14. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Tanzania

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14.1 Importance of agriculture in Tanzania

Agriculture is the most important sector to the economy of Tanzania. It accounts for 26.4% of the total Gross Domestic Product (GDP), 30% of export earnings and 65% of raw material for domestic industries (World Bank 2010; Hepelwa et al., 2013). Over 80% of the population in rural areas depend on agriculture indicating the importance of the sector in poverty reduction and food security in the country.

The major food crops grown in the country are maize, sorghum, millet, cassava, sweet potato, Irish potato, banana, pulses, paddy and wheat. Maize is planted on 45% of total arable land. Rice is the third most important food and cash crop, generates much employment and rural income, and 99% is grown by smallholder farmers (Hepelwa et al., 2013). Common bean production occupies about 800,000 ha (Letaa et al., 2014) and is an important source of food and income for smallholder farmers with per capita bean consumption of about 19.3 kg/yr, contributing 16.9% of the protein and 7.3% of the calories for human nutrition (Rugambisa 1990). Cash crops grown in Tanzania include coffee, cashew nut, tea, cotton, tobacco, wheat and sisal. On average the crop sub sector contributes about 34.8% of the agricultural GDP.

14.2 Agro-ecological zones (AEZ) of Tanzania

The country is divided into Eastern, Northern, Southern, Southern Highlands, Western, Central, and Lake Zones (Figure 14.1). The zones are

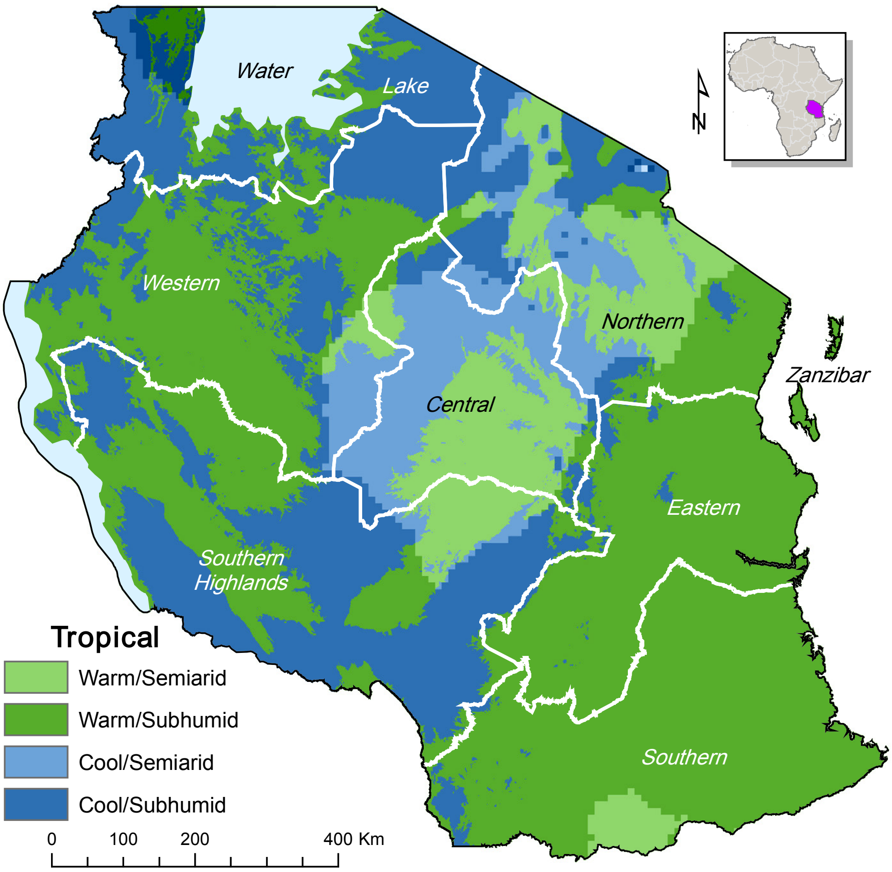

Figure 14.1: Major Agricultural Zones of Tanzania overlain on the AEZ map of HarvestChoice.

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

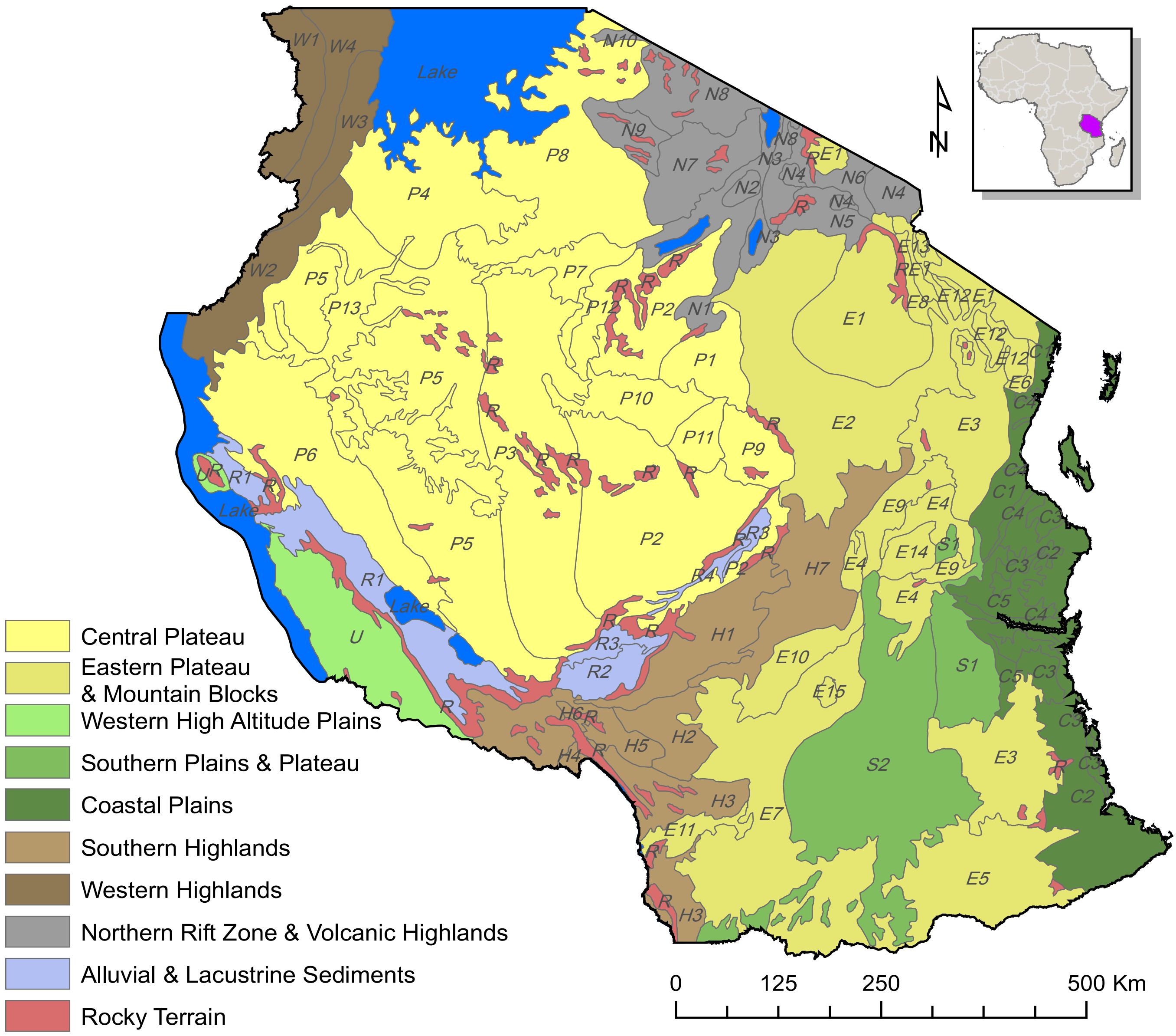

Figure 14.2: Agro-ecological Zones of Tanzania. Source: http://www.kilimo.go.tz/agricultural%20maps/Tanzania%20 Soil%20Maps/Webbased%20Districts%20Agricultural%20maps/Districts%20AEZs/Tanzania%20agro-ecological%20 zones.htm

further divided into 63 agro-ecological zones (AEZ) which are natural physical regions with similar climate, physiography and soil (De Pauw 1984) (Figure 14.2; Table 14.1).

Tanzania has four main climatic zones. The coast and immediate lowland is tropical with mean temperatures near 27°C, rainfall varying from 1000 to 1930 mm and high humidity, and covers much of Eastern and Southern Zones. Locations that represent parts of this climate zone include Bagamoyo, Mtwara and Kilosa (Table 14.2). Kilosa and Bagamoyo have bimodal rainfall pattern with long (March to June) and short (October to December) rain seasons (De Pauw 1984). Mtwara has mono-modal rainfall from November to May.

The climatic zone of the central plateau, represented by Dodoma, is hot and dry with mono-modal December to April rainfall of 500 to 760 mm, and with considerable daily and seasonal temperature variation (Table 14.2). The semi temperate highland climate zone covers Southern Highland and Northern Zones and is represented by Selian, Arusha and Mbeya with mono-modal rainfall of December to April. The climatic zone of the high, moist lake regions cover Lake Zone and Western Zone near Lake Tanganyika in Kigoma. There are two rainy seasons of November to December and March through May in the northern Lake Zone, e.g. Tarime, and Western Zone. The uni-modal rainfall of southern Lake Zone is from November to March as in Tabora and Ukiriguru.

Table 14.1: Application of OFRA fertilizer optimization tools by AEZ (Figure 14.2)

FOT	AEZ†
Eastern	All C; E <1000 m in Eastern and Northern Zones except for E1
Northern	E2 (>1000 m); N3, N4, N5, N6
Southern Highlands	H except for H4, U, E7, E14, U
Lake Zone >1300 m	N8, N9, N10, W1, W4
Lake Zone <1300 m	W3, P4, P8
Western	W2, P3, P4, P5, P6, P7, P8
Central	P1, P2, P9, P10
Southern	E <1000 m in Southern Zone, S1, S2

†Description of the AEZ groups:
C: Coastal plains
E: Eastern plateau and mountain blocks
H: Southern highlands
N: Northern rift zones and volcanic highlands
P: Central plateaux (plains)
R: Rocky terrain in several zones
S: Southern low altitude plains and plateau
U: Southwestern high-altitude plain
W: Western highlands

Soils of the AEZ of Tanzania were well described by De Pauw (1984) and are covered only generally in this chapter. The soil types are widely diverse and the dominant soil types are Cambisols with ferrallic properties (36%), Acrisols (8.6%), Leptosols (8.1%), Luvisols (7.3%) and Ferralsols (6.3%). The most fertile soils, apart from volcanic soils (Andosols) in the north and south, are the Vertisols (Mbuga soils) that occupy 5% of the country although these are difficult to manage being very hard when dry and easily waterlogged when wet (Mlingano ARI 2006).

14.3 Current soil fertility management

Most croplands of Tanzania have low fertility and nitrogen is the most limiting nutrient (Mowo et al., 1993; Marandu et al., 2014). Soil phosphorus availability is commonly low. Potassium and S deficiencies are locally important. There are occasional indications of localized Cu, Zn and Mn deficiencies. Current fertilizer use is reported to average 17 kg/ha/yr with most used for maize, rice and vegetable production (World Bank 2014). In 2008, a subsidy on fertilizers and seeds was introduced under the National Agricultural Input Voucher Scheme (NAIVS) to promote adoption of improved seed and fertilizers, especially for high potential maize and rice production and fertilizer use has increased from 9 to 17 kg/ha/yr since then. Generally less than 5% of farmers in 50% of the districts use fertilizers. MAFS (2012) indicated that 42% of fertilizer is used in the Southern Highlands, 17% in Shinyanga and Tabora Regions, 12% in Kilimanjaro and Arusha Regions, 10% in Morogoro Region and 5% in Kagera and Kigoma Regions. Urea accounts for about 65% of fertilizer usage.

Traditional soil management practices include incorporation of crop residues, fallow, use of farmyard manure, and inter-cropping or rotation of legumes and non-legumes (Shekiffu 2011). Most farmers, however, harvest or burn crop residue. In Eastern Zone, almost 70% of the farmers in cassava based production systems burned crop residues during land preparation, 12.5% farmers incorporated crop residues, 16.5% fallowed land for 1 to 3 years, 2.5% used farmyard manure, and none used fertiliser (Shekiffu 2011). In Northern Zone, crop residues are commonly burnt or harvested with no significant incorporation of organic material into the soil to maintain topsoil structure and nutrient status.

The first fertilizer recommendations were issued in 1982 for 20 AEZ and later adapted to a district basis (Harrop and Samki 1984)

Table 14.2: Mean monthly rainfall (mm), maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of selected AEZ of Tanzania

	J	F	M	A	M	J	J	A	S	O	N	D
Ilonga-Kilosa (AEZ: E9), Eastern Zone												
Rainfall	124	111	158	235	76	13	9	7	18	37	78	110
Tmax	32	31	31	30	28	27	27	28	30	31	31	32
Tmin	21	21	21	21	19	17	16	16	17	18	20	21
Bagamoyo (AEZ: C1), Eastern Zone												
Rainfall	67	68	100	222	162	36	29	27	30	63	96	115
Tmax	33	33	33	32	31	30	29	30	30	31	32	33
Tmin	24	23	23	23	22	21	20	19	19	20	22	23
Selian Arusha (AEZ: N5), Northern Zone												
Rainfall	71	68	151	289	122	27	11	13	12	33	149	106
Tmax	27	28	27	25	23	23	22	23	25	27	26	26
Tmin	14	13	15	16	15	13	12	13	13	14	15	14
Mbeya (AEZ: H5), Southern Highland Zone												
Rainfall	198	178	175	95	17	1	0	0	1	18	69	203
Tmax	23	23	23	23	22	21	21	22	25	27	27	24
Tmin	14	14	14	13	11	9	8	9	11	13	14	14
Mtwara (AEZ: C2), Southern Zone												
Rainfall	219	169	214	176	59	15	14	9	12	28	59	171
Tmax	29	29	30	30	28	28	28	28	28	29	30	30
Tmin	24	24	24	23	21	21	20	20	20	22	23	24
Dodoma (AEZ: P11), Central Zone												
Rainfall	127	111	110	64	7	0	0	1	0	4	33	122
Tmax	29	29	29	29	28	27	27	27	29	31	32	31
Tmin	18	18	18	18	16	14	13	14	15	16	18	19
Tabora (AEZ: P5), Western Zone												
Rainfall	141	138	146	109	25	0	0	0	1	18	95	190
Tmax	28	28	28	28	28	28	28	29	32	32	31	28
Tmin	17	17	18	17	17	15	14	16	17	19	19	18
Tarime (AEZ: N10), Lake Zone >1300 m												
Rainfall	68	87	132	200	131	39	26	29	48	73	129	97
Tmax	28	28	28	27	27	26	27	27	28	28	28	27
Tmin	15	15	15	16	15	14	14	14	14	15	15	15
Ukiriguru (AEZ: H5), Mwanza, Lake Zone <1300 m												
Rainfall	101	128	138	159	69	14	7	9	25	58	150	122
Tmax	28	27	28	27	28	29	29	30	31	31	28	27
Tmin	18	18	18	18	17	15	15	16	17	18	18	18

Sources: http://en.climate-data.org/location/781083/
http://www.climate-zone.com/climate/tanzania/
http://www.kilimo.go.tz/agricultural%20maps/Tanzania%20Soil%20Maps/Webbased%20Districts%20Agricultural%20maps/Districts%20AEZs/Tanzania%20agro-ecological%20zones.htm

based on results of fertilizer trials conducted by different institutions (Mowo et al., 1993). World Bank supported a project to update fertilizer recommendations for rice and maize in some AEZ in 2009 to 2012 (Marandu et al., 2014) with differentiation for production potential, e.g. the N recommendation for lowland rice in high potential (HP) areas like Mombo irrigation scheme is 120 kg N/ha but 80 kg/ha for rainfed lower potential areas.

14.4 Diagnosis of nutrient deficiencies in Tanzania

In the 2014-2015 season, 41 trials were conducted for upland crops which included a comparison of N+P+K+Mg+S+Zn+B with N+P+K to determine if one or more of the secondary or micronutrients resulted in increased yield. The overall effect of the diagnostic package was little effect on cereal yield but a 12.6% reduction in legume yield in the Southern Highlands (Figure 14.3; AEZ H3 and H5 from Figure 14.2). Bean and pigeonpea yield were increased by 15% and 27% in the Northern Zone with the diagnostic treatment but cereal yield was decreased (AEZ N3 and N6). In the Eastern Zone, cassava tuber yield was increased by 12.3% but other crops were not affected by the diagnostic package (AEZ C1). The negative effect of the diagnostic package in some situations could not be accounted for with existing data. The lack of predictable positive response indicates that application of any of these secondary or micronutrients is not likely to be profitable without more site-specific information. Further investigation is needed to determine which of these four secondary or micronutrients account for the yield increases.

14.5 Optimizing fertilizer use in Tanzania

As indicated in section 14.3, most smallholders do not use fertilizers and rates of application are generally less than currently recommended. Most smallholders live and operate under severe financial constraint and investment in fertilizer use competes with other uses of financial resources for meeting immediate needs. Fertilizer use investments must give high returns with little risk.

OFRA (Optimizing Fertilizer Use in Africa), an Alliance for a Green Revolution in Africa (AGRA) funded project, has strengthened the information basis for determining more cost-effective fertilizer use. The typical crop response to an applied nutrient is curvilinear to plateau. Such a yield response (vertical axis, y-axis) of rice to applied N (horizontal axis or x-axis) is displayed in Figure 14.4 with a steep yield increase with increasing N at low rates, a lessor rate of yield increase at higher N rates, until yield reaches a plateau with no more yield increase. This tells us that the net returns relative to amount invested at low rates of nitrogen application are greater than with higher rates. Such response curves are typical for most crops and nutrients and are essential to determining the profitability of fertilizer use for all farmers.

Another important aspect of achieving high profit from fertilizer use for financially constrained farmers is that profit potential varies with nutrients and the crops to which these are

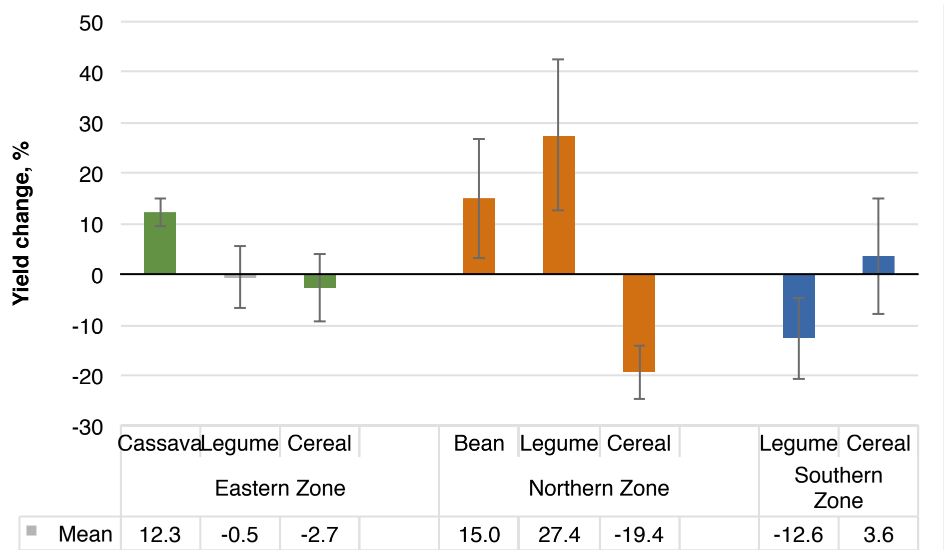

Figure 14.3: Crop response to applied secondary and micronutrients (Mg+S+Zn+B) for 48 research sites in Tanzania.

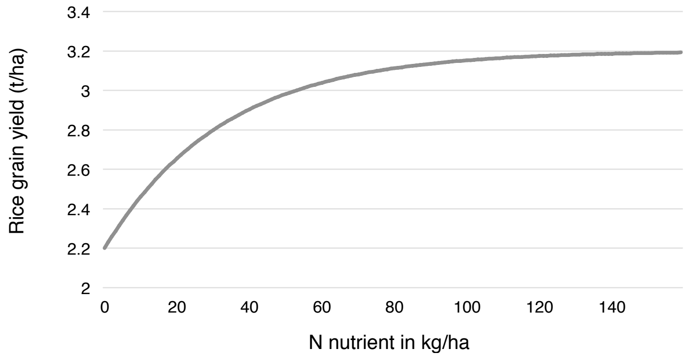

Figure 14.4: Response of lowland rice to N application in the Southern Highland Zone of Tanzania.

applied (Figure 14.5). In this figure, each curve represents the profit potential of a nutrient applied to a crop. When the slope of the curve is steep, net returns to investment are very high. As the amount invested increases (the x-axis) the slope decreases but is still upward, profit is increasing. When the slope is steep, the expected return on investment is high. The steepest slope for the Southern Highlands is with about TSh 20,000/ha (x-axis) of S applied to maize with an expected net return of nearly TSh 400,000/ha (y-axis). When TSh 100,000 is invested in N applied to rice (on x-axis), the expected mean net return is approximately TSh 1,150,000 (on the y-axis) to farmers in the Southern Highland Zone. Nitrogen applied to bean also has much profit potential at low rates and net returns to TSh 25,000 worth of N is about TSh 300,000/ha. The peak of the curves is the point of maximum profit per hectare for that nutrient applied to that crop. In this chapter, the rate at this peak is referred to as the economically optimal rate (EOR) and the rate for which farmers should strive if their fertilizer use is not economically constrained. When slopes decline, profit is declining. The financially constrained farmer wants to first take advantage of the most profitable crop-nutrient combinations for crops in their cropping system.

Making decisions in consideration of these curves for the amount of nutrient to apply to each crop is, however, very complex. The responses of the farmer's crops of interest to applied nutrients needs to be considered together with the farmer's land allocation to different crops, the value of the grain, the costs of fertilizer use, and the money available for fertilizer use need to be considered in optimizing fertilizer use for high profit. Therefore, fertilizer optimization tools which use complex mathematics to integrate economic and

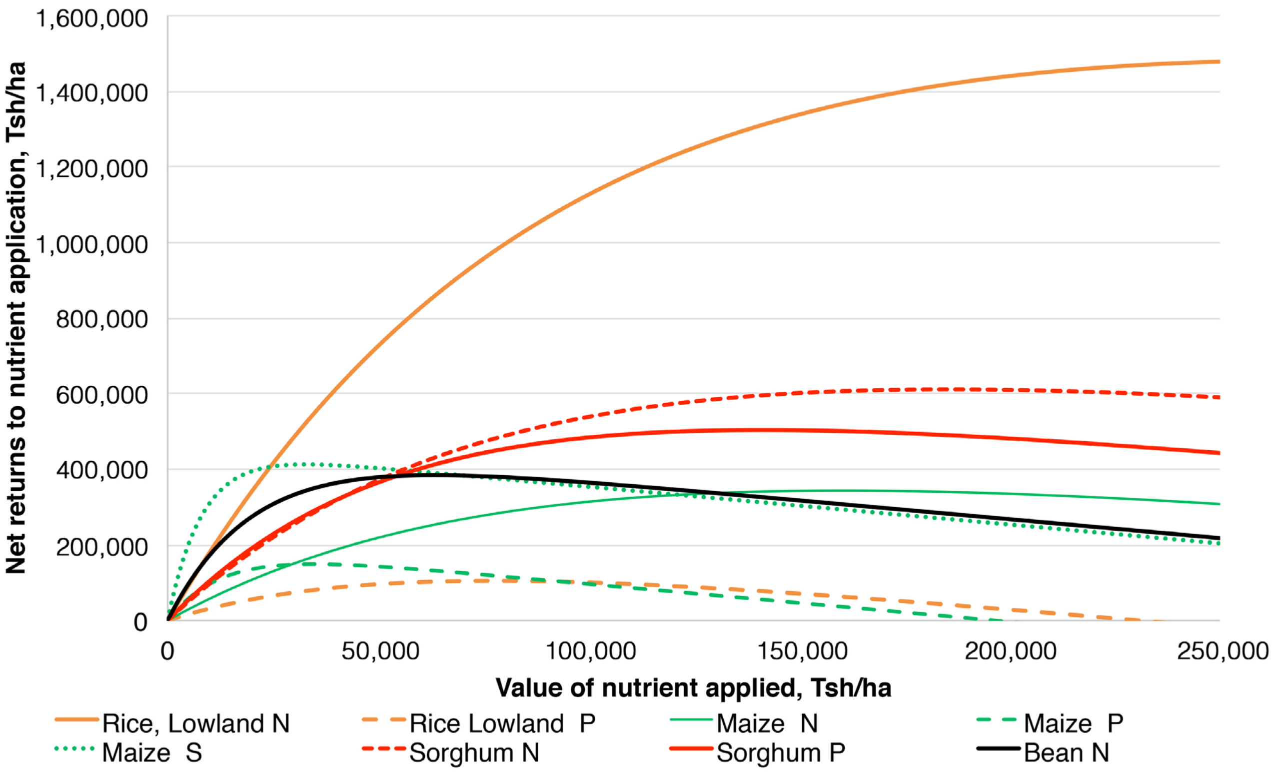

Figure 14.5: Net return from fertilizer use in the Southern Highland Zone of Tanzania. Less profitable and unprofitable nutrient applications were excluded from the figure. This graphic is dependent on grain values and fertilizer use costs. Grain values used were Tsh 1000 for rice and bean; sorghum 725; and maize 400. Fertilizer use costs were: Tsh 55,000 for urea; 65,000 for TSP; 75,000 for DAP; and 60,000 for KCl and ammonium sulphate.

agronomic information were developed using Excel Solver© (Frontline Systems Inc.).

14.6 Fertilizer use optimization tools (FOTs) for Tanzania

Fertilizer Optimization Tools (FOTs) were developed to integrate the economic and agronomic aspects of a farmer's situation with the crop nutrient response functions determined from many field research trials through complex calculations involving linear optimization (see Chapter 1). Fertilizer use optimization refers to maximizing profit from fertilizer use, either maximizing profit per hectare for farmers with adequate finance or profit on the small investment in fertilizer use by the financially constrained farmers. These easy to use tools were designed to make decisions to maximize profits from fertilizer use.

Fertilizer Optimization Tools were developed for eight zones in Tanzania as shown for the Western Zone FOT input screen (Figure 14.6) but application of FOTs are by AEZ rather than by zone (Table 14.3). The FOTs use acres rather than hectares for land area measurement as farmers are more accustomed to use of 'acres'. The user enters the land area in acres 'Area Planted, (Ac)' and expected on-farm value of the commodity considering the expected value of that kept for home consumption and that to be marketed 'Excepted Grain Value/kg'. If a crop is not planted, '0' is entered for acres. Next, the cost of using available fertilizers are entered considering the purchase price, and transport and application costs 'Cost/50 kg bag'. If the fertilizer is not available, '0' is entered for the cost. An optional fertilizer can be added under the 'Muriate if potash, KCl' row with the nutrient concentrations. Finally, the amount of money that the farmer has for fertilizer use is entered under 'Budget Constraint'. In the bottom-left, click on 'Optimize' to run the optimization.

The FOT output is in three tables (Figure 14.7). The upper table 'Application rate - kg/Ac' gives the recommended fertilizer rates for each crop. Some recommended rates are less than 10 kg/Ac and too low for feasible application; these should be reallocated such as the 2 kg/Ac DAP might instead be allocated to maize or as another fertilizer to another crop. The next table 'Expected Average Effects per Ac' addresses expected average yield increases and net return per acre due to the recommended fertilizer use. This table indicates the relative profitability associated with fertilizer applied to the different crops; we see the most profitable is with sweet potato suggesting that the farmer may want to increase area planted to sweet potato. The third table 'Total Expected Net Returns to Fertilizer' is an average estimate, adjusted for land allocated to each crop. Effects per acre and total net return are expected to be more in some years and less in other years compared with the reported expected mean. These results can only be expected if the farmer uses good agronomic practices such as variety selection, planting, and control of weeds, disease and pests.

The FOTs developed can be used to assist decision making at the district level such as to ensure that the most cost effective fertilizers are available to farmers when needed. Optimizing fertilizer use implies that other good agronomic practices are applied which implies availability of other agricultural inputs. Therefore, the FOTs can be useful in determining fertilizer supply.

Each Excel Solver© FOT has a companion paper FOT to be used when a computer is not available (Table 14.3). The paper FOT is devised for three financial ability levels. Financial ability level 1 is for the farmer who has no more money than one-third the amount required to apply fertilizer to all cropland at the rate to maximize economically optimum rate (EOR). Financial ability level 2 is for farmers with no more money than two-thirds the amount required to apply fertilizer to all cropland at EOR. Financial ability level 3 is for farmers with enough money to apply fertilizer to some cropland at EOR.

The paper tool makes assumptions about:

- measuring units to be used by farmers in adjusting their eyes and feel for applying the right rate of fertilizer as in Table 14.3 where the measuring units are the Uhai water bottle lid with a volume of 7 ml and the 500 ml Uhai water bottle cut to 2-cm height giving a volume of 70 ml;
- crop row and plant spacing;
- fertilizer use costs per 50 kg bag;
- expected grain values on-farm at harvest, considering the value both for home consumption and for market; and,
- application guidelines.

Producer Name:	xxx
Prepared By:	xxx
Date Prepared:	**July 20, 2016**

Crop Selection and Prices		
Crop	**Area Planted (Ac)***	**Expected Grain Value/kg †**
Rice, lowland Paddy	1	1000
Maize	1	650
Sorghum	1	725
Sweet Potato	1	500
Soybean	1	1200
Groundnut	1	780
	0	0
Total	**6**	

Fertilizer Selection and Prices					
Fertilizer Product	**N**	**P2O5**	**K2O**	**S**	**Costs/50 kg bag ¶***
Urea	46%	0%	0%	0%	55,000
Triple super phosphate, TSP	0%	46%	0%	0%	65,000
Diammonium phosphate, DAP	18%	46%	0%	0%	75,000
Murate of potash, KCL	0%	0%	60%	0%	60,000
xxx	0%	%	%	0%	0

Budget Constraint	
Amount available to invest in fertilizer	300000

Figure 14.6: Input data options for the computer generated FOT.

Fertilizer Optimization					
	Application Rate - kg/Ac				
Crop	**Urea**	**TSP**	**DAP**	**KCL**	**xxx**
Rice, lowland Paddy	58	0	0	0	0
Maize	32	0	13	8	0
Sorghum	28	0	2	14	0
Sweet Potato	40	0	17	0	0
Soybean	0	28	0	5	0
Groundnut	0	8	0	0	0
0	0	0	0	0	0
Total fertilizer needed	157	36	32	26	0

Expected Average Effects per Ac		
Crop	**Yield Increases**	**Net Returns**
Rice, lowland Paddy	964	900,214
Maize	945	550,111
Sorghum	1,085	737,094
Sweet Potato	3,221	1,540,617
Soybean	701	798,609
Groundnut	113	77,436
0	0	0

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer	4,604,081

Figure 14.7: Optimization output showing fertilizers needed and the expected returns.

Table 14.3: An example paper Fertilizer Optimization Tool

TANZANIA WESTERN ZONE

(AEZ: W2, P3, P4, P5, P6, P7, P8)

FERTILIZER USE OPTIMIZER: PAPER VERSION

The below assumes:

Calibration measurement is with a:

- Uhai water bottle lid (lid, 7 ml) for 4.9 g urea, or 7.7 g of DAP, TSP or KCl.
- 500 ml-Uhai water bottle (UWB; cut at 2 cm height to approximate 70 ml) to hold 49 g urea or 77 g DAP, TSP or KCl.

It is assumed maize is planted with 75 x 60 cm spacing, rice with 20 x20 cm spacing, sweet potato 100 x 30 cm, soybean 50 x 10 cm; sorghum 75 x 60 cm and groundnut 20 x 20 cm.

It is assumed crop prices per kg (TSh): 650 maize; 1000 rice; 500 sweet potato; 725 sorghum.

It is assumed 50 kg of fertilizer use costs (TSh): 55,000 urea; 65,000 TSP; 75,000 DAP and 60,000 KCl.

Application rates are in kg/ac. The minimum application rate is 15 kg/ac. Broadcast application width is 2 or 3 m.

Level 1 financial ability.	
Sorghum	Point apply urea 15 kg (1 lid per 3.2 plant hills) 6 WAP
Sweet potato	Point apply 36 kg urea (1 lid per 2 plant hills) at 6 WAP
Soybean	Broadcast 22 kg TSP (apply one UWB for 4.7 m length and 3 m width OR 1 lid for 1 m length and 3 m width) at planting
Rice	Broadcast 43 kg urea (apply one UWB for 2 m length x 2 m width) at 2 panicle initiation
Maize	Point apply 16 kg urea (1 lid per 2.5 plant hills) at 6 WAP
Level 2 financial ability.	
Sorghum	Point apply 20 kg urea (1 lid per 2 plant hills), 16 kg KCl (1 lid per 4.4 plant hills) at planting and urea 19 kg (1 lid per 2 planting hills) at 6 WAP
Sweet potato	Point apply 27 kg DAP (1 lid per 4 plant hills) at planting and 44 kg urea (1 lid per 1.5 plant hills) at 6 WAP
Soybean	Broadcast 33 kg TSP (apply one UWB for length 4.7 m and 2 m width) at planting
Rice	Broadcast 36 kg urea (apply one UWB for length 2.5 m x 2 m width) at 2 WAP and 36 kg urea (apply one UWB for 2.5 m length x 2 m width) at panicle initiation
Maize	Point apply 24 kg urea (1 lid per 2 plant hills), 18 kg DAP (1 lid per 4 plant hills) and 23 kg urea (1 lid per 2 plant hills) at 6 WAP
Level 3 financial ability (maximize profit per acre).	
Sorghum	Point apply 30 kg urea (1 lid per 1.5 planting hills), 18 kg DAP (1 lid per 4 planting hills), 20 kg KCl (1 lid per 3.3 planting hills) at planting and urea 31 kg (1 lid per 1.5 plant hills) at 6 WAP
Sweet potato	Point apply 44 kg DAP (1 lid per 4 planting holes) at planting and 53 kg urea (1 lid per 2 plant hills) at 6 WAP
Soybean	Broadcast 32 kg TSP (apply one UWB for length 5 m and 2 m width) at planting
Groundnut	Broadcast 22 kg TSP (apply one UWB for length 4.7 m and 2 m width) at planting
Rice	Broadcast 50 kg urea (apply one UWB for 2 m length) at 2 WAP and 50 kg urea (apply one UWB for 2 m length x 2 m width) at panicle initiation
Maize	Point apply 38 kg urea (1 lid per 1 planting hills), 27 kg DAP (1 lid per 2 planting hills), 18 kg KCl (1 lid per 3.9 planting hills) at planting and 37 kg urea (1 lid per 1 plant hills) at 6 WAP

The paper FOTs address the 4Rs of Nutrient Stewartship, advising on the right product, rate, time and method of application. It also advises on calibration, that is the length of band or the number of plants for the recommended fertilizer rate with one measuring unit. Consider as an example the Level 2 financial ability recommendation ‘Sorghum: point apply 20 kg urea (1 lid per 2 planting holes), 16 kg KCl (1 lid per 4.4 planting holes) at planting and urea 19 kg

(1 lid per 2 planting holes) at 6 WAP' (Table 14.3). Urea and KCl are to be applied at least 5 cm to the side of planting holes of sorghum at rates of 20 and 16 kg/ac, respectively. One Uhai bottle lid is sufficient for 2 planting holes with urea and 4.4 planting holes with KCl. Another 19 kg/ha urea are to be top dress applied at six weeks after planting by point applying at least 5 cm away from the plant; one Uhai bottle lid is sufficient for 2 planting holes.

The Excel and paper FOT are available at http://agronomy.unl.org/OFRA. The website also has training materials and other tools useful to fertilizer use optimization.

14.7 Adjusting fertilizer rates for other practices and soil test information

Fertilizer use decisions need to consider the effects of other practices that supply soil nutrients as well as soil test information (Table 14.3). Manure application to a field calls for adjustment of the recommended fertilizer rate according to the fertilizer substitution value of the manure which varies with the quality. Poultry and dairy manure have greater fertilizer substitution value than farmyard manure. Other practices with fertilizer substitution values considered in Table 14.4 include having a green manure crop and a cereal following a legume in rotation. Intercropping may require more fertilizer than the sole crop.

Soil test values are also considered. Soil test P values are often low for smallholders' fields not near the household and P should be applied according to the FOT unless the soil test P value is above 20 mg kg^{-1} by Bray 1 for soils with pH of less than 7 or above 10 ppm by Olsen for soils with pH greater than 7. Fertilizer K should be applied as recommended by the FOT unless the soil test K is less than 100 ppm, when 20 kg/ac muriate of potash or potassium sulphate should be applied.

Table 14.4: Fertilizer substitution value of good agronomic practices and soil test implications

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT CONTEXT

FERTILIZER SUBSTITUTION AND SOIL TEST IMPLICATIONS

ISFM practice	Urea	DAP or TSP	KCl	NPK 17-17-17
	Fertilizer reduction, % or kg/ac			
Previous crop was a green manure crop (azolla in lowland rice and tithonia for maize)	100%	70%	70%	70%
Farmyard manure per 1 t of dry material (low quality)	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
Poultry manure, per 1 t dry material	9 kg	4 kg	5 kg	16 kg
Residue value of poultry manure, per 1 t dry material	2 kg	2 kg	1 kg	3 kg
Compost, per 1 t	8 kg	3 kg	3 kg	15 kg
Maize-bean intercropping	Increase DAP/TSP by 7 kg/ac, but no change in N and K compared with sole maize rates			
Maize-pigeonpea intercropping	Increase DAP/TSP by 11 kg/ac, reduce urea by 9 kg/ac, and no change in K compared with maize rates			
Maize-lablab rotation	0% reduction but more yield expected			
Rice-bean rotation	0% reduction but more yield expected			
Maize or upland rice-cowpea/pigeonpea/green gram rotation	Reduce urea by 20 kg/ha, and more yield expected			
If Bray-Kurtz I P >20 ppm, or Olsen P >10 ppm	Apply no P			
If soil test K <100 ppm	Band apply 20 kg/ac KCl			

14.8 Targeted crops and cropping systems by AEZ

Crop responses to nutrients were determined for important food crops in each zone using results of past and recent field research (Tables 14.5a-h). The first two columns are for crop and nutrient. Columns 3-5 have coefficients a, b, c for the curvilinear to plateau response function: $Y = a - bc^r$. The next four columns report the expected yield increase with increased nutrient rates compared with the lower rate, and the right-most columns report the EOR compared with the current or recently recommended rate (REC). The commodity values and fertilizer costs used in determining EOR are given in the footnote of Table 14.5a. Nutrient applications exceeding the field research based EOR is expected to result in loss of profit. Any nutrient application less than the EOR will be less than maximum potential profit per acre to fertilizer use, but lower rates are typically most profitable with financially constrained fertilizer use.

The greatest yield increases, the b value and for the first increment of applied nutrient, in Eastern Zone was with cassava for N, P and K (Table 14.5a). Lowland high potential rice also had a

Table 14.5a: Eastern Zone, Tanzania (AEZ: all C; E <1000 m in Eastern and Northern Zones except for E1; Fig. 14.2): 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 by agro-ecological zones. $P_2O_5 = P \times 2.29$; $K_2O = K \times 1.2$. 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			Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡ ††**
			t/ha			t/ha			kg/ha	
Rice, lowland HP	N	6.248	3.57	0.986	1.231	0.807	0.528	0.346	150	120
Rice, lowland LP	N	4.164	1.731	0.974	0.946	0.429	0.195	0.088	111	80
Cassava	N	32.671	10.678	0.973	5.980	2.631	1.157	0.509	125	NA
Maize	N	3.344	1.442	0.964	0.962	0.320	0.107	0.035	65	60 – 80
Sorghum	N	1.693	0.748	0.94	0.631	0.099	0.015	0.002	28	30
Cowpea	N	1.223	0.383	0.923	0.348	0.031	0.003	0.000	27	NA
					0-5	**5-10**	**10-15**	**15-20**		
Rice, lowland HP	P	6.01	0.16	0.9	0.153	0.006	0.000	0.000	10	20
Rice, lowland LP	P	3.319	0.16	0.908	0.151	0.008	0.000	0.000	10	8
Cassava	P	26.875	5.994	0.940	5.057	0.790	0.123	0.019	30	15 -30
Maize	P	3.055	0.561	0.850	0.312	0.138	0.061	0.027	12	8 – 40
Sorghum	P	2.559	0.789	0.882	0.771	0.018	0.000	0.000	13	10 – 20
Cowpea	P	1.223	0.383	0.923	0.348	0.031	0.003	0.000	11	NA
Cassava	K	29.171	4.550	0.899	4.363	0.179	0.007	0.000	43	40
Maize	K	2.980	0.636	0.650	0.636	0.000	0.000	0.000	9	NA
Cowpea	K	1.111	0.168	0.780	0.168	0.000	0.000	0.000	10	NA

† EOR was determined with the cost of using 50 kg urea, TSP and KCl at Tsh 55,000, 60,000, 60,000, respectively. Commodity values (Tsh/kg) used were: rice paddy 1000; cassava 250; cowpea 700; wheat 550; bean 1000; finger millet 700 in Northern and 900 in Lake; pigeonpea 1500; soybean 1200; sweet potato 500; groundnut 780; Irish potato 800; and sorghum 300; exceptions include: 700 rice paddy for Northern; cowpea 500 in Southern and 1000 in Central; sorghum 650 to 725 in all zones except Eastern; bean 900 in Lake; and sweet potato 300 in Lake. Maize value differed widely: 250 in Southern; 400 in Southern Highland and Lake; 500 in Eastern; 650 in Western and Central; and 700 in Northern. Rice lowland HP and LP refer to expected yield more or less than 3 t/ha, respectively.

‡ Recommendations for rice and maize in Eastern and Southern Highland Zones were cited from Marandu et al. (2014).

†† Recommendations for other crops were cited from Mowo et al. (1993) and cassava from Shekiffu (2011).

Table 14.5b: Northern Zone, Tanzania (AEZ: E2 (>1000 m), N3, N4, N5, N6)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC‡††
		t/ha			t/ha				kg/ha	
Rice, lowland	N	5.625	2.897	0.966	1.871	0.663	0.235	0.083	98	NA
Maize	N	3.159	1.191	0.976	0.616	0.297	0.143	0.069	74	45-112
Wheat HP	N	4.039	0.736	0.939	0.625	0.095	0.014	0.002	38	30
Wheat LP	N	1.868	0.353	0.913	0.330	0.022	0.001	0.000	22	
Bean	N	1.415	0.715	0.950	0.562	0.121	0.026	0.006	46	30
Finger millet	N	2.100	0.923	0.944	0.759	0.135	0.024	0.004	48	NA
					0-5	**5-10**	**10-15**	**15-20**		
Rice, lowland	P	5.665	0.828	0.871	0.815	0.013	0.000	0.000	19	NA
Maize	P	4.474	0.770	0.898	0.000	0.029	0.001	0.000	18	NA
Wheat HP	P	3.219	1.211	0.949	0.959	0.199	0.041	0.009	30	7 – 13
Wheat LP	P	1.439	0.147	0.873	0.144	0.002	0.000	0.000	4	NA
Bean	P	1.138	0.263	0.848	0.148	0.065	0.028	0.012	12	7-13
Finger millet	P	2.101	0.537	0.798	0.363	0.118	0.038	0.012	12	NA
Pigeonpea	P	2.538	0.487	0.758	0.487	0.000	0.000	0.000	9	NA
Maize	K	2.502	0.251	0.940	0.212	0.033	0.005	0.001	19	NA
Pigeonpea	K	2.535	0.127	0.666	0.127	0.000	0.000	0.000	6	NA

Table 14.5c: Southern Highland, Tanzania (AEZ: H except for H4, U, E7, E14)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC‡††
		t/ha			t/ha				kg/ha	
Rice, lowland	N	4.085	1.851	0.974	1.011	0.459	0.208	0.094	116	80
Maize	N	4.407	1.463	0.971	0.858	0.355	0.147	0.061	67	60-120
Sorghum	N	3.409	1.204	0.969	0.736	0.286	0.111	0.043	59	NA
Bean	N	0.868	0.468	0.888	0.455	0.013	0.000	0.000	26	30
Wheat	N	2.900	1.577	0.983	0.634	0.379	0.227	0.136	125	40
					0-5	**5-10**	**10-15**	**15-20**		
Rice, lowland	P	3.703	0.233	0.880	0.110	0.058	0.031	0.016	12	40
Maize	P	3.773	0.492	0.830	0.298	0.117	0.046	0.018	13	20-40
Sorghum	P	3.608	0.967	0.890	0.938	0.028	0.001	0.000	17	NA
Bean	P	1.138	0.263	0.848	0.148	0.065	0.028	0.012	12	12
Wheat	P	2.405	0.340	0.837	0.200	0.082	0.034	0.014	12	NA
Maize	K	2.759	0.134	0.8	0.134	0.000	0.000	0.000	7	NA
Maize	S	5.008	1.135	0.7	1.135	0.000	0.000	0.000	11	NA

Table 14.5d: Western Zone, Tanzania (AEZ: W2, P3, P4, P5, P6, P7, P8)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡††**
		t/ha			**t/ha**				**kg/ha**	
Rice, lowland	N	5.646	2.896	0.974	1.582	0.718	0.326	0.148	66	NA
Maize	N	4.618	2.369	0.978	1.154	0.592	0.304	0.156	43	NA
Sorghum	N	2.289	1.634	0.972	0.937	0.400	0.170	0.073	33	NA
Sweet potato	N	18.699	7.72	0.951	6.010	1.331	0.295	0.065	53	NA
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	5.1	0.805	0.841	0.801	0.004	0.000	0.000	5	NA
Sorghum	P	2.292	0.326	0.866	0.322	0.004	0.000	0.000	0	NA
Sweet potato	P	13.033	1.437	0.912	0.530	0.335	0.211	0.133	7	NA
Soybean	P	2.533	1.78	0.85	0.990	0.439	0.195	0.086	14	NA
Groundnut	P	1.036	0.561	0.847	0.316	0.138	0.060	0.026	4	NA
Maize	K	4.9	0.555	0.899	0.532	0.022	0.001	0.000	10	NA
Sorghum	K	2.409	1.78	0.85	1.766	0.013	0.000	0.000	17	NA
Soybean	K	2.679	0.191	0.8	0.191	0.000	0.000	0.000	0	NA
Groundnut	K	1.09	0.059	0.86	0.031	0.015	0.007	0.003	0	NA

large response to N. Maize had relatively large responses to P and K. Recommended rates were near or lower than EOR. The EOR was determined for several crop-nutrients for which REC rates were missing.

Lowland rice and wheat response to applied N was relatively great and low, respectively, in comparison with other cereals in Northern Zone (Table 14.5b). All crops except for low potential wheat responded well to applied P. Only maize and pigeonpea were found to have profitable response to applied K. The EOR for N and P were generally similar or higher compared with REC rates. Numerous EOR were determined for crop-nutrients lacking REC rates.

Maize and wheat responses to N were relatively great in the Southern Highlands (Table 14.5c). Maize had a relative great response to P and S, but there was limited response to K for all crops. Wheat had a high EOR for N and lowland rice had a similar EOR compared with the REC nutrient rate but otherwise EOR and the REC were similar.

Sweet potato was found to have a large yield response to applied N in Western Zone (Table 14.5d). The cereal crops also had large responses to N application. More than 50% of the response to N occurred with 30 kg/ha N applied. All crops had good yield increases with 5 kg/ha P applied and maize and sorghum had good response to 5 kg/ha K. Recommended rates were not available for Western Zone.

In Southern Zone, all non-legumes had good yield increases with 30 kg/ha N applied and smaller increases with higher rates (Table 14.5e). Besides cassava, sorghum had a relatively large increase with P application. All crops had an economical response to 5 kg/ha of K applied. Only maize and lowland rice had recommendations for nutrient application. The EOR N was higher for high potential maize and lowland rice compared with REC. The EOR P was zero for rice due to lack of rice response to P. Several EOR values were determined for crop-nutrients without recommendations.

Sweet potato and lowland rice had large responses to N for Central Zone (Table 14.5f). All crops except maize were found to have profitable responses to applied P and cowpea was found to be responsive to K. No REC were available for this zone.

All crops had profitable response to N application, especially Irish potato, sweet potato and banana in the higher elevation parts of Lake Zone such

Table 14.5e: Southern Zone, Tanzania (AEZ: E <1000m in Southern Zone, S1, S2)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡††**
		t/ha			t/ha				kg/ha	
Rice, lowland	N	4.010	1.401	0.967	0.889	0.325	0.119	0.043	85	40 - 60
Maize HP	N	3.783	1.928	0.977	0.969	0.482	0.240	0.119	61	50
Maize LP	N	2.493	1.601	0.966	1.034	0.366	0.130	0.046	47	NA
Sorghum	N	1.725	0.612	0.964	0.408	0.136	0.045	0.015	49	NA
Cassava	N	31.785	8.058	0.960	5.690	1.672	0.491	0.144	46	NA
					0-5	**5-10**	**10-15**	**15-20**		
Rice, lowland	P	2.354	0.000	0.000	0.000	0.000	0.000	0.000	20	5 – 9
Maize HP	P	3.721	0.267	0.958	0.193	0.053	0.015	0.004	3	10
Maize LP	P	2.533	0.431	0.976	0.223	0.108	0.052	0.025	24	NA
Sorghum	P	2.047	0.656	0.914	0.238	0.152	0.097	0.062	10	NA
Cowpea	P	1.110	0.181	0.900	0.074	0.044	0.026	0.015	-	NA
Cassava	P	27.634	5.270	0.877	2.536	1.316	0.683	0.354	-	NA
Groundnut	P	1.600	0.373	0.79	0.258	0.079	0.024	0.008	-	NA
Rice, lowland	K	1.748	0.114	0.800	0.077	0.025	0.008	0.003	10	NA
Maize HP	K	3.854	0.208	0.932	0.062	0.043	0.031	0.021	4	NA
Maize LP	K	2.759	0.134	2.759	0.090	0.030	0.010	0.003	4	NA
Sorghum	K	1.986	0.183	0.913	0.067	0.042	0.027	0.017	16	NA
Cowpea	K	0.821	0.134	0.800	0.090	0.030	0.010	0.003	8	NA
Cassava	K	27.674	3.314	0.908	1.269	0.783	0.483	0.298	35	NA
Groundnut	K	1.797	0.075	0.750	0.057	0.014	0.003	0.001	6	NA

as Tarime and Karagwe, and for lower elevation Lake Zone (Table 14.5g,h). All but banana in the higher elevation and lowland rice in the lower elevation had a profitable response to applied P. Maize, bean, and high potential banana had profitable yield increases with K application in the higher elevation areas but there was no evidence of response to K in the lower elevation parts of the zone. The EOR N rates were low compared with REC rates except for similar EOR and REC for rice and sorghum at the lower elevations. The EOR P varied inconsistently compared with REC P. There were no recommendations for K application.

In 21 cases with higher REC compared with the EOR, these ranged from 4 to 450% higher and were on average of 142% higher (Table 14.4a-h). In 19 cases with lower REC compared with the EOR, the REC ranged from 32 to 96% of EOR and on average were 72% less. Over all comparisons, the REC were 41% higher than EOR. No REC were available for 64% of the AEZ specific crop nutrient functions but EOR were estimated for all cases although EOR was 0 in 10% of the cases. Recommended rates were lacking but EOR were determined for cassava, cowpea, sweet potato, soybean, and pigeonpea. For other crops, REC were available for some AEZ but not for others. Applying at the REC when it is above EOR means a loss of profit potential although there will often be a yield gain. Financially constrained farmers should normally be applying at less than EOR when striving to maximize returns on their investment in fertilizer use.

14.9 Conclusion

Crop production is very important to human livelihood and economic growth in Tanzania. Yields are low and there is a need for increased fertilizer use integrated with other soil management practices and good agronomy to

Table 14.5f: Central Zone, Tanzania (AEZ: P1, P2, P9, P10)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC‡††
		t/ha			t/ha				kg/ha	
Rice, lowland	N	5.15	2.238	0.976	1.158	0.559	0.270	0.130	132	NA
Maize	N	4.7	1.2	0.862	1.186	0.014	0.000	0.000	27	NA
Sorghum	N	1.599	0.099	0.98	0.045	0.025	0.013	0.007	0	NA
Sweet potato	N	18.699	7.72	0.951	6.010	1.331	0.295	0.065	89	NA
Cowpea	N	1.223	0.383	0.923	0.348	0.031	0.003	0.000	33	NA
					0-5	**5-10**	**10-15**	**15-20**		
Rice, lowland	P	5.126	0.695	0.89	0.307	0.171	0.096	0.053	22	NA
Maize	P	3.443	0.093	0.917	0.033	0.021	0.014	0.009	0	NA
Sorghum	P	2.284	0.925	0.914	0.335	0.214	0.136	0.087	24	NA
Sweet potato	P	13.033	1.437	0.913	0.525	0.333	0.211	0.134	24	NA
Cowpea	P	1.138	0.640	0.760	0.478	0.121	0.031	0.008	12	NA
					0-5	**5-10**	**10-15**	**15-20**		
Cowpea	K	1.111	0.168	0.780	0.119	0.035	0.010	0.003	12	NA

Table 14.5g: Lake Zone >1300 m elevation, Tanzania (AEZ: N8, N9, N10, W1, W4)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				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 HP	N	4.476	1.376	0.966	0.889	0.315	0.112	0.040	27	80
Maize LP	N	2.112	0.955	0.96	0.674	0.198	0.058	0.017	21	50
Irish potato	N	12.086	3.475	0.944	2.858	0.507	0.090	0.016	28	NA
Finger millet	N	1.690	0.790	0.892	0.764	0.025	0.001	0.000	11	30
Sweet potato	N	17.971	9.513	0.923	8.653	0.782	0.071	0.006	23	NA
Bean	N	1.016	0.269	0.78	0.269	0.000	0.000	0.000	5	NA
Banana HP	N	39.250	6.625	0.903	6.315	0.296	0.014	0.001	18	NA
					0-5	**5-10**	**10-15**	**15-20**		
Maize HP	P	4.313	1.113	0.95	0.252	0.195	0.151	0.117	12	8
Maize LP	P	2.534	0.824	0.95	0.186	0.144	0.112	0.086	9	8
Irish potato	P	12.311	3.702	0.902	1.492	0.891	0.532	0.318	12	NA
Finger millet	P	1.784	0.246	0.939	0.066	0.048	0.035	0.026	2	11
Sweet potato	P	13.257	3.828	0.911	1.426	0.895	0.561	0.352	12	NA
Bean	P	1.138	0.323	0.826	0.199	0.076	0.029	0.011	5	13
Maize HP	K	4.000	0.381	0.950	0.086	0.067	0.052	0.040	11	NA
Maize LP	K	2.615	0.101	0.940	0.027	0.020	0.014	0.011	2	NA
Bean	K	2.117	0.264	0.890	0.117	0.065	0.036	0.020	9	NA
Banana HP	K	37.177	3.302	0.970	0.466	0.401	0.344	0.295	20	NA

Table 14.5h: Lake Zone <1300 m elevation, Tanzania (AEZ: W3, P4, P8)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of elemental nutrient rate (kg/ha) on yield				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡††**
		t/ha			t/ha				kg/ha	
Rice, lowland	N	5.276	2.402	0.971	1.409	0.583	0.241	0.100	46	40
Maize	N	2.308	0.790	0.947	0.636	0.124	0.024	0.005	16	50 - 80
Sweet potato	N	15.716	5.672	0.95	4.455	0.956	0.205	0.044	28	NA
Sorghum	N	2.372	0.366	0.954	0.277	0.067	0.016	0.004	13	12
Bean	N	1.244	0.653	0.878	0.640	0.013	0.000	0.000	11	NA
Finger millet	N	1.690	0.790	0.892	0.764	0.025	0.001	0.000	11	30
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	2.032	0.083	0.858	0.044	0.021	0.010	0.004	0	8
Sweet potato	P	13.108	2.234	0.913	0.817	0.518	0.329	0.209	10	NA
Sorghum	P	2.866	0.918	0.911	0.342	0.215	0.135	0.084	9	7
Bean	P	1.231	0.249	0.81	0.162	0.057	0.020	0.007	4	13
Finger millet	P	1.784	0.246	0.939	0.066	0.048	0.035	0.026	2	11

increase productivity. Most farmers are poor and are financially constrained in fertilizer use. Therefore, returns to investment in fertilizer use need to be high to be a means to alleviating the financial constraint. Optimization of fertility use aims to maximize profit from fertilizer use, both for the farmer who is not limited in fertilizer use and can apply at EOR to all cropland and for the financially constrained farmer who needs to maximize net returns from a limited investment in fertilizer use. Field research results were applied in determining crop nutrient response functions which are the basis of FOTs which aid in choice of crop-nutrient-rate combinations specific for the farmer's context.

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