16. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Zambia

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16.1 Introduction

Fertilizer use is an important part of soil fertility management and for substantially increased levels of crop production but it has to be adequately profitable to the farmer to justify the investment. High rates of return are especially important to farmers with little money available for fertilizer use.

The Zambia Agricultural Research Institute partnered with national agricultural research organizations of 12 other countries to improve the field-research-derived information base needed for optimizing fertilizer use for high profitability to farmers.

This chapter provides background information of agricultural systems and current soil fertility management practices in the three regions of Zambia. It provides a conceptual basis for optimization of fertilizer use and introduces

decision tools to aid farmers and their advisors in determining the fertilizer use options expected to be most profitable to farmers. The nutrient application rates expected to maximize net returns per hectare to fertilizer use are compared to current recommendations with the latter typically higher than the economically optimum rates.

16.2 Agricultural systems of Zambia

Zambia is divided into three agro-ecological regions based on rainfall (Figure 16.1) (http://en.climate-data.org/). Region I is characterized by mean annual rainfall of less than 800 mm and is dominated by slightly acid to alkaline Luvisols (Table 16.1). Region II has mean annual rainfall ranging from 800-1000 mm. Region III has mean annual rainfall of above 1000 mm and comprises half of the land area of Zambia.
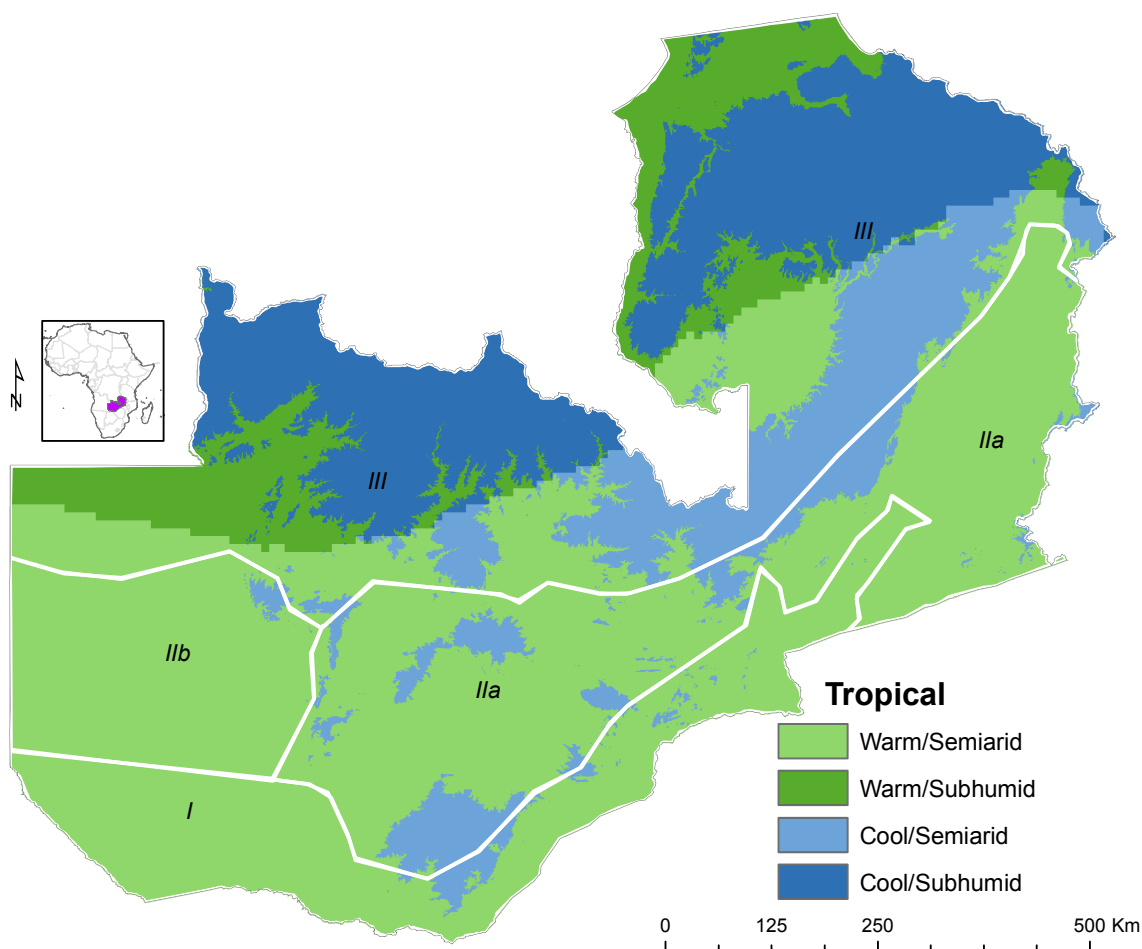

Figure 16.1: Agro-ecological regions of Zambia.

Zambia has the November to April rainy season, the cool dry season of May to August and the hot dry season of August to November. The annual rainfall decreases from an average of 1000 mm in the northern part of the country to an average of 800 mm in the southern part. The annual temperature ranges between 18°C to 20°C. The highest annual average temperature is 32°C and the lowest temperature average is 4°C.

Region I is the low rainfall region of Zambia (Table 16.1). It covers major valleys of Gwembe, Lunsemfwa and Luangwa in the south and south-eastern margin of the country, and is about 23% of Zambia's total land area. Mean annual rainfall is less than 800 mm, erratic and often of high intensity. Long dry spells during the rainy season limit crop and livestock production. The length of the cropping season ranges between 60-90 days. The dominant soils in the valley areas are slightly acid to alkaline and generally have higher levels of fertility than soils of plateau areas. Soil acidity is a dominant constraint to crop production.

Region II is commonly classified as the medium rainfall region of Zambia (Table 16.1). It forms a central band stretching from western to eastern Zambia. The region is characterized by a mean annual rainfall of between 800 to 1000 mm and has a cropping season of 90-150 days. The dominant soils are sandy, acidic and have low nutrient reserves and poor water retention capacity. These soils are prone to leaching of nutrients after heavy rainfall and to water stress during dry spells because of their limited ability to retain nutrients and water. Region II is divided into sub-regions IIa and IIb. The combination of moderately fertile soil with medium rainfall and a moderately long growing season makes sub-region IIa the most productive region of the country for most arable crops particularly maize, wheat, soybean, groundnut and tobacco. Sub-region IIb comprises the Kalahari sand plateau and Zambezi flood plains in Western Province and other parts of Region II not covered by Kalahari sands. The area of Region II is approximately 27.4 million hectares. The dominant soils include sandveld soils which are moderately leached, medium to strongly acid with sandy top soils overlying loamy subsoil. They also include some moderately weathered, moderate to slightly acidic red to strong brown soils derived from limestone. In low lying areas or flood plains, there may be slightly acidic to neutral heavy dark cracking clays.

Table 16.1: Mean monthly rainfall (mm) and maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of AEZ of Zambia (http://en.climate-data.org)

	J	F	M	A	M	J	J	A	S	O	N	D
Region I (Choma)												
Rainfall	203	161	85	28	7	1	0	0	1	23	93	198
Tmax	26.9	26.8	26.8	26.4	24.8	22.4	22.9	25.4	29.2	30.9	29.4	27.2
Tmin	16.7	16.4	15.2	12.1	7.8	4.7	4.8	6.5	10.7	14.3	16.2	16.6
Region IIa (Lusaka)												
Rainfall	231	191	147	18	0	0	0	0	0	10	91	150
Tmax	26	26	26	26	25	23	23	25	29	31	29	27
Tmin	17	17	17	15	12	10	9	12	15	18	18	17
Region IIb (Mongu)												
Rainfall	213	190	145	43	5	0	0	1	3	35	106	198
Tmax	29.3	29.3	29.4	30.3	29.1	27.0	27.2	30.4	34.4	35.3	32.2	29.5
Tmin	18.8	19.0	18.6	16.7	12.9	9.9	9.5	12.0	16.0	18.4	18.4	18.3
Region III (Kasama)												
Rainfall	281	232	235	89	12	0	0	0	3	21	150	274
Tmax	26.0	26.0	26.0	26.2	25.5	24.5	24.6	26.7	29.3	31.0	28.6	26.5
Tmin	16.1	16.2	16.1	15.2	12.5	10.0	9.5	11.0	13.7	16.0	16.5	16.2

Region III is the high rainfall region in the northern part of the country and has a rain-fed crop growing season of 140-200 days. Soils are highly weathered and highly leached, acidic, depleted of nutrients and of low productivity compared with the soils of Regions I and II.

16.3 Current soil fertility management

Farmers have traditional practices for soil and water management. Conservation basins are used to harvest water in Regions I and IIa. Shifting of livestock pens is an indigenous practice of confining a herd of cattle on a small piece of land at night for three to four days and then moving to enrich the soil with excreted urine and faeces. Farmers address acid soils in Region III with the slash and burn practice known locally as chitemene. These practices are insufficient to maintain productivity under intensive cropping and need to be integrated with other practices (Bekunda et al., 2010). Such practices may include conservation tillage, crop rotation with legumes, improved soil cover with mulch, cover crops and crop residues, application of manure and other organic material, and fertilizer use.

Two limitations of using organic materials as nutrient sources are that nutrient release is often out of synchrony with crop demand and nutrient contents are commonly very low. Agro-forestry such as tree fallows may be an acceptable practice for breaking hard pans, fixing nitrogen and capturing and recycling leached nutrients. Integrating organic resources with fertilizer use is often the best option for enhancing soil nutrient availability. Use of biochar is of interest to some on acid soils with low cation exchange capacity (CEC) as it is a carbon form that persists in the soil and adds to CEC and water-holding capacity. Use of lime is important to productivity of acid soils in Region III. Use of wood ash to amend acid soils is a common traditional farming practice but the available quantity is small outside of areas of slash and burn.

Fertilizer is an expensive input and efficient use is important for good profitability and to reduce nutrients lost to the environment and soil acidification due to nitrogen application. The negative effects of nutrient application are reduced through efficient fertilizer use and the practice of the 4Rs of Nutrient Stewardship, that is, to apply the right product at the right rate, at the right time and using the right method, especially for N fertilizers as N is easily lost. Much of the fertilizer N should be applied shortly before or during periods of rapid vegetative growth of crops, approximately six weeks after planting maize. The farmer is the final decision-maker in determining practices suited to local soil, weather, cropping system and social economic conditions but the 4Rs of fertilizer use are a good framework for making decisions.

Efficient fertilizer use requires a healthy and well managed crop. Minimizing potential yield-limiting situations allows for maximum response to applied fertilizer. Use of recommended and adopted varieties, cultural practices and pest control helps maximize fertilizer response. Also important to profitable and efficient fertilizer use may be consideration of soil test information and the effects of other practices such as manure application and use of lime or wood ash to reduce soil acidity.

16.4 Fertilizer use optimization

Normally farmers wish to maximize profit from fertilizer use. This may be to maximize net returns per hectare resulting from fertilizer use. In the case of financially constrained fertilizer use, profit maximizing means to achieve high returns on their small investment. Investment in fertilizer competes with other uses of financial resources by the financially constrained. In order to meet immediate livelihood needs, fertilizer investments must give high returns with little risk. Therefore, fertilizer use optimization refers to maximizing profit from fertilizer use according to the farmer's agronomic and economic situation.

The nature of crop response to applied nutrients, over a large number of trials, is usually curvilinear and reaching a plateau, as illustrated by the typical cowpea response to applied P in Zambia (Figure 16.2). With the first 5 kg/ha of elemental P, or 11 kg of phosphate, applied there is a very good yield increase. The yield increase continues up to 10 kg/ha (22 kg/ha of phosphate.) Yield increases past 10 kg/ha is very low and probably not enough to pay for the cost of applying additional P. Therefore, the potential for profit per unit of investment is greatest at low input rates.
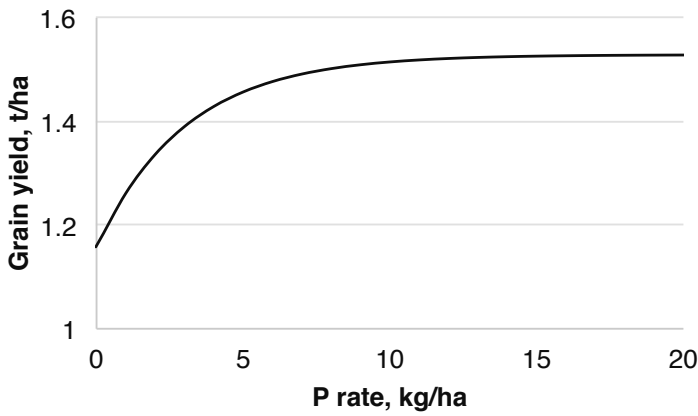
Figure 16.2: Response curve of cowpea for P application.

There are several mathematical formulas that are used to model fertilizer response. Creating an equation to represent crop response to a fertilizer input allows economic analysis to determine the return on an investment over a range of prices and costs. In this case the curvilinear to plateau yield response to applied nutrient is represented by the equation $Y = a – bc^r$ where Y is yield, a is yield at the plateau, b is the yield increase due to application of the concerned nutrient, c is a determinant of the shape of the response curve, and r is the nutrient application rate. Crop nutrient response

equations were determined for maize, cowpea and soybean in all three regions. In addition, sorghum was addressed in Regions I and III, bean in Regions II and III, and groundnut in Region I.

Another important aspect of achieving high profit from fertilizer use for financially constrained farmers is the need to know the return of a kwacha invested over a range of nutrients applied to a range of crops. In other words, which nutrients applied to which crops bring the most return for the amount available to invest?

An example of the data needed to make these decisions is shown in Figure 16.3. In this graph from Region III, the x-axis (horizontal axis) is Zambia kwacha (ZMK), net returns are on the y-axis. Each line represents the profit potential of a nutrient applied to a crop. When the slope of the curve is steep, it shows that the net returns per ZMK 100 invested per hectare are very high. As the amount invested (the x-axis) in a crop-nutrient increases, the slope decreases but if still upward then the profit is increasing. Where a curve peaks is its point of maximum profit per hectare. The greatest rate of return
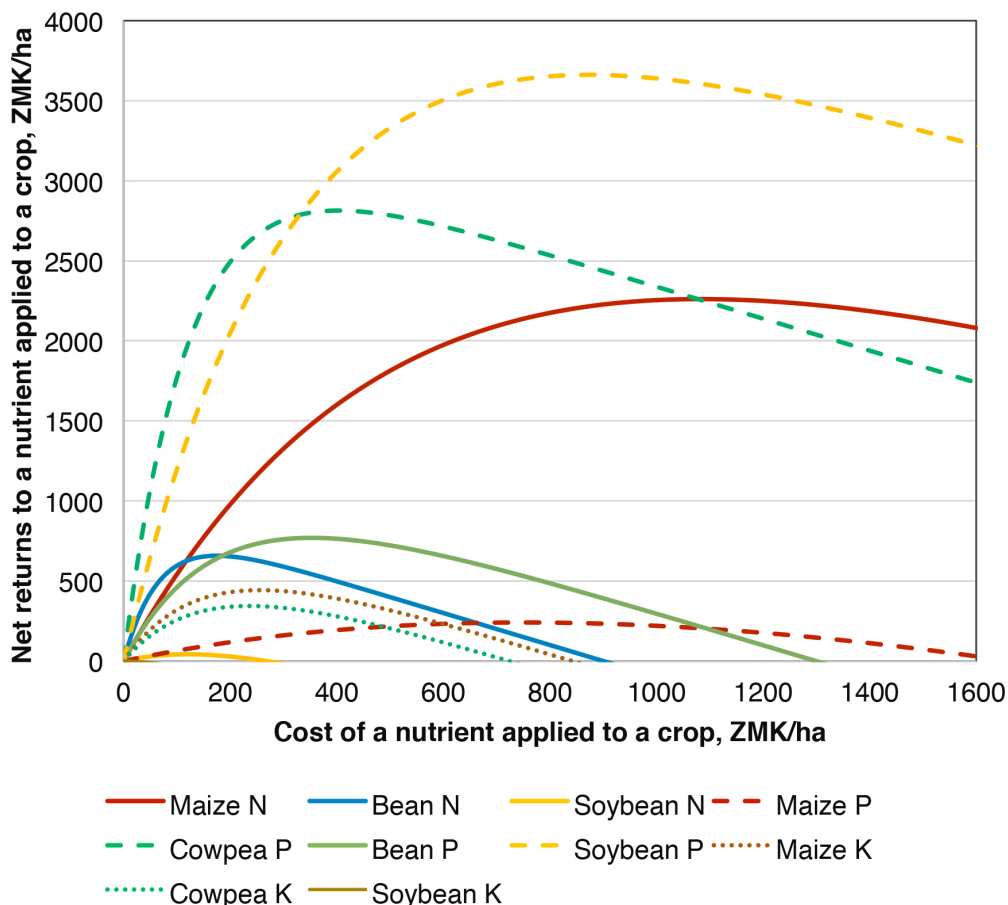

Figure 16.3: Nutrient returns to investment in nutrient application in Region III of Zambia.

per kwacha invested is achieved with K applied to cowpea, followed by similar profitability with bean N and cowpea P. When slopes decline, total profit is declining. However, only a small amount of applied nutrient is needed with these options before the profit potential peaks. Application of N to maize is more profitable compared with the lower lying curves until about ZMK 800 worth of N is applied at which point P applied to maize at low rates is of similar profit potential. Applications of P to bean and soybean have modest profit potential at low rates of application. An example application of the information in Figure 16.3 is that in this case, the farmer who has ZMK 1000 for fertilizer and one hectare for each crop would near optimization by applying: ZMK 200 each of P and K to cowpea; ZMK 200 of N to bean; and ZMK 400 of N to maize.

16.5 Fertilizer optimization tools for Zambia

Decisions on choices of amount of each fertilizer to apply to each crop are very complex if the intent is to maximize potential for profit and if the farmer prefers to have several different crops. The nature of the response of each crop to each applied nutrient needs to be considered, but also the farmer's land allocation to different crops, the expected value of the grain on-farm near harvest time considering the value of the grain kept for home consumption and that to be marketed, the costs of fertilizer use and the money that the farmer has available for fertilizer use. Therefore, easy to use fertilizer optimization tools (FOTs) have been developed which use complex mathematics of linear programming to integrate economic and agronomic information (http://agronomy.unl.edu/OFRA).

The FOTs work in Excel Solver© (Frontline Systems Inc., Incline Village, NV, USA). Use of the FOT requires that the add-in Solver be activated and that macros are enabled; this is addressed in the 'Help and Instructions' worksheet of the FOT and in more detail in an FOT user manual in Extension Training Materials at http://agronomy.unl.edu/OFRA.

The data input screen (Figure 16.4) requires entry of the land area to be planted to each crop and the estimated on-farm value per kilogram of grain near harvest time. The cost of using different fertilizers and the available money of

the farmer for fertilizer use are also entered. The optimize button is left-clicked to run the optimization. The output includes: the amount of fertilizer to apply to each crop; the expected average yield increases and net returns to fertilizer use per hectare; and the total net returns to fertilizer use for the farm (Figure 16.5).

For each Excel FOT, there is a companion paper FOT to be used when a computer is not available (Table 16.2). The paper FOT has three financial levels as follows: Level 1 for the poor farmer who has no more money than one-third of the required amount to buy the fertilizer to apply to all the cropland at the rates to maximize profit per hectare, also referred to as the economically optimal rate (EOR); level 2 for the farmer who has no more than two-thirds of the money to apply fertilizer to all cropland at EOR; and level 3 for the farmer with enough money to apply fertilizer to some cropland at EOR. The paper FOT begins by stating assumptions: the volume of measuring units to be used by farmers in adjusting their eyes and feel for applying the right rate of fertilizer; inter- and intra-row spacing of plants; the costs of fertilizer use per 50 kg bag; and the expected commodity values on-farm at harvest, considering the value of both home consumption and for market.

The paper FOT advises on the fertilizer to use and the application rate for each crop according to the farmer's financial level but also includes the method and time of application, thereby advising on the 4Rs of fertilizer use. It also advises on calibration to help the farmer to adjust his/her eyes and feel to the rate of application, that is a water bottle lid full of fertilizer is sufficient for so many metres of band application or so many plants.

In using the paper FOT for Region II (Table 16.2), first consider the farmer's financial ability for fertilizer use. If the farmer has little money, begin with financial level 1 which has options for three crops. For example, one recommendation is 'For maize, point dress 45 kg/ha urea 6 WAP (1 CAP for 5 plants)'; therefore 45 kg/ha urea is to be applied at least 5 cm from the maize plants at 6 weeks after planting with one water bottle lid sufficient for 5 plants. If the farmer has money in excess of

Zone 2

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

Crop Selection and Prices		
Crop	**Area Planted (Ha)***	**Expected Grain Value/kg †**
Maize	3	1.5
Cowpea	0.25	9
Bean	0.5	13
Soybean	0.5	8
Total	**4.25**	

Fertilizer Selection and Prices					
Fertilizer Product	**N**	**P2O5**	**K2O**	**xx**	**Costs/50 kg bag ¶***
Urea	46%	0%	0%	0%	350
Triple super phosphate, TSP	0%	46%	0%	0%	0
NPK	10%	20%	10%	0%	400
Blank	0%	0%	0%	0%	0
	0%	0%	0%	0%	0

Budget Constraint	
Amount available to invest in fertilizer	1250

Figure 16.4: The input sheet for the Excel Solver Fertilizer Optimization Tool.

Fertilizer Optimization					
	Application Rate - kg/Ha				
Crop	**Urea**	**TSP**	**NPK**		
Maize	36	0	0	0	0
Cowpea	0	0	44	0	0
Bean	35	0	0	0	0
Soybean	0	0	69	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
Total fertilizer needed	126	0	46	0	0
Expected Average Effects per Ha					
Crop	**Yield Increases**	**Net Returns**			
Maize	673	756			
Cowpea	266	2,040			
Bean	266	3,213			
Soybean	368	2,392			
	0	0			
	0	0			
	0	0			
Total Expected Net Returns to Fertilizer					
Total net returns to investment in fertilizer	5,579				

Figure 16.5: The output sheet for the Excel Solver Fertilizer Optimization Tool.

Table 16.2: Fertilizer use optimizer paper
Zambia Fertilizer Use Optimizer: Region II.
Prepared Davy Nkonde
April 2016

The below assumes:
Calibration measurement is with a water bottle lid (CAP); contains 8 ml, 5.6 g urea, 8 g NPK.
Row spacing: maize at 75 x 30 cm; cowpea at 60 x 15 cm; bean at 60 x 15 cm.
Grain prices per kg (ZMK): 2 maize; 8 cowpea; and 13 bean.
50 kg of fertilize use costs (ZMK): 350 urea; 400 NPK.
Application rates are in kg/ha.

Level 1 financial ability.	
Maize	Point dress 45 kg/ha urea 6 wap (1 cap for 5 points)
Bean	Band dress 52 kg/ha npk applied at planting (1 cap for 3 m)
Cowpea	Band dress 46 kg/ha npk applied at planting (1 cap for 3 m)
Level 2 financial ability.	
Maize	Point dress 97 kg/ha urea 6 wap (1 cap for 2.5 points)
Bean	Band dress 85 kg/ha npk applied at planting (1 cap for 2 m)
Cowpea	Band dress 61kg/ha npk applied at planting (1 cap for 2 m)
Level 3 financial ability (maximize profit per acre).	
Maize	Point dress 147 kg/ha urea 6 wap (1 cap for 1.5 points)
Bean	Band dress 117 kg/ha npk applied at planting (1 cap for 1 m)
Cowpea	Band dress 76 kg/ha npk applied at planting (1 cap for 2 m)

the level 1 options, level 2 options should be considered. Fertilizer use options within levels have similar profit potential.

16.6 Fertilizer use in an integrated nutrient management framework

Fertilizer use decisions need to consider the effects of other practices that supply soil nutrients as well as soil test information (Table 16.3). The use of green manure and the application of manure calls for adjustment of fertilizer rates to be applied. The fertilizer substitution value varies with the quality of manure. Poultry and dairy manure are expected to have greater fertilizer substitution value than farmyard manure. Other practices with fertilizer substitution value include bringing material such as tree prunings into the field, rotations and intercropping. Soil test information should be considered. When soil test information is not available, soil test P should be considered low and fertilizer P applied according to the FOT recommendations. If soil test K is found to be very low, apply K even if not recommended by the FOT. As an example, 'For each 1 t of fresh leguminous leafy tree prunings applied (e.g,

Gliricidia, Leucaena, Sesbania, Senna)', the urea, TSP or DAP, or NPK rate can be reduced from the FOT recommendation for the field by 10, 1 and 6 kg/ha, respectively. The prunings may be from alleys within the field, field boundary areas, or nearby treelots.

16.7 Crops addressed by region for optimized fertilizer use

The crops and nutrients addressed by Optimising Fertilizer Recommendations in Africa (OFRA) research in 2013-15 are given in column 1-2 of the three parts of Table 16.4. The response coefficients a, b, and c for the above defined equation $Y = a - bc^r$ are reported in columns 3-5. The effects on changes in nutrient rates on yield increases are reported in columns 6-9. The elemental nutrient application rates at EOR and as currently recommended in Zambia (REC) are given in columns 10-11.

Maize and sorghum had >1100 and >400 kg/ha, respectively, responses to applied N in Region I but the sorghum response was not economical (Table 16.4a). Groundnut had a sufficient response to N to justify a low rate of application

Table 16.3: Fertilizer use in an ISFM framework: fertilizer substitution and soil test implications

ISFM practice	Urea	DAP or TSP	NPK 10-20-10+6S
	Fertilizer reduction, % or kg/ha		
Previous crop was a green legume manure crop (Mucuna, Crotalaria and Lablab)	100%	8 kg	28 kg
Early incorporation of a green legume manure (Mucuna, Crotalaria and Lablab) crop	57 kg	3 kg	11 kg
For each 1 t of fresh leguminous leafy tree prunings applied (e.g. Gliricidia, Leucaena, Sesbania, Senna)	10 kg	1 kg	6 kg
Farmyard manure per 1 t of dry material	2 kg	1 kg	1 kg
Residual value of FYM applied for the previous crop, per 1 t	1 kg	0.4 kg	0.4 kg
Dairy or poultry manure, per 1 t dry material	24 kg	7 kg	14 kg
Residual value of dairy and poultry manure applied for the previous crop, per 1 t	5 kg	1.4 kg	3 kg
Compost, per 1 t/ha dry wt	20 kg	1 kg	20 kg
Doubled-up legume-technology (pigeonpea)	In the second year of rotation a mean reduction of over 50 kg urea		
Cereal-bean intercropping	Increase DAP/TSP by 18 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 20 kg/kg, reduce urea by 30 kg/ha, and no change in K compared with sole cereal fertilizer		
If Mehlich III P >18 ppm	Do not apply P		
If soil test K < 0.25 cmol/kg	Apply 20 kg/ha KCl		

at planting or shortly after emergence. All crops responded to P application but the response was not economical for sorghum. Maize and groundnut responded to K application. With the exception of P applied to groundnut, EOR was always less than REC for Region I indicating that those with the financial ability to apply according to the recommendations are over-applying and losing profit potential.

Maize and bean had an economic response to N in Region II and all crops considered had a profitable response to some level of P (Table 16.4b). Only cowpea had an economical response to K because of the high value given to the grain. The EOR were always less than REC except for P application to maize.

Yield increases with nutrient application in Region III were greater than in other regions. Maize and sorghum had economic responses to N and all crops had economic responses to P. Maize responded to applied K. As in other

regions, EOR were low compared with REC but the maize P and K rates were similar.

The RECs in Zambia are high compared with the EOR determined from field research in 28 of 31 comparisons. Across all crop nutrient recommendations, the RECs were on average 112% more than the EOR. Farmers who apply at REC are therefore over-applying fertilizer and missing much profit opportunity as compared to using rates nearer to EOR. Financially constrained farmers need to apply rates of less than EOR and as determined by use of the FOT.

Another concern that arises from analyses and interpretation of research information is associated with the very limited availability of fertilizer types in Zambia. Urea is the only single nutrient fertilizer that is regularly available to farmers. All other nutrient needs must be met using the NPK blend of 10-20-10. The restricted availability of fertilizer types is based on the assumption that a nationally determined

Table 16.4a: Region I: 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 have zero response or insufficient information to determine EOR.

Crop	Nutrient	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effects of elemental nutrient rate (kg/ha) changes on grain yield				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR[†]	REC
		t/ha			t/ha				kg/ha	
Maize	N	2.130	1.192	0.974	0.651	0.295	0.134	0.061	43	112
Sorghum	N	2.828	0.473	0.977	0.238	0.118	0.059	0.029	0	66
Groundnut	N	1.260	0.075	0.800	0.075	0.000	0.000	0.000	10	15
Cowpeas	N	1.465	0.154	0.835	0.154	0.001	0.000	0.000	0	30
					0-5	5-10	10-15	15-20		
Maize	P	4.133	0.532	0.858	0.285	0.133	0.062	0.029	6	17
Soybean	P	1.407	0.250	0.916	0.089	0.057	0.037	0.024	11	34
Sorghum	P	2.774	0.408	0.865	0.211	0.102	0.049	0.024	6	17
Groundnut	P	1.337	0.273	0.898	0.116	0.067	0.038	0.022	16	13
Cowpea	P	0.720	0.084	0.900	0.034	0.020	0.012	0.007	16	26
Maize	K	3.539	0.455	0.900	0.186	0.110	0.065	0.038	14	17
Groundnut	K	1.260	0.075	0.800	0.050	0.017	0.005	0.002	10	13

[†] EOR was determined with the cost of using 50 kg urea and NPK at ZMK 350 and 400, respectively. Commodity values (ZMK/kg) used were: maize 1.5; sorghum 1.5; cowpea 9.0; groundnut 8.0; soybean 8.0; and bean 13.

Table 16.4b: Region II.

Crop	Nutrient	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effects of elemental nutrient rate (kg/ha) changes on grain yield				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR[†]	REC
		t/ha			t/ha				kg/ha	
Maize	N	4.906	2.572	0.982	1.080	0.626	0.363	0.211	84	112
Bean	N	0.838	0.293	0.862	0.289	0.003	0.000	0.000	23	30
Soybean	N	1.131	0.046	0.929	0.041	0.004	0.000	0.000	0	-
					0-5	5-10	10-15	15-20		
Maize	P	2.853	1.794	0.972	0.238	0.206	0.179	0.155	23	17
Cowpea	P	1.529	0.371	0.720	0.299	0.058	0.011	0.002	10	26
Bean	P	0.884	0.058	0.869	0.029	0.015	0.007	0.004	7	26
Soybean	P	1.359	0.608	0.868	0.309	0.152	0.075	0.037	8	34
Maize	K	4.084	0.097	0.900	0.040	0.024	0.014	0.008	0	17
Cowpea	K	1.563	0.081	0.898	0.034	0.020	0.011	0.007	15	25
Soybean	K	1.402	0.508	0.781	0.360	0.105	0.030	0.009	0	-

blend is better for farmers than allowing them to apply fertilizers according to their perceived needs. All crops in all regions responded to P but to apply P, farmers need to use their scarce financial ability to pay for the N and K in the NPK blend. However, only 6 of the 14 crop by region considerations had an economic response to some applied N and 5 of 14 had an economic response to K. In addition, blends are more costly to supply than the basic fertilizers from which blends are produced. These factors add to real costs of applying nutrients which give

Table 16.4c: Region III.

Crop	Nutrient	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effects of elemental nutrient rate (kg/ha) changes on grain yield				Recommended nutrient rate	
		a	b	c	0-30	30-60	60-90	90-120	EOR[†]	REC
		t/ha			t/ha				kg/ha	
Maize	N	5.100	2.600	0.973	1.446	0.636	0.280	0.123	71	112
Bean	N	0.429	0.100	0.798	0.100	0.000	0.000	0.000	0	30
Sorghum	N	4.071	0.730	0.964	0.487	0.162	0.054	0.018	23	66
					0-5	5-10	10-15	15-20		
Maize	P	2.900	1.600	0.972	0.215	0.187	0.162	0.141	18	17
Cowpea	P	1.529	0.371	0.720	0.299	0.058	0.011	0.002	10	26
Bean	P	0.429	0.100	0.798	0.068	0.022	0.007	0.002	9	26
Sorghum	P	4.047	0.651	0.856	0.352	0.162	0.074	0.034	10	17
Soybean	P	1.457	0.607	0.883	0.281	0.151	0.081	0.043	22	34
Maize	K	4.863	0.563	0.896	0.238	0.137	0.079	0.046	16	17
Cowpea	K	1.563	0.081	0.898	0.034	0.020	0.011	0.007	15	25
Soybean	K	0.837	0.019	0.908	0.007	0.005	0.003	0.002	0	-

profitable returns. The implication is especially great for the finance constrained farmer as the added cost is a lost opportunity of investing in the nutrients with potential to give high rates of return.

16.8 Acknowledgements

16.9 Reference

Bekunda M, Sanginga N and Woomer PL (2010) Restoring soil fertility in Sub-Sahara Africa. Advan Agron 108:183-236