and the cost of using different fertilizers (Figure 15.7). The amount of money which the farmer has to invest in fertilizer use is also entered. Clicking on the 'Optimize' button then runs the optimization calculations. In the example, the farmer wishes to plant six crops to six acres of land. If no land is allotted to a crop or if the crop value is not given, the crop is not considered. In the example, DAP is given a cost of zero and it is not considered in the optimization. The budget constraint to fertilizer use is UgSh 600,000.

The output panel displays the recommended fertilizer rates for each crop, the expected mean yield increases and net returns for each crop, and the expected mean total net return to investment in fertilizer (Figure 15.8). The approach strives to maximize profitability of fertilizer use through consideration of the farmer's financial constraint, costs and prices of inputs and outputs, and farmer's cropping system. It identifies the crop-nutrient-rate combinations expected to maximize returns on investment in fertilizer.

In the example, some fertilizer has been recommended for all crops. In some cases, such as TSP applied to maize and banana, the amount is too small for feasible application and the fertilizer or the money should be allocated to another crop or fertilizer. The fertilizer needed totalled to 118, 148 and 31 kg of urea, TSP and KCl, respectively. The average expected total net return to the UgSh 600,000 invested in fertilizer use is UgSh 2,729,469. If a crop has a high net return to fertilizer use, such as upland rice in this example, the farmer may try allocating more land to the crop to determine if total profit is adequately increased, although more than profit from fertilizer use needs to be considered in land allocation.

Often farmers and their advisors are not able to use the Excel Solver© FOT due to lack of access to a computer. Therefore a paper FOT was developed for each AEZ. The paper FOT for Eastern Uganda – Lake Kyoga basin is given as an example (Table 15.4).

The paper FOT is devised for three financial levels based on the farmer's budget constraint for fertilizer use. The level 1 financial ability is for the poor farmer who has less than one-third the amount of budget required to apply fertilizer to all cropland at EOR; level 2 is for the farmer with less than two-thirds but greater than one-third of the money required to apply fertilizer to all cropland at EOR; and level 3 is for the farmer with enough money to apply fertilizer at EOR to at least some of the cropland.

The paper tool makes assumptions about the: measuring units to be used by farmers in adjusting their eyes and feel for applying the right rate of fertilizer; crop inter-row and intra-row spacing; the fertilizer use costs per 50 kg bag; and the expected commodity values on-farm at harvest, considering the value both for home consumption and for market.

Consider as an example level 1 financial ability recommendations in the paper FOT for the Lake Kyoga Basin 'Finger millet: broadcast 14 kg/ac DAP at planting (CAP for 2.4 m); 17 kg/ac urea at 2nd weeding (CAP for 1.2 m)'. Therefore, the farmer should broadcast apply 14 kg/ac of DAP to finger millet at planting. This is calibrated using a Highland brand water bottle lid which is sufficient for 2.4 m when the application width is 1 m. The farmer should also broadcast apply 17 kg/ac of urea to finger millet at the second weeding. This is calibrated using a Highland water bottle lid which is sufficient for 1.2 m when the application width is 1 m.

Fertilizer use decisions need to consider the effects of other practices that supply soil nutrients as well as soil test information (Table 15.4). Typically, a farmer may apply such a practice to only one or a few parcels of several land parcels that comprise the farm's cropland. For example, manure application to a parcel

Central

Producer Name:	xxx
Prepared By:	xxx
Date Prepared:	**July 23, 2016**

Crop Selection and Prices		
Crop	**Area Planted (Ac)***	**Expected Grain Value/kg †**
Maize	1	600
Banana	1	800
Upland rice	1	1500
Beans	1	1200
Soybeans	1	1000
Groundnuts, unshelled	1	2400
Total Acres	**6**	

Fertilizer Selection and Prices				
Fertilizer Product	**N**	**P2O5**	**K2O**	**Price/50 kg bag ¶***
Urea	46%	0%	0%	120000
Triple super phosphate, TSP	0%	46%	0%	120000
Diammonium phosphate, DAP	18%	46%	0%	140000
Murate of potash, KCL	0%	0%	60%	100000
xxx	17%	17%	17%	140000

Budget Constraint	
Amount available to invest in fertilizer	600000

Figure 15.7: Input screen of the fertilizer optimizer tool for Central Uganda.

Fertilizer Optimization					
	Application Rate - kg/Ac				
Crop	**Urea**	**TSP**	**DAP**	**KCL**	**xxx**
Maize	35	0	4	0	0
Banana	21	0	20	0	0
Upland rice	44	0	26	0	0
Beans	15	0	16	0	0
Soybeans	0	30	0	4	0
Groundnuts, unshelled	0	47	0	22	0
Total fertilizer needed	**116**	**77**	**67**	**26**	**0**

Expected Average Effects per Ac		
Crop	**Yield Increases**	**Net Returns**
Maize	632	282,572
Banana	947	650,146
Uplandrice	689	854,427
Beans	429	433,048
Soybeans	353	273,608
Groundnuts, unshelled	423	860,012

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer	3,353,781

Figure 15.8: Output of the FOT.

Table 15.4: Example of paper fertilizer optimization tool

UGANDA FERTILIZER USE OPTIMIZER:
Eastern Lake Kyoga Basin

The below assumes:
Cost of fertilizer use for 50 kg bag (UgSh): urea, TSP and KCl is 120,000/-; DAP is 140,000/-.
Grain values (UgSh/kg): maize 600; Sorghum 500; finger millet 1200; upland rice paddy 1500; bean 1200; soybean 1000; and groundnut unshelled 2500.
Calibration measurement units: a Highland water bottle cap (CAP) that holds 7.5 ml, about 5.25 g urea, 8.25 g DAP, TSP or KCl; and Highland water bottle cut at 2 cm (2-cm bottle) holds 59.3 ml, 41.5 g urea and 65.2 g of DAP, TSP or KCl.
Row spacing: maize 75 x 30 cm; sorghum, 60 cm; finger millet and upland rice, 20 cm; banana 3 x 3 m; bean 60 cm; soybean and groundnut 45 cm.
Rates are at least 10 kg/ac. **Broadcast width** is 1 m.

Level 1 financial ability.	
Finger millet	Broadcast 14 kg/ac DAP at planting (CAP for 2.4 m); 17 kg/ac urea at 2nd weeding (CAP for 1.2 m)
Sorghum	Band 11 kg/ac urea after 2nd weeding (CAP for 3.2 m)
Upland rice	Broadcast 13 kg/ac DAP at planting (CAP for 2.6 m); 17 kg/ac urea at panicle initiation (CAP for 1.2 m)
Bean	Band apply 12 kg/ac urea at planting time (CAP for 3.0 m band)
Groundnut	Band apply 14 kg/ac DAP and 12 kg TSP at planting time (2-cm bottle to cover 4.2 m band for DAP and 6.7 m band for TSP)
Level 2 financial ability.	
Maize	Point apply 17 kg/ac urea at planting (CAP for 3.1 plants); apply 17 kg/ac urea at second weeding (CAP for 3.1 plants)
Finger millet	Broadcast 22 kg/ac DAP at planting (CAP for 1.5 m); apply 17 kg/ac urea at 2nd weeding (CAP for 1.2 m)
Upland rice	Broadcast 23 kg/ac DAP at planting (CAP for 1.5 m); 38 kg/ac urea at panicle initiation (CAP for 0.6 m)
Sorghum	Band 19 kg/ac urea at 2nd weeding (CAP for 1.9 m)
Bean	Band 18 kg/ac urea at planting (CAP for 2 m band)
Soybean	Band 25 kg/ac TSP at planting (CAP for 3.0 m band)
Groundnut	Apply 40 kg/ac DAP at planting (CAP for 2.9 m band)
Level 3 financial ability (maximize profit per acre).	
Maize	Point apply 10 kg/ac DAP at planting (CAP for 16 plants); band 43 kg/ac urea at 2nd weeding (CAP for 2.2 plants)
Finger millet	Apply 28 kg/ac DAP at planting (CAP for 1.2 m); apply 41 kg/ac urea at 2nd weeding (broadcast 2-cm bottle for 0.5 m)
Sorghum	Band 14 kg/ac DAP at planting (CAP for 4 m); 24 kg urea at 2nd weeding in a band (CAP for 2.5 m)
Upland rice	Broadcast 31 kg/ac DAP at planting (CAP for 1.1 m); 54 kg/ac urea at panicle initiation (CAP for 0.4 m)
Bean	Apply 14 kg/ac urea (CAP for 2.5 m band); 27 kg/ac DAP at planting time (CAP for 2.1 m band)
Soybean	Band 37 kg/ac TSP at planting time (CAP for 2 m band)
Groundnut	Band 40 kg/ac DAP time (CAP for 1.9 m); 14 kg/ac TSP and 13 kg/ac KCl at planting time (CAP for 5.3 m band for each)

may justify allocating some of the recommended fertilizer to another parcel of land. The fertilizer substitution value varies with the quality of manure; poultry and dairy manure have greater fertilizer substitution value than farmyard manure. If intercropping, the fertilizer rate should be increased relative to the sole cereal crop recommendation. Soil test P is commonly low for smallholder fields not near the household. Phosphorus should be applied according to the

FOT, unless the Mehlich III soil test P value is above 15 ppm when the fertilizer P should be applied to another piece of land or the money used differently. Potassium should be applied according to the FOT unless soil test K is below 100 ppm, then more KCl should be applied than indicated by the FOT.

15.5 Targeted crops by AEZ

Results for past and recent OFRA-supported trials conducted in Uganda were used to determine response functions by AEZ for maize, upland rice, sorghum, banana, soybean, groundnut, wheat and finger millet. Data from similar growing conditions in Rwanda and Kenya were used to determine response functions for Irish potato. Maize and bean were addressed for all seven AEZ (Table 15.5a-g). Soybean and groundnut were addressed for four AEZ and finger millet and Irish potato for three AEZ. Upland rice, wheat, sorghum and high potential banana were addressed for two AEZ and low potential banana for one AEZ. There was AEZ differentiation of response functions for maize, finger millet, soybean and groundnut. For other crops, the research results did not indicate differentiation of response functions by AEZ and some repetition occurs in Table 15.5a-g.

All non-legumes and bean responded well to applied N. More than 50% of the yield response to N occurred with 30 kg/ha N applied except for Irish potato which had a relatively more linear response. All targeted crops had an economic response to P. Soybean, groundnut and banana responded to K, but the cereals did not have economic responses to K. Data availability for Irish potato response to K was inadequate to develop a reliable response function.

Results presented in Tables 15.5a-g indicate that the current N and P recommendations (REC) for maize and banana are higher than the EOR. The same applies to K on banana and N on groundnut and wheat. This implies that

Table 15.4: Fertilizer use in an ISFM framework

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT FRAMEWORK

FERTILIZER SUBSTITUTION AND SOIL TEST IMPLICATIONS

ISFM practice	Urea	DAP or TSP	KCl	NPK 17-17-17
	Fertilizer reduction, % or kg/acre			
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	4 kg	2 kg	2 kg	8 kg
Farmyard manure per 1 t of dry material	5 kg	3 kg	2 kg	10 kg
Residual value of FYM applied for the previous crop, per 1 t	2 kg	1 kg	1 kg	3 kg
Dairy or poultry manure, per 1 t dry material	9 kg	4 kg	5 kg	16 kg
Residual value of dairy and poultry manure applied for the previous crop, per 1 t	2 kg	2 kg	1 kg	3 kg
Compost, per 1 t	8 kg	3 kg	3 kg	15 kg
Residual value of compost applied for the previous crop, per 1 t	3 kg	2 kg	1 kg	5 kg
Rotation	0% reduction but more yield expected			
Cereal-bean intercropping	Increase DAP/TSP by 7 kg/ac, but no change in N and K compared with sole cereal fertilizer			
Cereal-other legume (effective in N fixation) intercropping	Increase DAP/TSP by 11 kg/ac, reduce urea by 9 kg/ac, 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 20 kg/ac KCl			

Table 15.5a: Central Region - Lake Victoria Crescent. Response functions, expected yield increases (t/ha) for crop-nutrients, and OFRA economically optimal rate (EOR) to maximize profit per hectare compared to current or recent (REC) recommendations. P_2O_5 = P x 2.29; K_2O = K x 1.2. Some functions are not presented because of lack of response or lack of information

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop†	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
		t/ha			**t/ha**				**kg/ha**	
Maize	N	3.711	1.823	0.960	1.287	0.378	0.111	0.033	53	60
Banana <20t	N	7.60	1.95	0.92	1.80	0.14	0.01	0.00	40	100
Upland rice	N	2.06	1.28	0.97	0.81	0.30	0.11	0.04	77	46
Bean	N	1.79	0.99	0.89	0.96	0.03	0.00	0.00	30	26
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.91	0.20	0.84	0.12	0.05	0.02	0.01	5	25
Banana <20t	P	19.64	0.68	0.88	0.33	0.17	0.09	0.04	16	30
Upland rice ††	P	2.21	0.63	0.82	0.40	0.15	0.05	0.02	15	10
Bean ††	P	1.81	0.29	0.93	0.09	0.06	0.04	0.03	14	10
Soybean	P	1.66	0.98	0.88	0.46	0.24	0.13	0.07	18	20
Groundnut	P	1.79	0.94	0.89	0.40	0.23	0.13	0.07	27	10
Banana <20t	K	6.85	1.58	0.84	0.92	0.39	0.16	0.07	39	100
Soybean	K	1.761	0.099	0.900	0.041	0.024	0.014	0.008	0	0
Groundnut	K	1.720	0.221	0.942	0.057	0.042	0.031	0.023	14	42

†EOR was determined with the cost of using 50 kg urea and TSP, DAP and KCl at UgSh 120,000, 140,000 and 100,000, respectively. Commodity values (UgSh/kg) used were: paddy rice 1500; maize 600; banana 800; sorghum 500; finger millet 1200; Irish potato 800; bean 1200; groundnut (unshelled) 2400; and soybean 1000.

‡NARO 2001; Nyombi 2013.

††Upland rice and Irish potato have recommended K rates of 11 and 28 kg/ha but the EORs were determined to be 0 kg/ha.

farmers do not recover part of the money they have invested in buying the excess N, which is wastage of their scarce resource. The reverse is true for N and P applied to upland rice, sorghum, finger millet, Irish potato and wheat. In this situation farmers lose money by not achieving the economically optimum yield in response to applied nutrients (i.e. they get lower yield and profit than they would have got if they increased the rates applied).

The EOR and REC differed inconsistently for crop-nutrients (Tables 15.5a-g). The REC for maize N, except for lower altitude eastern Uganda, bean N, Irish potato N, soybean P, and soybean K, were somewhat similar compared with EOR determined from field research results. The REC for upland rice N and P, finger millet N and P, sorghum N and P, wheat P, bean P and groundnut P were considerably lower than EOR. The REC for banana N, wheat N, maize P, banana P, banana K and groundnut K were considerably higher than EOR. Currently fertilizer prices in Uganda are very high. If the prices can be reduced through more efficient supply and/or subsidies, the EOR will increase assuming no significant change in the relative commodity values. Most Ugandan farmers are financially constrained in fertilizer use and should apply at rates below EOR to take advantage of the steeper parts of response curves.

15.6 Conclusion

Nutrient response functions were generated from present and past research for maize, upland rice, finger millet, sorghum, wheat, beans, soybean, groundnut and banana, and from similar AEZ in Rwanda and Kenya for Irish potato. The response functions were used in the development of FOTs and to determine the optimal crop-nutrient-rate combination for

Table 15.5b: Eastern Uganda – Lake Kyoga Basin (Eastern and Southern Lake Kyoga Basin)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
			t/ha			**t/ha**			**kg/ha**	
Upland rice	N	3.670	2.400	0.958	1.738	0.480	0.132	0.037	83	46
Maize	N	2.569	0.838	0.930	0.743	0.084	0.010	0.001	28	60
Sorghum	N	2.270	1.580	0.932	1.389	0.168	0.020	0.002	35	0
Finger millet	N	2.056	1.283	0.958	0.929	0.256	0.071	0.020	61	40
Bean	N	1.790	0.989	0.892	0.957	0.031	0.001	0.000	31	0
					0-5	**5-10**	**10-15**	**15-20**		
Upland rice	P	3.790	0.556	0.947	0.133	0.101	0.077	0.059	29	10
Maize	P	2.911	0.342	0.880	0.162	0.085	0.045	0.024	8	25
Sorghum	P	2.305	0.362	0.839	0.212	0.088	0.037	0.015	7	0
Soybean	P	1.219	0.559	0.905	0.220	0.134	0.081	0.049	15	20
Finger millet	P	2.210	0.629	0.820	0.396	0.147	0.054	0.020	14	10
Bean	P	1.810	0.286	0.926	0.091	0.062	0.042	0.029	14	10
Groundnut	P	1.792	0.937	0.893	0.405	0.230	0.131	0.074	27	10
Soybean	K	1.761	0.099	0.900	0.041	0.024	0.014	0.008	8	0
Groundnut	K	1.720	0.221	0.942	0.057	0.042	0.031	0.023	29	42

Table 15.5c: Eastern Uganda: 1400–1800 masl (Mt Elgon High Farmlands)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
			t/ha			**t/ha**			**kg/ha**	
Maize	N	3.711	1.823	0.960	1.287	0.378	0.111	0.033	53	60
Banana	N	39.400	6.560	0.905	6.232	0.312	0.016	0.001	46	100
Irish potato	N	12.560	2.277	0.985	0.830	0.527	0.335	0.213	116	100
Bean	N	1.790	0.989	0.892	0.957	0.031	0.001	0.000	31	26
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.910	0.203	0.840	0.118	0.049	0.021	0.009	5	25
Banana	P	19.640	0.680	0.875	0.331	0.170	0.087	0.045	0	30
Irish potato	P	15.326	3.303	0.944	0.827	0.620	0.465	0.348	40	10
Bean	P	1.810	0.286	0.926	0.091	0.062	0.042	0.029	14	10
Soybean	P	1.662	0.979	0.880	0.464	0.244	0.128	0.068	18	21
Groundnut	P	1.792	0.937	0.893	0.405	0.230	0.131	0.074	27	10
Banana	K	34.810	8.712	0.969	1.269	1.084	0.926	0.791	0	100
Soybean	K	1.761	0.099	0.900	0.041	0.024	0.014	0.008	15	0
Groundnut	K	1.720	0.221	0.942	0.057	0.042	0.031	0.023	29	42

Table 15.5d: Eastern Uganda: above 1800 masl (Kapchorwa Farmlands – Forest)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
		t/ha			**t/ha**				**kg/ha**	
Maize	N	3.711	1.823	0.960	1.287	0.378	0.111	0.033	53	60
Banana	N	7.603	1.953	0.918	1.803	0.138	0.011	0.001	40	100
Wheat	N	3.113	0.570	0.904	0.542	0.026	0.001	0.000	24	50
Bean	N	1.790	0.989	0.892	0.957	0.031	0.001	0.000	31	26
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.910	0.203	0.840	0.118	0.049	0.021	0.009	5	25
Banana	P	19.640	0.680	0.875	0.331	0.170	0.087	0.045	15	30
Wheat	P	2.616	0.605	0.900	0.248	0.146	0.086	0.051	16	12
Bean	P	1.810	0.286	0.926	0.091	0.062	0.042	0.029	14	10
Soybean	P	1.662	0.979	0.880	0.464	0.244	0.128	0.068	18	21
Groundnut	P	1.792	0.937	0.893	0.405	0.230	0.131	0.074	27	10
Banana	K	6.850	1.583	0.841	0.917	0.386	0.162	0.068	39	100
Soybean	K	1.761	0.099	0.900	0.041	0.024	0.014	0.008	15	0
Groundnut	K	1.720	0.221	0.942	0.057	0.042	0.031	0.023	28	42

Table 15.5e: Northern, mid-west and western Uganda: (Northern Moist Farmlands, and Western Mid-Altitude Farmlands)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
		t/ha			**t/ha**				**kg/ha**	
Upland rice	N	3.670	2.400	0.958	1.738	0.480	0.132	0.037	83	46
Maize	N	3.771	1.828	0.960	1.291	0.379	0.111	0.033	53	60
Sorghum	N	2.270	1.580	0.932	1.389	0.168	0.020	0.002	35	0
Finger millet	N	1.608	0.876	0.957	0.642	0.172	0.046	0.012	52	40
Bean	N	1.790	0.989	0.892	0.957	0.031	0.001	0.000	31	26
					0-5	**5-10**	**10-15**	**15-20**		
Upland rice	P	3.790	0.556	0.947	0.133	0.101	0.077	0.059	29	10
Maize	P	3.910	0.203	0.840	0.118	0.049	0.021	0.009	5	25
Sorghum	P	2.305	0.362	0.839	0.212	0.088	0.037	0.015	7	0
Soybean	P	1.662	0.979	0.880	0.464	0.244	0.128	0.068	18	20
Finger millet	P	1.841	0.446	0.900	0.183	0.108	0.064	0.038	17	10
Bean	P	1.810	0.286	0.926	0.091	0.062	0.042	0.029	14	10
Groundnut	P	1.792	0.937	0.893	0.405	0.230	0.131	0.074	27	10
Soybean	K	1.761	0.099	0.900	0.041	0.024	0.014	0.008	15	0
Groundnut	K	1.720	0.221	0.942	0.057	0.042	0.031	0.023	58	42

Table 15.5f: South-western Highland: 1400–1800 masl (South-western medium-highlands, Bushenyi-N.Rukungiri Farmlands)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop	Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC‡
		t/ha			t/ha				kg/ha	
Maize	N	3.711	1.823	0.960	1.287	0.378	0.111	0.033	53	60
Banana	N	39.400	6.560	0.905	6.232	0.312	0.016	0.001	48	100
Irish potato	N	12.560	2.277	0.985	0.830	0.527	0.335	0.213	115	100
Finger millet	N	1.608	0.876	0.957	0.642	0.172	0.046	0.012	52	40
Bean	N	1.790	0.989	0.892	0.957	0.031	0.001	0.000	29	26
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.910	0.203	0.840	0.118	0.049	0.021	0.009	5	25
Banana	P	19.640	0.680	0.875	0.331	0.170	0.087	0.045	15	30
Irish potato	P	15.326	3.303	0.944	0.827	0.620	0.465	0.348	44	10
Soybean	P	1.662	0.979	0.880	0.464	0.244	0.128	0.068	20	21
Finger millet	P	1.841	0.446	0.900	0.183	0.108	0.064	0.038	17	10
Bean	P	1.810	0.286	0.926	0.091	0.062	0.042	0.029	11	10
Banana	K	34.810	8.712	0.969	1.269	1.084	0.926	0.791	83	100
Soybean	K	1.761	0.099	0.900	0.041	0.024	0.014	0.008	18	0

Table 15.5g: South Western Highland: above 1800 masl (Kabale–Rukungiri Highlands, Kabale–Kisoro Highlands).

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of nutrient element rate (kg/ha) on yield increase				Recommended nutrient rate	
Crop	Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC‡
		t/ha			t/ha				kg/ha	
Maize	N	3.771	1.828	0.960	1.291	0.379	0.111	0.033	53	60
Irish potato	N	12.560	2.277	0.985	0.830	0.527	0.335	0.213	46	100
Wheat	N	3.113	0.570	0.904	0.542	0.026	0.001	0.000	11	50
Bean	N	1.790	0.989	0.892	0.957	0.031	0.001	0.000	12	26
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.910	0.203	0.840	0.118	0.049	0.021	0.009	5	25
Irish potato	P	15.326	3.303	0.944	0.827	0.620	0.465	0.348	20	10
Wheat	P	2.616	0.605	0.900	0.248	0.146	0.086	0.051	18	12
Bean	P	1.810	0.286	0.850	0.159	0.071	0.031	0.014	11	10

maximizing net returns on investment in fertilizer use. Paper FOTs were developed for each AEZ to be used by farmers and their advisors who do not have access to a computer. A fertilizer calibration tool was developed to guide farmers in application to achieve the correct rate of fertilizer application.

Current recommended fertilizer application rates were found to be generally high compared to the EOR determined from results of field research. The results presented show the potential of the FOT in improving on the profitability of farming. Responses to secondary and trace elements call for more research to determine the extent and conditions of the occurrence of deficiencies, and the economics of application and which nutrients are limiting production in Uganda.

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