7. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Kenya

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7.1 Agricultural systems of Kenya

7.1.1 Introduction

Agriculture is essential for sustainable development, poverty reduction and enhanced food security in many sub-Saharan African (SSA) countries. The economic pillar of Kenya's Vision 2030 Strategy puts the agricultural sector among the six key growth drivers of the economy (GoK 2014). Agricultural productivity contributes about 30% to its Gross Domestic Product (GDP) and 60% to foreign exchange earnings. About 75% of Kenya's population of approximately 42 million works in the agricultural sector. Only about one third of Kenya's total land area, from the Kenyan highlands, the coastal plains and the lake region, is used for crop production (Fig. 7.1). The rest of the land area, which is semi-arid to arid, is used for pastoralism.

7.1.2 Agro-ecological zones (AEZ)

The zonation most used in Kenya for economic planning and agricultural development is by Jaetzold and Schmidt (1983). Kenya is divided

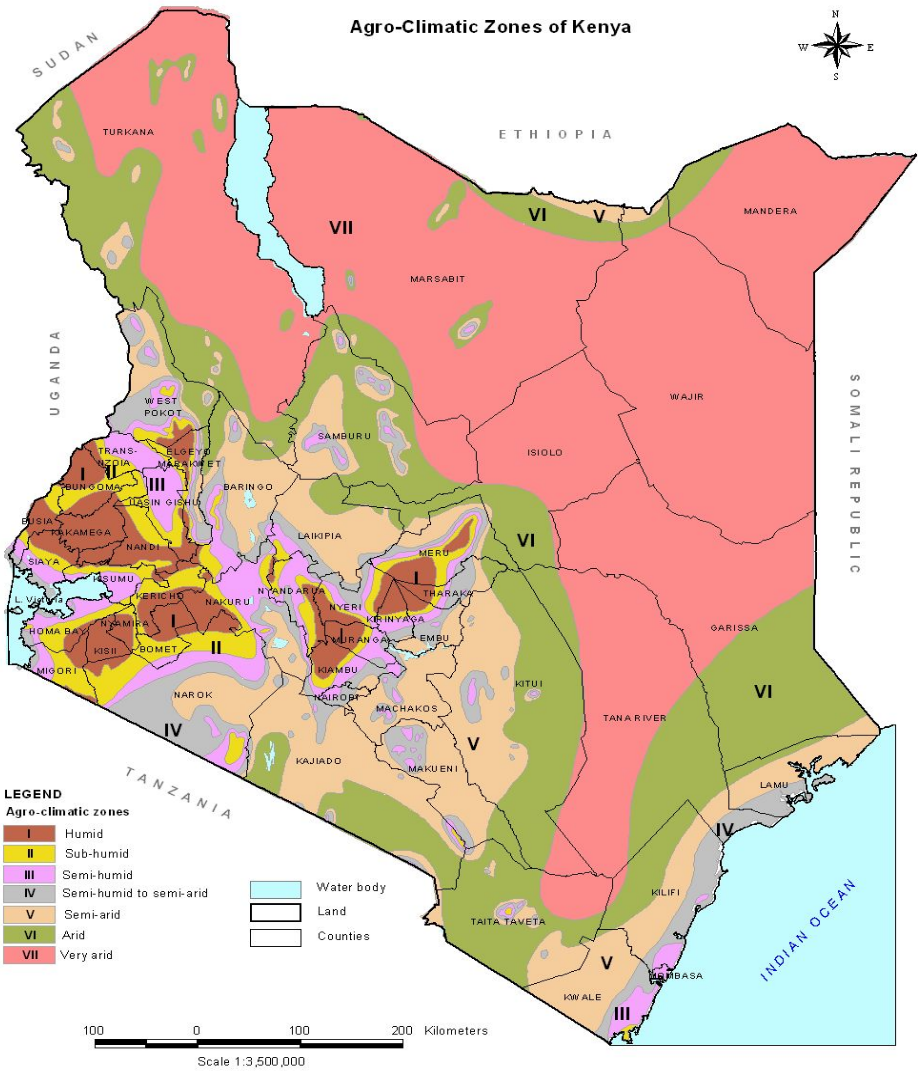

Figure 7.1: Agro-ecological zones (AEZ) of Kenya (Source: Kenya Soil Survey 2007).

Table 7.1: Mean monthly rainfall (mm) and maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of AEZ of Kenya for year 2015

	J	F	M	A	M	J	J	A	S	O	N	D
Eastern Upper												
Rainfall	27	26	113	278	164	32	29	38	41	171	234	53
Tmax	29	30	32	31	29	27	26	26	29	30	29	28
Tmin	10	10	11	10	10	9	9	9	10	10	10	9
Eastern Lower												
Rainfall	39	29	65	120	28	3	1	1	3	39	192	99
Tmax	35	37	37	35	34	32	31	31	34	36	35	34
Tmin	12	12	12	12	11	11	10	10	11	12	12	11
Central												
Rainfall	44	50	94	212	167	50	18	27	29	65	145	88
Tmax	27	28	27	25	24	22	22	22	25	26	25	25
Tmin	12	13	14	15	14	12	11	11	12	13	14	13
Rift Valley Upper												
Rainfall	20	30	63	121	148	86	79	92	88	69	78	49
Tmax	28	28	29	29	27	27	26	26	26	27	26	27
Tmin	9	9	10	10	9	9	9	9	9	9	9	9
Rift Valley Lower												
Rainfall	85	80	96	152	94	34	22	21	26	32	71	84
Tmax	26	26	27	27	26	23	23	23	25	26	25	25
Tmin	9	9	9	9	**9**	**8**	**8**	**8**	8	9	8	9
Western Upper												
Rainfall	28	57	91	162	187	107	139	168	105	99	89	37
Tmax	28	30	30	29	28	27	26	27	27	28	28	28
Tmin	10	10	10	10	10	9	9	9	9	9	9	9
Western Lower												
Rainfall	105	190	297	292	111	99	156	169	158	179	87	29.3
Tmax	30.0	30.4	30.0	28.7	27.9	27.4	27.2	27.7	27.0	29.1	28.4	29.3
Tmin	15.9	15.7	15.7	16.5	16.3	15.8	15.6	15.5	14.7	16.0	15.9	15.8
Coastal												
Rainfall	34	16	56	153	223	87	69	64	68	103	105	75
Tmax	41	42	43	41	39	37	36	36	37	39	40	41
Tmin	14	14	14	14	13	12	12	12	12	13	13	14

into seven agro-climatic zones using a moisture index (Sombroek et al. 1982) based on annual rainfall expressed as a percentage of annual potential evaporation (Figure 7.1).

The humid highlands, with a moisture index greater than 50% and with high potential for crop production, are designated as Zone I (humid with a moisture index of >80% and annual rainfall of 1100-2700 mm), Zone II (sub-humid with a moisture index of 65-80% and annual rainfall of 1000 -1600 mm) and Zone III (semi-humid with a moisture index of 50-65% and annual rainfall of 800-1400 mm). Together they account for 12% of the land area. The remaining land has a moisture index of less than 50% and a mean annual rainfall

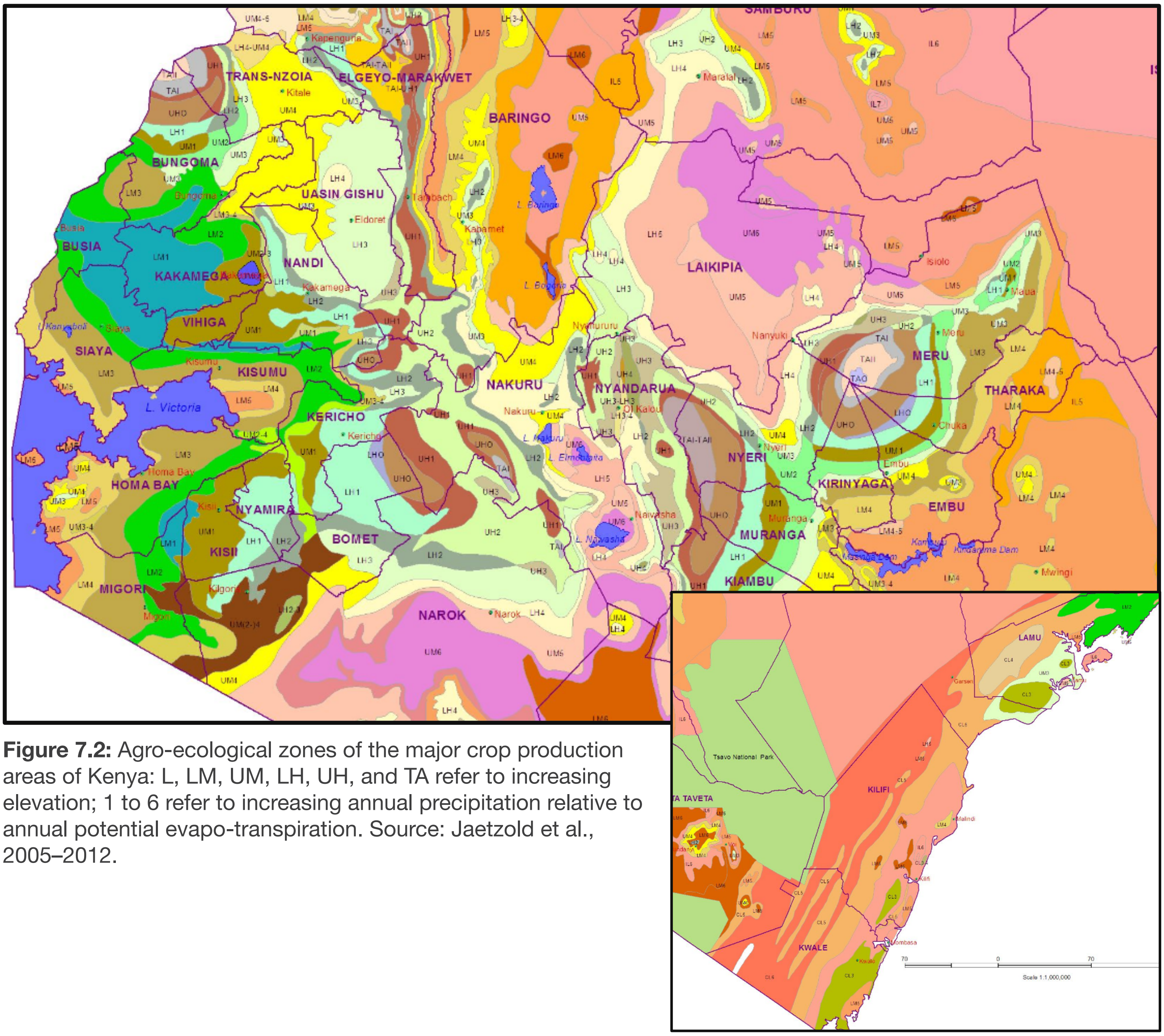

Figure 7.2: Agro-ecological zones of the major crop production areas of Kenya: L, LM, UM, LH, UH, and TA refer to increasing elevation; 1 to 6 refer to increasing annual precipitation relative to annual potential evapo-transpiration. Source: Jaetzold et al., 2005–2012.

of less than 1100 mm, including Zone IV (the semi-humid to semi-arid transitional zone), Zone V (semi-arid), Zones VI (arid) and VII (very arid). These four zones are generally referred to as the Kenyan rangelands and account for 88% of the land area, which is mainly used for livestock rearing.

The seven agro-climatic zones are further sub-divided according to mean annual temperature to identify areas suitable for growing each of Kenya's major food and cash crops (Figure 7.2). Most of the high and medium potential areas, representing about 70% of the agricultural land, are located at an altitude of 1000 to 2800 m above sea level (masl) with mean annual temperatures ranging from 10-24°C (Jaetzold and Schmidt 1983). The dominant agricultural soils are Ferralsols, Vertisols, Acrisols, Lixisols, Luvisols and Nitisols (Jaetzold and Schmidt 1983).

The Tropical Alpine (TA) environments are humid highlands above 2800 masl with an average temperature of 2-10°C and an annual rainfall of 1100-2700 mm with a moisture index of >80% (Table 7.1). The natural vegetation is evergreen rainforest. The main agricultural activities include husbandry of sheep and cattle at the lower altitudes. The AEZ is comprised mainly of forest reserves and national parks.

The Upper Highlands (UH1 and UH2) or Sub-Humid Highlands at 2350 to 2800 masl has mean annual temperatures of 10-15°C, annual rainfall of 900 to 1600 mm with one or two dry months and a moisture index of 65-80%. These areas have underlying volcanic rocks with loamy soils and include the highlands east and west of the Rift Valley including the Rift Valley bottom. The natural vegetation is seasonal rainforest. The major crops include maize, wheat, pyrethrum, Irish potato, kale, cabbage and temperate fruits. Crops are slow to mature due to low temperature. Sheep and dairy cattle are major livestock enterprises and are grazed on natural pastures of Kikuyu grass. In some regions, the AEZ has forest reserves and national parks.

The Lower Highlands (LH) or Semi-humid Highlands are highly productive lands at 2000-2350 masl with an average temperature of 15-18°C, an annual rainfall of 900-1600 mm and a moisture index of 50-65%. The AEZ covers about 30% of the arable land. The natural vegetation corresponds to seasonal semi-deciduous moist forest or tall grass-broad-leaved trees savanna. The major agricultural activities include maize, wheat, barley, seed maize, tea, kale and cabbage. Dairy cattle and sheep are the main livestock enterprises.

The Upper Midlands (UM) are semi-humid to semi-arid, very productive and occupy about 5% of the total land area. It is at 1500-2000 masl with an average temperature of 18-21°C, an annual rainfall of 600-1350 mm and a moisture index of 40-50%. The original vegetation was deciduous woodland. The main agricultural enterprises include maize, maize-bean intercrop, sunflower, wheat, sweet potato, finger millet, sorghum, kale and cabbage. Crop residues are fed to dairy cattle and sheep.

The Lower Midlands (LM) are semi-arid lands of 1000-1500 masl with an average temperature of 21-24°C, annual rainfall ranging from 450-900 mm and a moisture index of 25-40%. The agriculture is a mix of livestock and crop production. The AEZ occupies about 15% of the total land area. The main agricultural enterprises are rainfed maize, sorghum, millet, cassava, bean, pigeonpea, cowpea, green gram, groundnut, citrus and mango. Banana is produced under furrow irrigation. Livestock types include cattle, goats, sheep, camels, donkeys and bees while forages used include acacia and grasses. The major soil types are Luvisols, Acrisols and Vertisols.

The Inner Lowlands (IL) are arid and very arid lands at 750-1000 masl with an average temperature of more than 24°C, less than 550 mm/yr of rainfall and a moisture index of 15-25% or less. The area occupies about 66% of Kenya's land area and is not suitable for rainfed crops. It is important for goats which are grazed on acacia and grasses but is commonly overgrazed resulting in land degradation.

The Coastal Lowlands (CL) include the Kenyan coastlands which have well-drained sandy soils with a loamy, sandy clay texture and other humid lowlands of less than 1500 masl, such as the Taita Hills with fertile loamy soils and the Tana and Sabaki river valleys with alluvial soils (silts). The coastal lands are characterized by sand dunes and mangrove swamps with deep, grey, saline and poorly drained soils which are not suitable for crop production.

7.2 Soil fertility management

Most of the agricultural soils in Kenya have inherently low soil fertility, low soil moisture retention and high erodibility, but have been intensively farmed by smallholders. There has been a general decline in crop and pasture yields, soil physical properties, vegetation cover and biological diversity but an increase in noxious weeds. The most critical limiting nutrients are N and P while K, S and some micronutrient deficiencies are often diagnosed.

Soil fertility research in East Africa began in the 1930s and addressed the restoration of soil fertility through the combined use of vegetative fallows and animal manures. Traditional farming systems in sub-Saharan Africa were supported by shifting slash-and-burn cultivation, a low input sustainable agricultural farming system that allowed for several years of native vegetative and woody plant growth that resulted in nutrient cycling, restoration of soil organic matter, and improved soil physical properties to restore soil productivity. However, population growth has increased demand for food, feeds and fuel which has led to decreased fallow with resultant soil fertility decline.

Manure is commonly used by most smallholders who practise mixed crop-livestock farming especially in maize, potatoes and vegetables but its widespread usage is limited by low availability. Other organic materials used are liquid manure, composts, green manures, crop residues and municipal wastes (Gachene and Kimaru 2003). Other sources of replenishment included use of rotation with grain legumes, cereal-legume intercropping systems, mulch, agroforestry trees for litter fall and shifting livestock holding pens periodically.

Substantial research in soil fertility status and restoration was carried out under the Fertilizer Use Recommendation Project (FURP) (1987-1993), which resulted in 24 district-based fertilizer recommendations for major crops including maize, sorghum, bean, cowpea, finger millet and other crops.

Other uncoordinated fertilizer use studies in various parts of the country have given rise to numerous fertilizer use practices targeting maize, which include soil nutrient replenishment with rock phosphate (PREP), fortified composting (COMP), relay intercropping with *Lablab purpureus* (LABLAB), staggered-row intercropping (MBILI, an acronym for managing beneficial interactions in legume intercrops) and short-term improved *Crotolaria grahamiana* fallows (IMPFAL).

Most fertilizer is applied to maize, rice and horticultural crops in Kenya (GoK 2014). Fertilizer use in these and other crops is still low. For example, Kenyan farmers apply an average of 50 kg/ha of nutrients to maize compared to 125, 180 and 300 kg/ha in South America, India and the European Union, respectively (Ariga and Jayne 2010; Jama et al. 2013).

Agro-ecological potential affects fertilizer use decisions with much more fertilizer applied to maize in the high-potential areas compared with the semi-arid areas, such as the lower eastern region where fertilizer used is often unprofitable for farmers unless highly subsidized (Ariga et al. 2008). Fertilizer price levels, household income and education level of the household head also affect fertilizer use.

The main fertilizer types used for maize production are calcium ammonium nitrate, urea, compound fertilizers like diammonium phosphate (DAP) and ammonium sulphate, and NPK blends such as 23:23:0 and 17:17:17.

Fertilizer is a costly input to crop production and efficient use is needed to improve profitability, minimize loss of nutrients to the environment and reduce soil acidification due to N application.

The 4Rs of nutrient management are important, that is to apply the right product, the right rate, at the right time and using the right method. This is especially important for N, which is easily lost, e.g. most of the fertilizer nitrogen should be applied at the start of and/or during the period of rapid crop growth when the rate of N uptake is high and N should be incorporated to minimize ammonia volatilization. With maize, for example, this means that at least 50% of the fertilizer N should be applied six weeks after planting (6 WAP). However, when the recommended rate of N is low, it is advisable to apply all at 6 WAP. Fertilizer N should not be applied during dry periods. Also important to good response to fertilizer is to have a healthy and well managed crop with good choice of variety, timely planting, and good weed and pest control.

7.3 Diagnosis of soil nutrient deficiencies

In the Optimizing Fertilizer Recommendations in Africa (OFRA) project, 37 trials were conducted for various crops in four regions of Kenya. The mean responses to N, P and K across these trials were 39, 5 and 17%, respectively. Treatments were included to compare the diagnostic package of N+P+K+Mg+S+Zn+B with a treatment with the same N, P, and K rates for effect on grain yield. Any yield increase with the diagnostic treatment would indicate that deficiency of Mg, S, Zn and/or B may limit yield at that location. The mean yield increase was 10% in Rift Valley upper region, but mean effect of the diagnostic treatment was not different from zero in the other regions (Figure 7.3). Further investigation is needed to determine which nutrient is most deficient in the Rift Valley upper region such as with more nutrient specific trials and/or foliar tissue analysis.

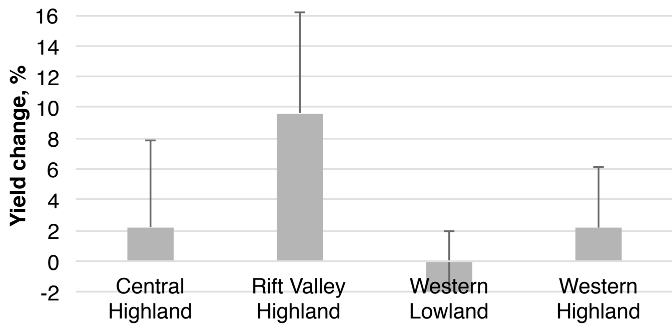

Figure 7.3: Yield change (%) due to secondary and micro-nutrient (diagnostic treatment) application in OFRA trials.

7.4 Optimizing fertilizer use in Kenya

Crop response to fertilizer application tends to be curvilinear to plateau with positive yield

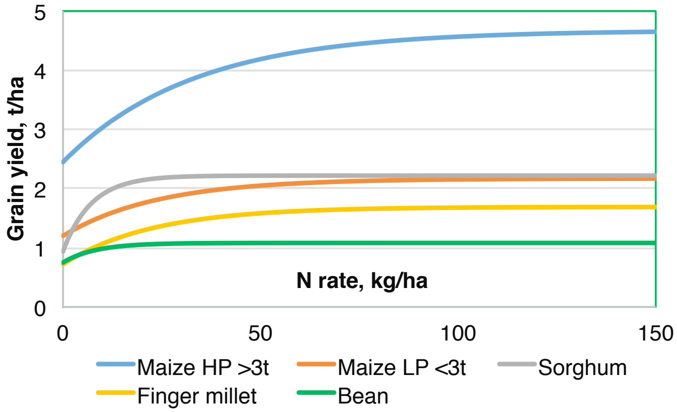

Figure 7.4: The curvilinear to plateau yield responses of five crops to fertilizer N in the Central Highlands of Kenya. HP and LP refer to high and low potential maize production situations

increases until a plateau (Fig. 7.4). Exceptions do occur as when the response is linear or when crop yield declines at high application rates. However, over many trials, curvilinear to plateau functions, such as the Mitscherlich 1909 function, capture crop response well.

Response functions can be derived using a simple asymptotic function: Yield = $a - bc^r$ where a is near maximum yield, b is gain in yield due to nutrient application, c determines the shape of the curve and r is the nutrient application rate.

The nature of the curvilinear response varies as in Fig 7.4 for five crops produced in the Central Region with differing responses to applied N. The magnitude of yield increase is relatively great for high potential (HP > 3 t/ha grain yield expected) maize but more gradual compared with some of the other displayed responses and continuing to relatively high N rates. In contrast, sorghum shows a substantial but steep response to N and is near the plateau with only 25 kg/ha N applied. Bean also has a steep response and a >40% yield increase with a very low N rate. Finger millet and low potential (LP < 3 t/ha grain yield expected) maize have similar magnitudes and shapes of response although maize has the higher yield potential. In all cases, there is a relatively steep yield increase with increasing N rate at low N rates and a reduced rate of yield increase at higher rates until yield reaches a plateau with no more yield increase. Therefore, the benefit to cost ratio of fertilizer use is expected to be greater at relatively low application rates.

Another aspect of the economics of fertilizer use for financially constrained fertilizer use is that some nutrients applied to some crops

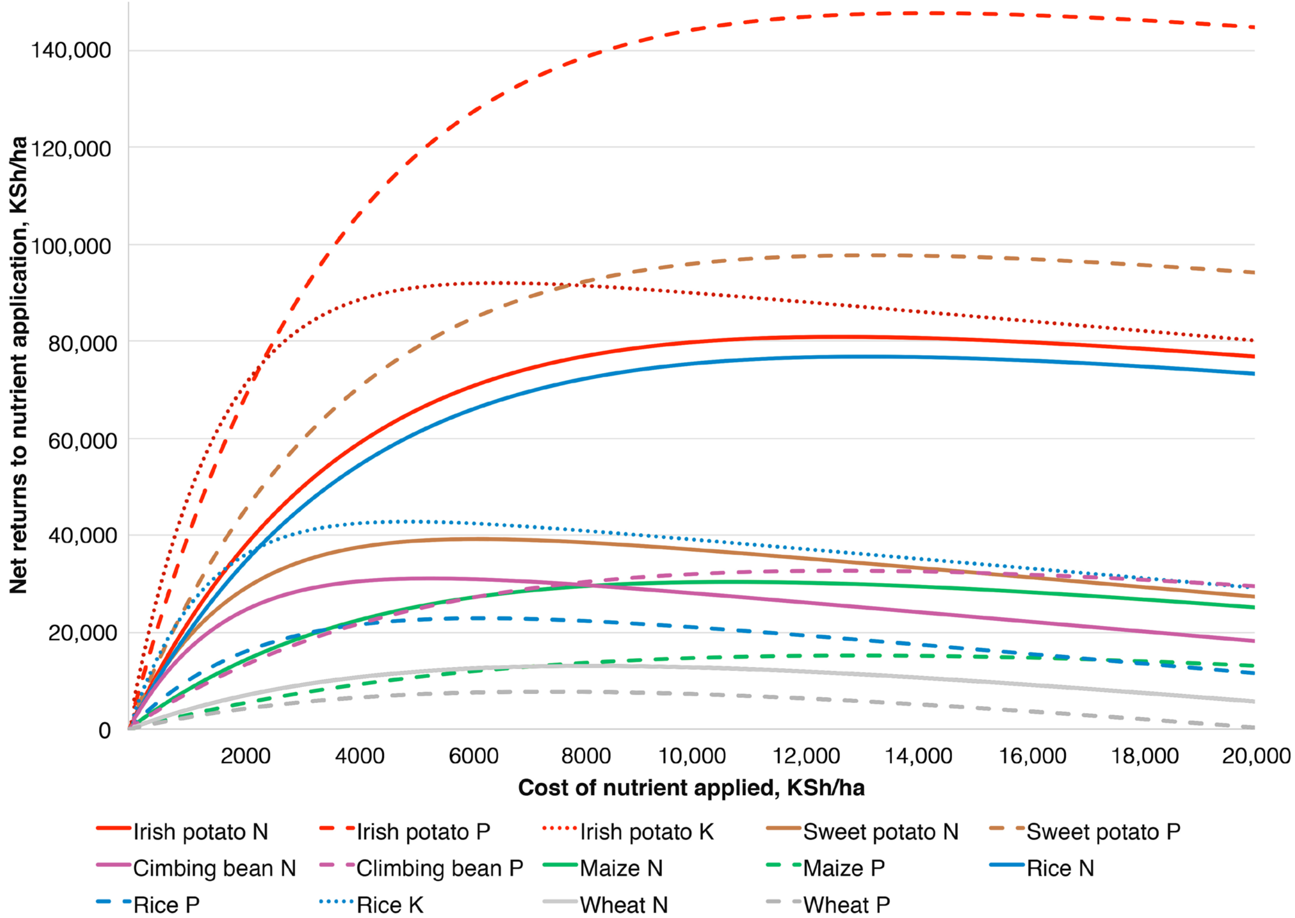

Figure 7.5: Net returns to investment in nutrient application in Western Kenya (>1400 masl).

have more profit potential than other nutrients applied to the same or other crops (Figure 7.5). The amount of money invested in one nutrient applied to one crop is on the x-axis. The y-axis shows net returns to investment for the nutrient applied. For each curve, the profit potential of the nutrient applied to a crop is displayed. The steeper the curve, the higher the net rate of return to investment. The slope decreases with higher investments, but profit is increasing if the slope is still upward. At the peak of a curve, the point of maximum profit per hectare is reached; this rate is often referred to as the economically optimum rate (EOR).

In this example from western Kenya, the expected yield increases are especially substantial for P and K applied to Irish potato and P applied to sweet potato, indicating these two options to have the most profit potential for a limited investment in fertilizer use (Table 7.2e). Nitrogen applied to Irish potato, rice, sweet potato and climbing bean, and K applied to rice also have high profit potential, at least at low rates of application. The lower curves represent profit potential but less potential compared with the upper curves with current commodity prices and fertilizer costs, and should be addressed by financially constrained farmers only after the more profitable options are addressed. Therefore, the choice and rate of nutrients applied to a crop is very important to fertilizer use profitability.

Table 7.2a: Central Highlands of Kenya. Response functions coefficients (col. 3-5), expected yield increases (t/ha) for crop-nutrient increments (col. 6-9), and OFRA economically optimal rate (EOR) to maximize profit per hectare (col 10) compared to current or recent (REC) recommendations (col. 11). P_2O_5 = P x 2.29; K_2O = K x 1.2. Some functions have zero response because of lack of response or lack of information

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			Yield increase t/ ha				kg/ ha	
Maize HP >5t	N	6.558	1.633	0.963	1.106	0.357	0.115	0.037	67	75
Maize LP <5t	N	4.061	1.242	0.961	0.865	0.262	0.080	0.024	58	75
Bean	N	0.955	0.125	0.798	0.125	0.000	0.000	0.000	12	NA
Maize-bean	N	5.210	1.830	0.960	0.338	0.275	0.225	0.183	66	75
Rice, lowland	N	5.248	2.397	0.967	1.522	0.556	0.203	0.074	104	NA
Wheat HP >3t	N	3.922	1.232	0.968	0.768	0.289	0.109	0.041	70	NA
Wheat LP <3t	N	2.563	1.160	0.969	0.710	0.276	0.107	0.042	69	NA
					0-5	**5-10**	**10-15**	**15-20**		
Maize HP >5t	P	3.762	0.281	0.934	0.191	0.166	0.144	0.125	16	11
Maize LP <5t	P	4.078	0.683	0.940	0.182	0.133	0.098	0.072	23	11
Bean	P	0.990	0.185	0.867	0.094	0.046	0.023	0.011	16	NA
Maize-bean	P	4.860	0.810	0.890	0.358	0.200	0.112	0.062	19	0
Rice, lowland	P	5.395	0.572	0.885	0.261	0.142	0.077	0.042	22	NA
Wheat HP >3t	P	4.000	0.671	0.941	0.176	0.130	0.096	0.071	26	NA
Wheat LP <3t	P	2.048	0.437	0.94	0.116	0.085	0.063	0.046	19	NA
Wheat	K	3.763	0.282	0.934	0.081	0.058	0.041	0.029	22	NA
Rice	K	6.253	0.984	0.898	0.409	0.239	0.140	0.082	35	NA

† EOR was determined with the cost of using 50 kg urea and DAP at KSh 2850 and 3600, respectively. Commodity values (KSh/kg) used were: rice 50; maize 25; bean 60; wheat 30; green gram 90; cowpea 50; groundnut unshelled 50; soybean 30; finger millet 50; cassava 30; sorghum 30; Irish potato 30; sweet potato 30; banana 30. NA - data not available.

‡ Fermont et al. (2010)

7.5 Crops targeted for optimization by region

The OFRA determined crop-nutrient response functions for important food crops and applied the functions in development of fertilizer use optimization tools (FOTs). Priority crops for different regions were chosen: maize, bean, Irish potato, lowland rice and wheat were common in most regions while banana, sweet potato, cowpea, green gram, sorghum and finger millet were selected for one or more regions (Table 7.2a-h).

Irish potato, lowland rice, green gram, soybean and wheat are mainly grown as sole crop in all the regions. However, maize-bean intercropping is common. Finger millet and sorghum, commonly grown in Rift Valley and Western regions, are grown on small land areas during the short rains due to high labour requirement.

In the Central Highlands (LU and UM), all crops except for bean had large responses to applied N with most of the yield gain with 30 kg/ha N applied and not much additional gain with more than 60 kg/ha applied (Table 7.2a). There were also good responses to applied P and not much response to applying P beyond the 10 kg/ha rate.

The available field research results did not show any of these crops to be generally responsive to applied K and Zn which agrees with the results of the diagnostic treatments (section 7.3). For the Central Highlands, the EOR compared with REC were lower for N but higher for P.

In the Coastal Lowlands, all crops responded well to applied N and P (Table 7.2b). Cassava yield increases were high with N, P and K applied. Cowpea responded to applied N and more so to applied P. Maize and cowpea had responses to applied K. The EOR compared with REC were lower for N applied to maize but higher for N applied to cassava, finger millet and sorghum, and lower for P and K rates. In six cases, EOR were determined from field research results where RECs were missing.

Table 7.2b: Coastal Lowlands

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			Yield increase t/ ha				kg/ ha	
Cassava	N	41.361	12.546	0.972	7.194	3.069	1.309	0.558	151	100‡
Maize HP >3t	N	4.374	2.130	0.980	0.968	0.528	0.288	0.157	90	150
Maize LP <3t	N	2.056	0.399	0.950	0.313	0.067	0.014	0.003	28	75
Rice, lowland	N	4.569	1.868	0.985	0.681	0.433	0.275	0.175	159	NA
Sorghum	N	3.993	1.436	0.974	0.785	0.356	0.162	0.073	84	50
Finger millet	N	1.692	1.003	0.961	0.699	0.212	0.064	0.019	70	0
Cowpea	N	1.222	0.382	0.920	0.351	0.029	0.002	0.000	31	NA
					0-5	**5-10**	**10-15**	**15-20**		
Cassava	P	25.905	6.787	0.882	3.164	1.689	0.902	0.481	37	22‡
Maize HP >3t	P	2.815	1.113	0.914	0.403	0.257	0.164	0.105	26	66
Maize LP <3t	P	2.815	1.113	0.914	0.403	0.257	0.164	0.105	26	33
Rice, lowland	P	3.773	0.862	0.875	0.420	0.215	0.110	0.057	24	NA
Sorghum	P	3.590	1.178	0.891	0.516	0.290	0.163	0.091	24	0
Finger millet	P	1.776	0.221	0.8	0.149	0.049	0.016	0.005	10	50
Cowpea	P	1.495	0.702	0.9	0.287	0.170	0.100	0.059	26	NA
Cassava	K	29.171	8.9499	0.878	4.280	2.233	1.165	0.608	43	83‡
Maize	K	3.143	0.177	0.911	0.066	0.041	0.026	0.016	13	NA
Cowpea	K	1.110	0.168	0.850	0.093	0.041	0.018	0.008	15	NA

In the Eastern Upper region (LM and UM), all crops except bean had large responses to N, with the highest yield gain occurring with 30 kg/ha N applied while application of N above 60 kg/ha gave less yield increments (Table 7.2c). Responses to applied P occurred in lower P application rates (up to 10 kg/ha). In this region, high responses to applied K only occurred in bananas, Irish potato and lowland rice. Bananas had the highest responses to K application, with high yield gains when 20 kg/ha was applied. The EOR compared with REC were lower for N applied to Irish potato and maize but higher for N applied to banana. The EOR compared with REC was inconsistent for P but EOR were higher than REC for K.

Table 7.2c: Eastern Upper (>1200 masl)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			**Yield increase t/ ha**				**kg/ ha**	
Banana	N	46.500	7.900	0.896	7.607	0.282	0.010	0.000	49	0
Irish potato	N	12.378	3.960	0.952	3.055	0.698	0.160	0.036	78	150
Maize HP	N	5.398	1.679	0.964	1.120	0.373	0.124	0.041	69	75
Maize LP	N	2.410	0.770	0.875	0.756	0.014	0.000	0.000	23	75
Rice, lowland	N	5.030	1.612	0.981	0.705	0.397	0.223	0.125	132	NA
Bean	N	0.940	0.086	0.8	0.086	0.000	0.000	0.000	10	NA
					0-5	**5-10**	**10-15**	**15-20**		
Banana	P	24.531	1.681	0.874	0.824	0.420	0.214	0.109	25	33
Irish potato	P	16.195	5.289	0.903	2.113	1.269	0.762	0.457	41	33
Maize HP	P	5.680	1.280	0.940	0.341	0.250	0.183	0.135	34	33
Maize LP	P	2.609	0.709	0.940	0.189	0.138	0.102	0.075	24	33
Rice, lowland	P	5.241	2.329	0.964	0.390	0.325	0.270	0.225	32	NA
Bean	P	0.997	0.187	0.860	0.099	0.047	0.022	0.010	13	9
Banana	K	38.200	9.750	0.913	3.565	2.261	1.435	0.910	59	0
Irish potato	K	14.158	2.190	0.913	0.801	0.508	0.322	0.204	42	0
Rice, lowland	K	6.187	0.89	0.873	0.439	0.222	0.113	0.057	28	0

Table 7.2d: Eastern Lower (<1200 masl)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			**Yield increase t/ ha**				**kg/ ha**	
Maize	N	2.260	1.135	0.945	0.927	0.170	0.031	0.006	45	60
Bean	N	1.000	0.500	0.899	0.479	0.020	0.001	0.000	31	NA
Sorghum	N	2.050	0.000	0.000	0.000	0.000	0.000	0.000	0	NA
Irish potato	N	39.444	16.914	0.949	13.397	2.786	0.579	0.120	102	NA
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	2.027	0.079	0.885	0.036	0.020	0.011	0.006	0	NA
Bean	P	1.140	0.350	0.824	0.217	0.082	0.031	0.012	14	NA
Sorghum	P	2.500	0.207	0.750	0.158	0.037	0.009	0.002	7	NA

Table 7.2e: Western Upper (>1400 masl)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases			Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**EOR†**	**REC ‡**
		t/ ha			**Yield increase t/ ha**			**kg/ ha**	
Maize	N	5.290	1.830	0.974	1.000	0.454	0.206	86	60
Irish potato	N	12.899	3.898	0.969	2.383	0.927	0.360	108	90
Sweet potato	N	9.750	1.577	0.938	1.346	0.197	0.029	50	0
Rice, lowland	N	5.006	1.882	0.971	1.104	0.456	0.189	106	NA
Maize-bean	N	7.360	2.530	0.970	1.533	0.605	0.239	90	75
Climbing bean	N	2.293	0.636	0.931	0.562	0.066	0.008	43	0
Wheat	N	3.521	0.871	0.975	0.464	0.217	0.102	66	NA
					0-5	**5-10**	**10-15**		
Maize	P	5.396	1.496	0.962	0.263	0.217	0.179	36	26
Irish potato	P	16.095	5.517	0.908	2.112	1.303	0.805	43	33
Sweet potato	P	13.257	3.828	0.912	1.413	0.891	0.562	42	0
Rice, lowland	P	5.487	0.631	0.863	0.329	0.157	0.075	16	NA
Maize-bean	P	7.280	1.790	0.890	0.790	0.441	0.246	26	22
Climbing bean	P	2.199	0.852	0.940	0.227	0.166	0.122	41	NA
Wheat	P	4.000	0.700	0.940	0.186	0.137	0.100	27	NA
Irish potato	K	16.881	3.338	0.913	1.220	0.774	0.491	47	0
Rice, lowland	K	6.253	0.983	0.902	0.396	0.236	0.141	31	0

Table 7.2f: Western Lower (<1400 masl)

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			**Yield increase t/ ha**				**kg/ ha**	
Maize HP >3t	N	4.672	2.224	0.970	1.332	0.534	0.214	0.086	86	70
Maize LP <3t	N	2.170	0.970	0.959	0.694	0.198	0.056	0.016	50	60
Sorghum	N	2.220	1.281	0.870	1.261	0.019	0.000	0.000	27	NA
Finger millet	N	1.691	0.969	0.957	0.710	0.190	0.051	0.014	26	NA
Bean	N	1.082	0.331	0.885	0.322	0.008	0.000	0.000	24	NA
					0-5	**5-10**	**10-15**	**15-20**		
Maize HP >3t	P	4.310	0.848	0.940	0.226	0.166	0.121	0.089	27	NA
Maize LP <3t	P	2.624	0.744	0.940	0.198	0.145	0.107	0.078	25	NA
Sorghum	P	2.272	1.072	0.750	0.818	0.194	0.046	0.011	13	NA
Finger millet	P	1.776	0.221	0.800	0.149	0.049	0.016	0.005	10	NA
Bean	P	0.730	0.180	0.840	0.105	0.044	0.018	0.008	12	NA
Groundnuts, unshelled	P	1.230	0.288	0.904	0.114	0.069	0.042	0.025	14	NA
Maize	K	3.878	0.209	0.934	0.060	0.043	0.031	0.022	15	NA
Bean	K	2.117	0.264	0.889	0.118	0.065	0.036	0.020	23	NA
Groundnut	K	1.391	0.151	0.890	0.067	0.037	0.021	0.012	17	NA

Table 7.2g: Rift Valley Upper (>2000 masl)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			**Yield increase t/ ha**				**kg/ ha**	
Maize HP	N	7.490	2.640	0.903	2.516	0.118	0.006	0.000	39	75
Maize LP	N	3.700	0.200	0.886	0.195	0.005	0.000	0.000	13	75
Irish potato	N	10.883	2.342	0.988	0.712	0.495	0.345	0.240	159	0
Bean	N	0.783	0.122	0.963	0.744	0.027	0.009	0.003	21	0
Wheat	N	6.147	1.562	0.976	0.808	0.390	0.188	0.091	91	NA
Maize-bean	N	5.770	1.490	0.990	0.530	0.342	0.221	0.142	110	50
Green gram	N	1.159	0.324	0.860	0.320	0.003	0.000	0.000	20	0
					0-5	**5-10**	**10-15**	**15-20**		
Maize HP	P	6.087	0.738	0.904	0.292	0.177	0.107	0.064	20	0
Maize LP	P	4.663	0.792	0.990	0.039	0.037	0.035	0.033	0	NA
Irish potato	P	10.303	1.103	0.857	0.593	0.274	0.127	0.059	20	33
Bean	P	0.793	0.122	0.630	0.110	0.011	0.001	0.000	7	0
Wheat	P	6.859	1.104	0.809	0.721	0.250	0.087	0.030	16	NA
Maize-bean	P	6.542	1.084	0.887	0.489	0.268	0.147	0.081	21	17
Green gram	P	1.260	0.542	0.700	0.451	0.076	0.013	0.002	12	0

Table 7.2h: Rift Valley Lower (<2300 masl)

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Effect of nutrient element rate (kg/ha) on yield increases				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC ‡**
		t/ ha			**Yield increase t/ ha**				**kg/ ha**	
Maize	N	5.717	1.084	0.969	0.663	0.258	0.100	0.039	61	75
Irish potato	N	25.748	8.936	0.948	7.135	1.438	0.290	0.058	46	NA
Bean	N	1.218	0.112	0.899	0.107	0.004	0.000	0.000	16	NA
Wheat	N	2.825	0.838	0.952	0.646	0.148	0.034	0.008	47	NA
Maize-bean	N	6.870	1.670	0.970	1.077	0.382	0.135	0.048	76	50
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	6.564	1.109	0.898	0.461	0.269	0.157	0.092	23	NA
Soybean	P	1.012	0.157	0.878	0.075	0.039	0.020	0.011	7	NA
Irish potato	P	24.027	6.868	0.919	2.366	1.551	1.017	0.666	50	33
Bean	P	1.207	0.185	0.800	0.124	0.041	0.013	0.004	10	NA
Wheat	P	2.874	0.572	0.839	0.334	0.139	0.058	0.024	13	NA
Maize-bean	P	7.350	1.230	0.890	0.556	0.305	0.167	0.092	22	17
Green gram	P	1.301	0.601	0.803	0.400	0.134	0.045	0.015	11	NA
Maize	K	6.518	0.835	0.835	0.496	0.201	0.082	0.033	18	NA
Maize-bean	K	7.300	0.960	0.890	0.432	0.237	0.130	0.071	25	NA

In the Eastern Lower (LM) zone, all crops except sorghum had responses to applied N with more of the yield gain from application of 30 kg/ha N and small increases with applications beyond 60 kg/ha (Table 7.2d). Higher responses to applied P were only found in beans and sorghum but the response was low beyond the 10 kg/ha rate. The results did not show any of the crops to be generally responsive to applied K, which agrees with the results of the diagnostic treatments (section 7.3). The EOR compared with REC were lower for N applied to maize. The EOR for N and P were determined for several crop that did not have EOR.

The Western Upper (LM and UM) zone had high responses to N in all the crops with the highest yield gain occurring with 30 kg/ha N applied and lesser yield gains when more than 60 kg/ha was applied (Table 7.2e). Responses to 10 kg/ha of P occurred for all crops with the great yield responses for Irish potato and sweet potato. Only Irish potato and lowland rice benefitted from added K (up to 10 kg/ha), but the other crops did not respond to K. The EOR compared with REC were high for N, P and K in the Western Upper Altitude zone. No RECs were available for lowland rice, climbing beans and wheat despite these crops having responses to nutrient addition.

The Western Lower (LM) zone had high responses to applied N in all crops with more of the yield gains from application of 30 kg/ha N and small yield increments with applications beyond 60 kg/ha (Table 7.2f). Groundnuts did not respond to N application, while beans required applications of of less than 30 kg/ha. All crops responded to applied P but response was small to P rates greater than 10 kg/ha. High responses at 15 kg/ha of K occurred in three crops, but yield gains were lower beyond 20 kg/ha. For Western Lower, the EOR compared with REC were high for N, P and K.

In the Rift Valley Upper (UH, LH) zone, there were high responses to applied N in all the crops with the 30 kg/ha application having the highest yield gain but lower yield gains at applications beyond 60 kg/ha (Table 7.2g). All the crops responded to applied P but at modest rates of up to 10 kg/ha. No response to K occurred in all the crops. For Rift Valley Upper, the EOR compared with REC were low for N applied to maize but high for N applied to Irish potato, bean, wheat and green gram, and low for P applied to Irish potato but high for P applied to other crops.

In the Rift Valley Lower (UM) zone, all crops except soybean and green gram had responses to applied N with more of the yield gain from application of 30 kg/ha and small yield increments with applications beyond 60 kg/ha (Table 7.2h). All crops responded to applied P but the response was small to rates above 10 kg/ha except for Irish potato that responded well up to 20 kg/ha of P. Responses to applied K only occurred in maize and maize-bean intercrops, with more yield gain from applications up to 10 kg/ha. The EOR rates were mainly less than the REC, but in most crops, EOR was determined in crops that had no RECs.

The EOR determined from field research results varied inconsistently compared with REC (Table 7.2a-h). For 49 crop-nutrients across the eight recommendation domains, field-research-based EOR were determined where the REC was not available or was 0 kg/ha. In all regions, all non-legumes had an economic response to applied N and most of the yield gain was achieved with 30 kg/ha applied, and little additional gain with more than 60 kg/ha applied (Table 7.2a-h). Similarly, in all regions, all crops had an economic response to applied P with the exceptions of Irish potato in Eastern and low-potential maize in the Rift Valley Region. Responses to K occurred in less than one-third of the cases and most often with Irish potato, rice, groundnut and banana. Due to financial constraints, farmers can expect higher benefit to cost ratios when applying at less than EOR, particularly in the low-potential areas where fertilizer use is considered risky (Ariga and Jayne 2010). The results indicate good profitability with some fertilizer use on most crops.

7.6 Fertilizer use optimization tools (FOT) for Kenya AEZ

Optimization of profit from fertilizer use requires good choice of nutrient rates for each crop. Response to applied nutrients of different crops of interest, amount of land allocated to different crops, value of the produce, cost of fertilizer used and the money available for fertilizer use need to be considered in optimizing fertilizer use for high profit.

Considering these complex factors, fertilizer use optimization tools (FOTs) were developed using Excel Solver© (Frontline Systems Inc., Incline Village, NV, USA). The Solver function in the FOTs uses complex mathematics of linear optimization in the integration of the farmer's economic and agronomic information with up to 28 crop-nutrient response functions to develop recommendations. The design makes the FOTs easy to use. The choice of crop-nutrient-rate combinations is expected, on average, to maximize returns on investment in fertilizer use.

Eight FOTs were developed for recommendation domains in Kenya and are available at http://agronomy.unl.edu/OFRA. To use a FOT, Solver needs to be added on in Excel and the macros need to be enabled; see the Help and Instructions worksheet of the FOT for instructions.

Data input requires the farmer to estimate how much land will be planted to each crop of interest under 'Area Planted, Ac'. Next, the on-farm value at harvest time per kg of the produce is determined, considering the value of that kept for home consumption and the value of marketed surplus, and entered under 'Expected Grain Value' (Figure 7.6). The cost of using different fertilizers, including purchase price and costs of transport and application, is entered under 'Price/ 50 kg fertilizer'. The farmer's available money for fertilizer use is also entered as the 'Budget Constraint'.

The results are given in three sections (Figure 7.7) including the amount of each fertilizer to apply to each crop, the expected average yield increases and net returns, and the expected average total net returns to fertilizer use for the farm.

Differences in net returns to fertilizer use by crop are revealing. In this example, fertilizer use with Irish potato is estimated to have very high returns. The farmer should not increase the amount of fertilizer applied per acre above the recommended amount but should consider allocating more land to Irish potato production while decreasing land for another crop with low net returns, realizing that the return to fertilizer use is only one factor in the total profitability of a crop.

A farmer investing KSh 50,000 in fertilizer for seven crops is expected to get an average total return on investment of about KSh 362,400. For a farmer with lower investment potential of KSh 10,000 with the same crops and land allocation, the expected average net returns decline to KSh 210,000. These are partial budget net returns to fertilizer investment, without considering other production costs. Due to seasonal variation in input output prices, access to current information on fertilizer prices and grain market prices are required to most accurately optimize fertilizer use recommendations for the current season.

Paper versions of all FOTs were developed for county extension officers, agro-dealers and farmers without easy access to computers (Table 7.3; available at http://agronomy.unl.edu/OFRA). These are easy to use but need to be updated, maybe annually, with major changes in fertilizer costs relative to commodity prices.

Paper FOTs are developed with the farmer's ability for fertilizer use divided into three financial levels: level 1) for a poor farmer who has no more than one-third the amount of money required to apply fertilizer to all cropland at EOR; level 2) for a farmer with more money but with no more than two-thirds the amount required to apply fertilizers to all cropland at EOR; and level 3) for the farmer with enough money to apply fertilizer to at least some cropland at EOR.

The paper FOTs advise on the 4Rs, i.e. right product, rate, time and method of application. Mode of calibration is also given for guiding the farmer to calibrate his/her sense of feel and visual impression of the correct rate, e.g. the length of the band or the number of holes per measuring unit. The paper FOTs assume that the farmer will use the Keringet brand water bottle lid which has a volume of 4 ml, or for broadcast application, a Keringet or Aqua brand water bottle cut at 4 cm high from the bottom which has a volume of 78 ml. These measuring units were selected because of easy availability in rural areas.

Consider the use of the paper FOT (Table 7.3). If the farmer has only a small amount of money for fertilizer use, he/she is likely to be in financial level 1. This level has recommendations for five of the seven crops as the profit potential for

AEZ Western
Elevation >1400

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

Crop Selection and Prices		
Crop	**Area Planted (Ac)***	**Expected Grain Value/kg †**
Maize	1	25
Irish potato	1	30
Potato, sweet	1	30
Rice, lowland	1	60
Maize-bean	1	[redacted]
Beans, climbing	1	60
Wheat	1	40
Total	7	

Enter grain values for maize and bean sole crop.

Fertilizer Selection and Prices				
Fertilizer Product	**N**	**P2O5**	**K2O**	**Price/50 kg bag ¶***
Urea	46%	0%	0%	2850
Triple super phosphate, TSP	0%	46%	0%	4000
Diammonium phosphate, DAP	18%	46%	0%	3600
Murate of potash, KCL	0%	0%	60%	3600
P-mazao	10%	26%	10%	3250

Budget Constraint	
Amount available to invest in fertilizer	50,000

Figure 7.6: Input data options of crop prices and fertilizer costs in Upper western Region, Kenya.

Fertilizer Optimization					
	Application Rate - kg/Ac				
Crop	**Urea**	**TSP**	**DAP**	**KCL**	**P-ma**
Maize	43	0	61	0	0
Irish potato	59	0	61	31	23
Potato, sweet	16	5	61	0	0
Rice, lowland	61	0	43	27	0
Maize-bean	52	0	48	0	0
Beans, climbing	11	0	61	0	0
Wheat	37	0	55	0	0
Total fertilizer needed	280	5	388	58	23

Expected Average Effects per Ac		
Crop	**Yield Increases**	**Net Returns**
Maize	1,060	19,647
Irish potato	5,003	138,669
Potato, sweet	2,079	56,640
Rice, lowland	1,336	71,638
Maize-bean	1,621	34,090
Beans, climbing	534	27,044
Wheat	519	14,679

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer	362,407

Figure 7.7: Output data of optimized fertilizer rates and returns to fertilizer investment in Upper Western Region, Kenya.

Table 7.3: An example of a paper tool

Western Kenya Upper (>1400 m) Fertilizer Use Optimizer

The below assumes:
Calibration measurement is with i) a 5 ml water bottle lid (lid) that holds about 3.5 g urea and 5.5 g DAP and MOP, ii) a 500 ml water bottle of 5 cm diameter cut to height of 4 cm has approx. 80 ml to hold 56 g urea, and 88 g DAP and MOP.
Row spacing: maize, Irish potatoes, sweet potatoes and climbing bean have 75 cm; bean at 50 cm; wheat at 25cm.
Grain values per kg (Ksh): 25 maize, 30 Irish potatoes, 30 sweet potatoes, 50 rice, 60 bean, 30 wheat.
Cost of using 50 kg fertilizer (Ksh): 2850 urea; 3600 DAP; 3600 MOP.
Application rates are in kg/ac. Minimum rates are 10 kg/ac.

Level 1 financial ability.	
Maize HP (>3t)	at planting band 10 kg DAP (1 lid for 2.2 m)
Irish potato	at planting band 60 kg DAP (1 lid for 0.4 m) and 20 kg MOP (1 lid for 1 m)
Sweet potato	at planting band 39 kg DAP (1 lid for 0.6 m)
Maize-bean intercropping	at planting band 19 kg DAP (1 lid for 1.1 m) and sidedress by banding 15 kg urea at 6 WAP (1 lid for 0.9 m)
Climbing bean	at planting band 28 kg DAP (1 lid for 0.8 m)
Level 2 financial ability	
Maize HP (>3t)	at planting band 36 kg DAP (1 lid for 0.6 m) and sidedress by banding 26 kg urea at 6 WAP (1 lid for 0.5 m)
Irish potato	at planting band 61 kg DAP (1 lid for 0.3 m) and 30 kg MOP (1 lid for 0.8 m)
Sweet potato	at planting band 61kg DAP (1 lid for 0.3 m)
Rice, lowland	broadcast 25 kg DAP (one cut bottle for 6.7 m @ 2 m wide) and 20 kg MOP (one cut bottle for 5.6 m @ 2 m wide) at planting and sidedress by broadcast 51 kg urea (one cut bottle for 2.0 m @ 2 m wide) at panicle initiation
Maize-bean intercropping	at planting band 34 kg DAP (1 lid for 0.7 m) and sidedress by banding 35 kg urea at 6 WAP (1 lid for 0.4 m)
Climbing bean	at planting band 55 kg DAP (1 lid for 0.4 m)
Wheat	band at planting 19 kg DAP (1 lid for 3.5 m) and sidedress by banding 14 kg urea at panicle initiation (1 lid for 2.2 m)
Level 3 financial ability (maximize profit per acre).	
Maize HP (>3t)	at planting band 61 kg DAP (1 lid for 0.3 m) and sidedress by banding 52 kg urea at 6 WAP (1 lid for 0.25 m)
Irish potato	at planting band 61 kg DAP (1 lid for 0.3 m) and 30 kg MOP (1 lid for 0.7 m)
Sweet potato	at planting band 61kg DAP (1 lid for 0.3 m)
Rice, lowland	broadcast 45 kg DAP (one cut bottle for 3.7 m @ 2 m wide) and 28 kg MOP (one cut bottle for 1.8 m @ 2 m wide) at planting and sidedress by broadcast 61 kg urea (one cut bottle for 1.6 m @ 2 m wide) at panicle initiation
Maize-bean intercropping	at planting band 53 kg DAP (1 lid for 0.4 m) and sidedress by banding 58 kg urea at 6 WAP (1 lid for 0.25 m)
Climbing bean	at planting band 61 kg DAP (1 lid for 0.3 m) and sidedress by banding 14 kg urea at 6 WAP (1 lid for 1 m)
Wheat	band at planting 54 kg DAP (1 lid for 1.2 m or broadcast with cut bottle for 5 m) and sidedress by banding 37 kg urea at panicle initiation (1 lid for 1.1 m or broadcast with cut bottle for 2.9 m)

fertilizer use on wheat and lowland rice were inadequate to qualify for this financial level at the higher elevations of western Kenya. The recommendations for each crop in this level have somewhat similar potential for profit from fertilizer use. Therefore, the farmer can opt to use any or all of the options according to financial ability. If money for fertilizer is remaining, he/she may advance to one or more options in level 2.

One option in level 1 is 'For Irish potato, at planting band 60 kg DAP (1 lid for 0.4 m) and 20 kg MOP (1 lid for 1.0 m)'. Therefore, DAP and MOP fertilizers are to be applied to Irish potato at planting in a band passing near the row. The farmer calibrates him/herself to apply 60 kg/ac DAP by using the Keringet water bottle lid with one level full lid sufficient for 0.4 m of band. The calibration for the 20 kg/ac MOP is similarly done with one level full lid sufficient for 1.0 m of band. The instructions for all other options are also easy to follow.

Another aspect of optimizing fertilizer use is to account for the effects of other soil management practices and to consider soil test values. Organic inputs available at the farm level are generally inadequate to supply all the nutrients required, however, when used in combination with inorganic fertilizers, within the integrated soil fertility management (ISFM) framework, they improve crop productivity and profitability. Some of these materials include farmyard manure and composts, fresh vegetative materials such as tithonia and grevillea prunings, as well as green manures such as mucuna and Azolla.

Table 7.4 is a guideline to giving fertilizer substitution values to some common practices. For example, if the farmer applies 1 ton (dry weight) of low quality farmyard manure, this will substitute for about 5 kg urea, 3 kg DAP or TSP, and 2 kg KCl, or 10 kg NPK fertilizer during planting. On the other hand, if the previous crop was a green manure crop such as mucuna for maize and Azolla for lowland rice, then organic inputs substitute up to 100% of N and 70% of the P, K and NPK required for crop

Table 7.4: Fertilizer substitution guidelines using commonly available organic materials

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT CONTEXT

FERTILIZER SUBSTITUTION AND SOIL TEST IMPLICATIONS

ISFM practice	Urea	DAP/TSP	KCl	NPK 17-17-17
	Fertilizer reduction, % or kg/acre			
Previous crop was a green manure crop e.g. mucuna and crotalaria for maize or Azolla for lowland rice	100%	70%	70%	70%
Fresh vegetative material (e.g. prunings of *tithonia, Lantana camara, grevillea, Leucaena, Sesbania sesban,* banana leaves, coffee husks) 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			
Avail. P (Olsen) > 10 ppm	Apply no P			
If soil test K <100 ppm	Band apply 20 kg/ac KCl			

production leading to enhanced profitability. The instructions for other options are given in Table 4 and are also easy to follow.

It is recommended that soil tests be done every 4 years to assess the soil nutrient levels and optimize the fertilizer requirement by applying only what is deficient and hence improve on-farm profitability. For example, when the soil test for P is above 15 ppm, then it is recommended that no fertilizer P should be added. On the other hand, if the K soil gives a value of less than 100 ppm, then K should be applied at the rate of 20 kg/ac of KCl in a band at planting (Table 7.4).

7.7 Conclusions

Increased fertilizer use by smallholder farmers is essential to reversing the declining trend of food production in SSA. The combined application of organic inputs and inorganic fertilizers normally give improved yields, particularly when farmers apply the right fertilizer at the right rate, time and placement, and in consideration of other good agronomic practices.

Fertilizer usage is often limited by lack of sound knowledge required to develop and disseminate sustainable integrated fertilizer recommendations that are soil and crop specific and that are profitable to the farmer. The overall objective of OFRA was to provide farmers with decision tools which would allow them to choose the fertilizer rates and types for different crops in various agro-ecological zones to maximize their profits based on their economic constraints.

A total of 37 replicated trials were conducted for various crops in four regions of Kenya. The mean responses to N, P and K across these trials were 39, 5 and 17%, respectively and 49 crop-nutrient response functions for various recommendation domains were developed. In all regions, all non-legumes had an economic response to applied N and most of the yield gain was achieved with 30 kg/ha N applied and little additional gain with more than 60 kg/ha N applied. Similarly, in all regions, all crops had an economical response to applied P with the exceptions of Irish potato in Eastern and low potential maize in the Rift Valley Region. Responses to K occurred in less than one-third of the cases and most often with Irish potato, rice, groundnut and banana.

The optimal choice of crop-nutrient-rate combinations is expected, on average, to maximize returns on investment in fertilizer use. Eight fertilizer optimization tools (FOTs) were developed for eight recommendation domains in Kenya and are available at http://agronomy.unl.edu/OFRA. Paper versions of all FOTs were developed for use by county extension officers, agro-dealers and farmers without easy access to computers, which may need to be updated when situations like crop and fertilizer prices change.

In addition to the above, optimizing fertilizer use accounts for the effects of other soil management practices and soil test values. Organic inputs, such as farmyard manure and composts, and fresh vegetative materials, such as tithonia and grevillea prunings, may be used within an ISFM framework to improve crop productivity and profitability. Soil tests may be done every 4 years to assess soil nutrient availability and optimize the fertilizer requirement by applying only what is deficient and hence improve on-farm profitability.

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