5. Optimizing Fertilizer Use within an Integrated Soil Fertility Management Framework in Ethiopia

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5.1 Agricultural systems in Ethiopia

Agriculture is important for human welfare and economic growth in Ethiopia. Gross domestic product (GDP) from agriculture in Ethiopia is 41.6% of the total GDP. Exports are dominated by agricultural products and more than 80% of the population in Ethiopia depends on agricultural production for their livelihood. Ethiopia's 12.7 million smallholder farmers account for approximately 95% of agricultural GDP (Central Statistics Agency 2013).

With a total area of about 1.13 million km^2 and about 0.51 million km^2 of arable land, and with actual yields less than 25% of water-limited potential yield, the country has a tremendous potential for rainfed agricultural development (Global Yield Gap Atlas 2016). Nitosols (23%), Cambisols (19%) and Vertisols (18%) are the major agricultural soil groups in Ethiopia (Dubale 2001).

About 11% of total cultivated land is used by more than 6 million smallholders to produce non-food products. Cereal production occupied about 86% of the cropland with major cereals such as teff, maize, sorghum and wheat accounting for an estimated 24%, 17%, 15% and 13%, respectively, of cropland use during the main cropping season in 2015.

Use of fertilizer, seed of improved varieties, pesticides and irrigation remains low and agricultural production is primarily managed by low input-output rainfed smallholder farmers. Lack of timely input supply adds to the problem. Land holdings are small and fragmented.

Only 30–40% of smallholders use fertilizer (Spielman et al. 2011). Average fertilizer may be about 40 kg/ha of cropland. Farmers used improved seed on only 4.7% of cropland in the 2007/08 crop year (Spielman et al. 2011). Local

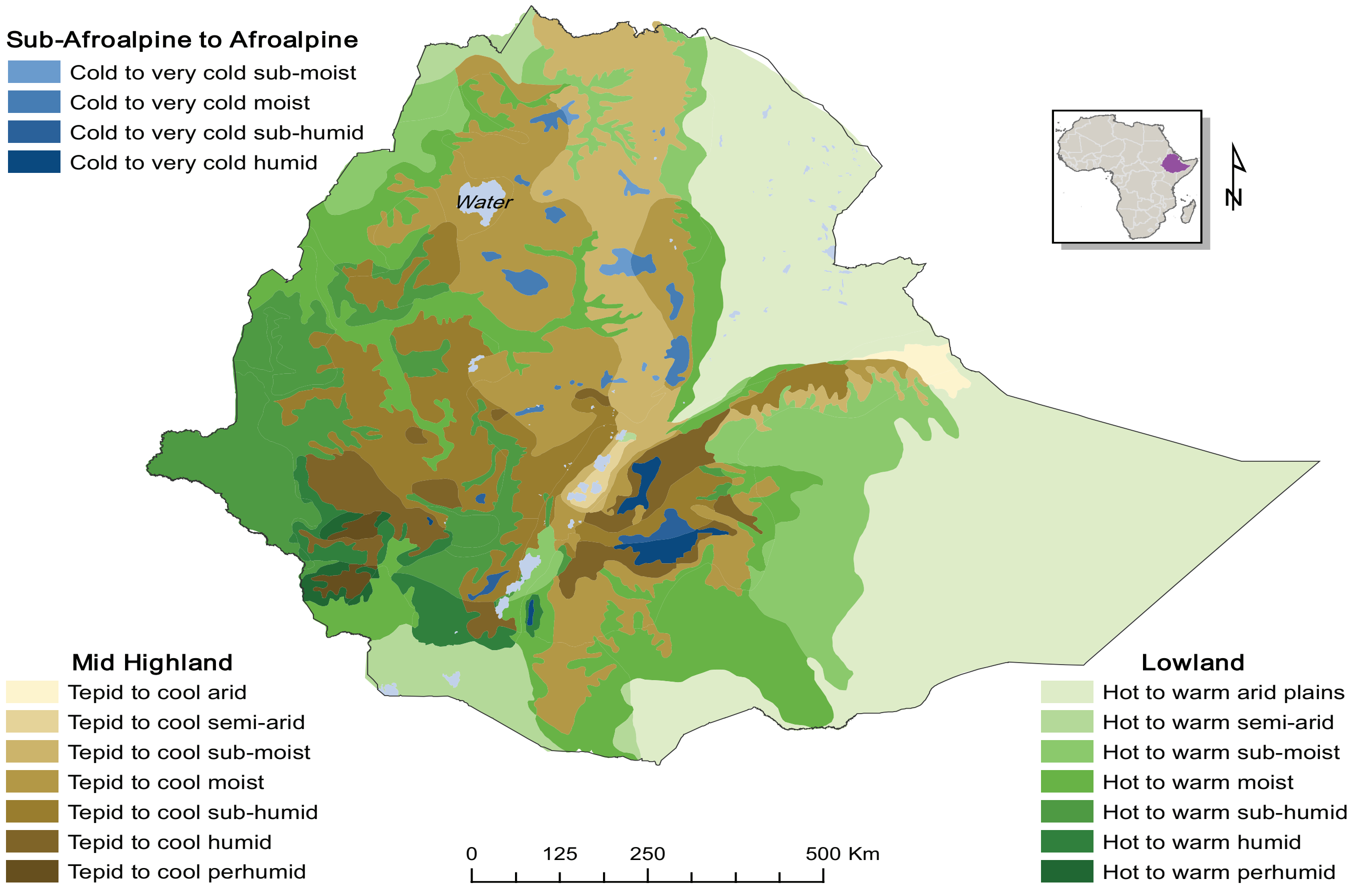

Figure 5.1: Agro-ecological zones of Ethiopia.

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

seed varieties and informal seed exchange systems account for most seed supply to smallholders.

Ethiopia has a great ecological diversity, ranging from tropical to temperate conditions. Altitude ranges from -126 masl (Danakil Depression) to 4620 masl in the Ras Dashen Mountains. Agro-ecological zones (AEZ) were determined with a crop suitability approach considering temperature, precipitation, soil characteristics and topography differences. The major crop growing areas are in sub-humid, humid, and moist semi-arid climatic zones (Figure 5.1). About 51% of the country is in arid, semi-arid and sub-moist zones (Fantaye 2016).

This chapter is focused on seven AEZ with the mid-highland AEZ sub-divided by altitude (Table 5.1) and lowland AEZ sub-divided by altitude or latitude. These AEZ cover most of the cropland of Ethiopia. The selected AEZ have an altitude ranging from 500 to > 3000 masl. Rainfall modality changes from near bimodal in the south to increasingly unimodal at higher latitudes. For example, 39 and 35% of annual rainfall occurs during March to May and September to November, respectively, at Konzo in southern Ethiopia. At Axum in northern Ethiopia, 83% of the rainfall occurs in July and August.

Table 5.1. Agro-ecological zones targeted for fertilizer use optimization in Ethiopia

Agro-ecological Zones	Altitude (masl)
Tepid to cold moist mid highland	1700 – 2200
Tepid to cold moist mid highland	>2000
Tepid to cold humid mid highland	1700 – 2200
Tepid to cold humid mid highland	>2000
Tepid to cold sub moist mid highland	1700 – 2200
Tepid to cold sub moist mid highland	>2000
Tepid to cold sub humid mid highland	1700 – 2200
Tepid to cold sub humid mid highland	>2000
Cold to very cold sub-afro Alpine	>2500
Hot to warm lowland, north of 9° latitude	
Hot to warm lowland, south of 9° latitude	
Hot to warm sub-moist and dry lowlands	<1000
Hot to warm sub-moist and drier lowlands	>1000

5.2 Soil fertility management

Ethiopia's diverse surface landforms and AEZ are associated with much diversity of indigenous knowledge and practices. Farmers in Ethiopia can characterize their local soil types and recognize differences in land used and crop suitability. Farmers distinguish soil fertility in terms of capacity of soils for long-term productivity, permeability, water holding capacity, drainage, tillage, manure requirement, cultivability, as well as crop productivity.

Farmers are aware and concerned of soil erosion and indigenous soil erosion control practices include traditional ditches locally called 'feses', waterways 'boi', stone terraces 'yedengay erken', cutoff drains 'tekebkeb', vegetative barriers 'geta' and contour ploughing 'shurube' and 'shaga'.

Many are aware that fertilizer use alone is not a solution to soil productivity problems. Traditionally, Ethiopian farmers used manure, crop rotation, mixed cropping, relay cropping and fallows for soil fertility maintenance.

Unfortunately, not all traditional practices are favourable to sustainable soil productivity. Erosion is a major cause of land degradation. The practice of transhumance is common with movement of livestock to semi-arid and arid grazing areas during the growing season but their return to crop production areas after harvest. Farmers have no control on cattle grazing of crop residues, thus leaving soil denuded with little organic material return and pulverized to dust by livestock traffic. As a result, soil physical properties are degraded and multiple tillage operations are conducted to overcome soil crusting as well as for weed control. The combined effect of destruction of soil aggregation, bare soil, soil crusting and tillage contribute to rainfall runoff and erosion.

Fertilizer use has increased from 250,000 t/yr in 1995 to 850,000 t/yr in 2014 according to unpublished estimates by the Ministry of Agriculture and Rural Development. Many smallholders have financial constraints to fertilizer use and are concerned about risk of lack of fertilizer response and/or difficulty in repaying loans. Between 30 and 40% of smallholders use some fertilizer, mostly for teff, wheat and maize production. Cereal production may account for 90% of fertilizer use with most of the remaining applied to pulse, oil seed crops and non-grain crops. Teff, wheat, maize, barley and sorghum production accounted for 40, 26, 17, 9 and 3% of fertilizer use. The main fertilizers used have been urea and diammonium phosphate (DAP).

Wheat and legumes often respond to applied sulphur (S) in the high potential Central Highlands where market-oriented crop production is associated with removal of crop residues, much tillage and little manure application leaving soil organic matter to be mostly very stable with little organic S mineralization.

Total cereal production has grown at 6% per year and production per capita at 3%, but yields per hectare have grown by just 0.5% per year. Fertilizer use has an additive effect and possibly a synergistic effect as well with other inputs (Dercon and Hill 2009). A poorly managed crop is not likely to be very responsive to applied nutrients. More than a threefold increase in fertilizer use in recent decades has not resulted in a significant increase in productivity.

Fertilizer is a costly input and its efficient use is important for profitability and minimizing nutrient loss to the environment and soil acidification due to excess N application. Key to efficient fertilizer use is to practise the 4Rs of nutrient stewardship, that is, to apply the right product, the right rate, at the right time and using the right method. The 4Rs are especially applicable to N which is subjected to loss through various pathways.

Most N application to non-legumes should be prior to or during the period of rapid crop growth when rate of N uptake is high, such as at 6- to 8-leaf stage of maize. For example, with maize, at least 50% of fertilizer N should be applied 4 to 7 weeks after planting; when the recommended rate of N is low, it is advisable to apply all of N at 4 weeks after planting. Aspects of the 4Rs are further addressed in section 5.3.

It is also important to have a healthy and well managed crop in order to achieve a good response to fertilizer. Therefore, good agricultural practices should be applied throughout including choice of variety, careful planting and good weed and pest control. Consideration of soil test information and the effects of other practices such as manure application is also important to fine-tune fertilizer use for greater profitability and efficient nutrient use. This topic is further addressed in section 5.5.3.

Recent recommendations and economically optimal rates (EOR) of nutrient application, determined from results of field research, are addressed in section 5.6.

5.3 Diagnosis of nutrient deficiencies in Ethiopia

Eighteen trials were conducted for determination of crop nutrient response functions that are essential for decisions aimed at maximizing profits from fertilizer use. The mean percent increases in grain yield of cereal crops for applied N, phosphorus (P) and potassium (K) were 55, 23 and 0%, respectively. Fertilizer optimization trials included treatments to determine the effect of the diagnostic nutrient

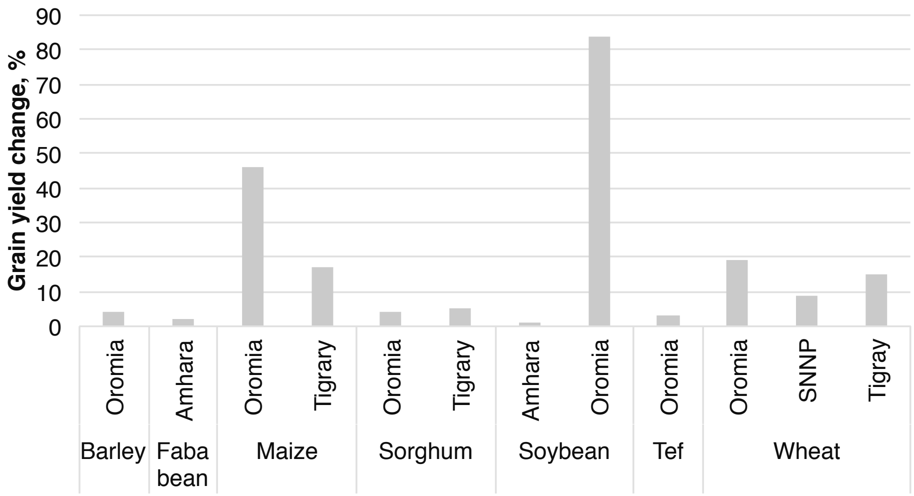

Figure 5.2: Percent yield increase due to a diagnostic treatment with N+P+K+Mg+S+Zn+B compared with N+P+K.

package of N+P+K+Mg+S+Zn+B compared with N+P+K on grain yield, where Mg is Magnesium, Zn is zinc and B is boron. A similar comparison was made for legumes with a low rate of applied N and/or with rhizobial inoculation.

The diagnostic treatment increased grain yield compared to N+P+K treatment in all crop-region combinations but the yield increase was less than the standard error of the means for most cases except for maize in Tigray and for maize, soybean and wheat in Oromia (Figure 5.2). However, the yield increases due to the diagnostic treatment prevailed with on-station trials and the mean effect was not statistically different from zero for on-farm trials (Figure 5.3). This contrast was unexpected and may be due to years of heavy fertilizer N and P use with high yields and depletion of one or many of the diagnostic nutrients on-station compared with for the farmers' fields.

Fertilizer N and P are of high priority compared with other nutrients. Crop response results do not indicate any reason for immediate concern generally with K, Mg, S, Zn, and B deficiencies. However, increased yield levels can deplete those nutrients in soil and yield responses to these nutrients may eventually occur as witnessed in some fields at research centres.

Results do indicate the great importance of verifying or fine-tuning interpretation of soil test results with crop responses. Globally, including for high yield situations, soil test results generally have not been highly predictive of crop response to applied S and micro-nutrients, although prediction of response to Zn is relatively better. Prediction of crop response to fertilizer is expected to be even weaker when crops

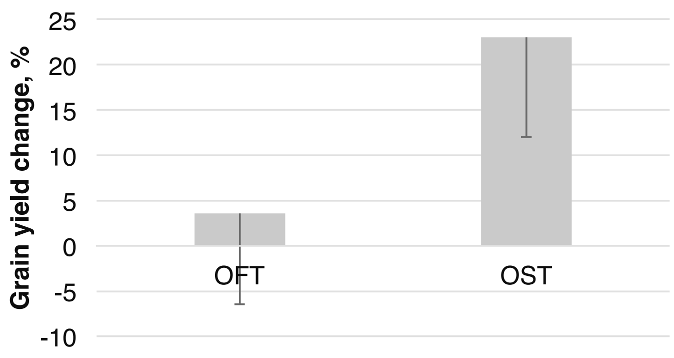

Figure 5.3: Percent yield increase due to a diagnostic treatment with N+P+K+Mg+S+Zn+B compared with N+P+K averaged over 20 on-farm (OFT) and on-station (OST) trials.

encounter any abiotic and biotic constraints in addition to nutrient deficiencies. For example, when soil water deficit is the most restricting constraint of yield in a given year, crop response to nutrients is likely to be small. Soil test results are used to determine if availability levels are enough to avoid future occasional yield losses, a useful strategy when finance for inputs is inadequate and risk of no net returns in the short term is a major concern. Where responses to the diagnostic package occurred, additional diagnostic information is needed to verify these responses and to determine which nutrient deficiencies were more important than others for crop response.

5.4 Optimizing fertilizer use in Ethiopia

Optimization of fertilizer use, in this chapter, refers to maximizing farmer profit resulting from fertilizer use, while not greatly adding to farmer risk. This implies maximizing profit per hectare for farmers with adequate finance and net returns on small investments in fertilizer use made by financially constrained farmers.

Estimation of profit from fertilizer use requires generating AEZ-specific robust nutrient response functions for important annual food crops from field research results. Crop response to an applied nutrient can be highly varied across site-years but when results of numerous trials are considered, the expected mean response is curvilinear to plateau. Such a response can be mathematically represented using asymptotic functions taking the form of an exponential rise to a maximum or plateau yield. The asymptotic function used for the Optimizing Fertilizer Recommendations in Africa (OFRA) research was $Y = a - bc^r$, where Y was yield (t/ha), coefficient a was the maximum or plateau yield (t/ha), coefficient b was the gain in yield (t/ha) due to nutrient application, and c^r represented the shape of the response curve, where c was a curvature coefficient and r the nutrient application rate (kg/ha).

Crop responses to applied N illustrate the curvilinear to plateau response in Figure 5.4. The curves differ in magnitude of response and shape of the curve. Maize and teff N curves are especially informative where there is a large yield increase per unit of applied N at low application rates. The curve becomes less steep as N rate

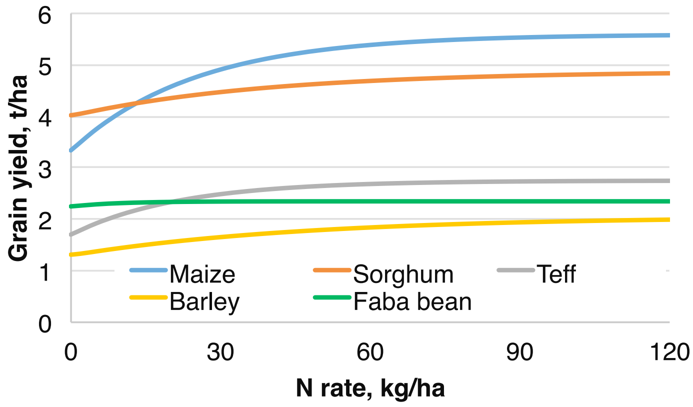

Figure 5.4: Curvilinear to plateau nature of crop response to applied N for the tepid to cold humid mid-highlands, 1700 - 2200 masl.

increases and rates > 80 kg/ha result in very little added yield. Response curves for sorghum and barley N are only slightly curvilinear without much slope suggesting relatively little N response compared with maize. The response of faba bean to applied N is curvilinear to plateau with the plateau reached at a low N rate, although magnitude of response is small. Response curves have economic implications. Farmers with adequate finance and risk security need to know the rate at which the value of yield gained justifies the cost of additional N in order to apply fertilizer at EOR. Financially constrained farmers need to apply fertilizer at less than EOR at a relatively steep part of the curve to maximize yield gain for a constrained investment.

Another economic consideration that is very important to financially constrained farmers is that the profit potential of applying a nutrient to a crop differs from the potential of applying the same nutrient to another crop and of other crop-nutrient combinations (Figure 5.5). In Figure 5.5, the x-axis gives the cost of a nutrient applied to a single crop (EtB/ha). The y-axis gives net returns to an investment in nutrient application. Each curve represents a different crop-nutrient combination.

The results show that the curve for N applied to teff is steep at low N rates and therefore has more profit potential per small investment than with other crop-nutrient options. At about EtB 750 worth of N applied to teff, P applied to teff at low rates has similar profit potential as indicated by a similar slope. Following teff, maize has a good profit potential to applied N. Lower in the chart are less profitable options. Some crop-nutrient options, such as K applied to crops other than maize, are not shown due to lack of profit potential. The financially constrained farmers need first to take advantage of the crop-nutrient-rate options with the highest profit potential if the crop is a part of cropping systems, and then go on to take advantage of some less profitable options in order to maximize profit from a constrained investment. Farmers with adequate finance

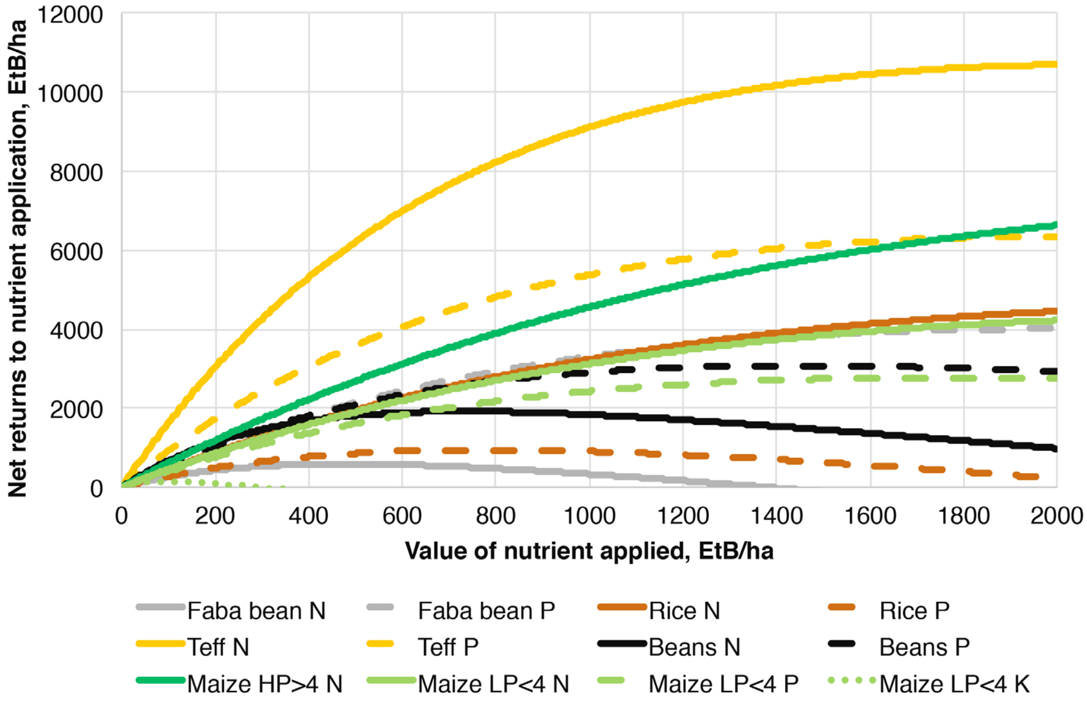

Figure 5.5: Net returns to investment in single nutrients applied to a crop for the tepid to cold moist mid-highlands, 1700-2200 masl.

need to maximize profit per hectare over all cropland and therefore need to apply fertilizer at a rate associated with the peak of the response curves. Note that the peak of net returns is not captured in the figure (Figure 5.5) for some curves, including for N applied to high potential maize, as the maximum investment on the x-axis is too low for the peaks to be reached.

5.5 Fertilizer use optimization tools

The decision on choices of crops, fertilizers to apply and the amount of each nutrient to apply requires consideration of several factors. Agronomy of nutrient responses for different crops that the farmer plants must be considered together with the farmer's land allocation to each crop, the expected commodity values, the costs of fertilizer use and the money available for fertilizer use. Soil test information and other practices that may affect the need for applied nutrients must be considered as well. With all these considerations, fertilizer optimization tools (FOTs) and a fertilizer rate adjustment tool were developed to help farmers decide on nutrient management for maximization of profit.

5.5.1 The Excel Solver FOT

Excel Solver © (Frontline Systems Inc., Incline Village, NV, USA) fertilizer optimization tools (FOTs) were developed for each of the 13 recommendation domains. The FOTs use complex mathematics of linear optimization but are easy to use.

The farmer needs to estimate how much land will be planted to each crop of interest, estimate the farm gate value per kg at harvest time considering that some is for home consumption (the most valuable) and the surplus will be marketed, and the costs of using different fertilizers (Figure 5.6). The amount of money which the farmer will invest in fertilizer use is also entered. In this example, the farmer allocates crops to four hectares and has EtB 6000 available for fertilizer use. Clicking on the 'Optimize' button then runs the optimization calculations.

The results are displayed as in Figure 5.7, including the amount of each fertilizer to apply to each crop, the expected average yield increases and net returns, and the total net returns to fertilizer use for the farm. Each of the selected crops has a recommendation for some fertilizer allocation. However, only 21 kg/ha of DAP is recommended for barley, which may be too little for feasible application and the farmer may want to allocate the fertilizer or the money elsewhere. A total of 241 kg/ha of DAP and 136 kg/ha of urea were recommended. No K application was recommended with this financial constraint. Net returns per hectare were highest for high potential maize, teff and faba bean, suggesting that the farmer may want to allocate more land to these crops, especially to faba bean, which achieves higher returns with relatively little fertilizer recommended. Expected average net return for this scenario is EtB 44,324 and a benefit to cost ratio of greater than 7. It is advisable that the farmer will use some of these net returns to gradually reduce financial constraint to fertilizer use and eventually apply fertilizer at EOR to all cropland.

5.5.2 The paper FOTs

Very often farmers and their advisors do not have access to a computer. Therefore, companion paper FOTs were developed for each recommendation domain (Table 5.2). The paper FOT is devised for three financial levels: 1) for a farmer who has no more money than one-third the amount required to apply fertilizer to all cropland at EOR; 2) for a farmer with more money but no more money than two-thirds the amount required to apply fertilizer to all cropland at EOR; and 3) for a farmer with enough money to apply fertilizer to at least some cropland at EOR.

The paper tool makes assumptions about the:

- calibration measuring units to be used by farmers in adjusting their eyes and feel for applying the right rate of fertilizer
- crop row and plant spacing
- fertilizer use costs per 50-kg bag
- expected grain values at on-farm at harvest, considering value both for home consumption and for market.

The paper FOTs address the 4Rs of nutrient stewardship advising on the right product, rate, time and method of fertilizer application. It also advises on calibration, that is, the length of the band or distance, or the number of points, covered by one measuring unit for the recommended fertilizer rate.

AEZ Tepid to cold humid mid high l
Elevation 1700-2200m

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

Crop Selection and Prices		
Crop	**Area Planted (Ha)***	**Expected Grain Value/kg †**
MaizeHP >5T	1	4
MaizeLP<5T	0.5	4
Sorghum	0.5	5.5
Teff	1	12
Barley	0.5	6
Faba bean	0.5	12
Total hectares	**4**	

Fertilizer Selection and Prices				
Fertilizer Product	**N**	**P2O5**	**K2O**	**Price/50 kg bag ¶***
Urea	46%	0%	0%	700
Triple super phosphate, TSP	0%	46%	0%	0
Diammonium phosphate, DAP	18%	46%	0%	850
Murate of potash, KCL	0%	0%	60%	800
xxx	%	%	%	0

Budget Constraint	
Amount available to invest in fertilizer	6000

Figure 5.6: Input screen of the fertilizer optimization tool of the tepid to cold mid-highlands, 1700 to 2000 masl.

Fertilizer Optimization					
	Application Rate - kg/Ha				
Crop	**Urea**	**TSP**	**DAP**	**KCL**	**xxx**
MaizeHP >5T	48	0	68	0	0
MaizeLP<5T	51	0	61	0	0
Sorghum	0	0	64	0	0
Teff	63	0	62	0	0
Barley	0	0	21	0	0
Faba bean	0	0	76	0	0
Total fertilizer needed	**136**	**0**	**241**	**0**	**0**

Expected Average Effects per Ha		
Crop	**Yield Increases**	**Net Returns**
MaizeHP >5T	4,274	15,275
MaizeLP<5T	2,491	8,209
Sorghum	1,574	7,578
Teff	1,264	13,229
Barley	216	934
Faba bean	1,350	14,919

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer	44,324

Figure 5.7: The output results corresponding to the input data of Figure 5.6.

Table 5.2: Paper FOT for tepid to cold humid mid highland elevation 2000- 2700 masl

Assumptions:

Measurement is with a: 500ml Highland water bottle CAP that holds 6.7 ml, 4.7 g urea, and 7.4 g DAP, TSP, and KCl; 500ml Highland water (2-cm bottle) to hold 47 ml, 33 g urea and 52 g DAP, TSP, or KCl.

Row spacing: 75 cm for maize; 20 cm for wheat and barley; 40 cm for faba bean; and teff is broadcast.

Grain prices per kg (Et Birr): 4 maize; 6 Barley; 12 Faba bean; and 8 Wheat.

Cost 50 kg of fertilize costs (Et Birr): 700 urea; 750 TSP; 850 DAP and 1500 KCl.

Fertilizer rate > 25 kg/ha. Broadcast width 2m

Level 1 financial ability.	
Maize HP	point apply 51.1 kg/ha DAP (1.9 plants per CAP)
Maize LP	point apply 41 kg/ha urea after 3 weeks of planting (1.9 plants per CAP)
Wheat HP	56.8 kg DAP broadcast at planting (4.5 m per 2-cm bottle) and top-dress 34.3 kg/ha urea (4.5 m per 2-cm bottle)
Wheat LP	no input
Barley	no input
Faba bean	38.1 kg/ha DAP band apply at planting (4.8 m per CAP)
Level 2 financial ability.	
Maize HP	point apply 71 kg/ha DAP (1.3 plants per CAP) and 53 kg/ha urea topdress (1.1 plants per CAP)
Maize LP	point apply 81 kg/ha urea (0.7 plants per CAP) after 3 weeks of planting
Wheat HP	broadcast 81.7 kg/ha DAP at planting (3.2 m per 2-cm bottle) and top-dress 50 kg/ha urea (3.1 m per 2-cm bottle)
Wheat LP	broadcast 53 kg/ha DAP at planting 4 m per 2-cm bottle and topdress 51 kg/ha urea (3.1 m per 2-cm bottle)
Barley	broadcast 27.2 kg/ha DAP at planting (11.4 m per 2-cm bottle)
Faba bean	band apply 71.5 kg/ha DAP (2.6 m per CAP) at planting
Level 3 financial ability (maximize profit per acre).	
Maize HP	point apply 83 kg/ha DAP (1 plant per CAP) at planting and topdress 73 kg/ha urea (0.8 plants per CAP) after 3 weeks of planting
Maize LP	point apply 86 kg/ha DAP (1 plant per CAP) at planting and topdress 71 kg/ha urea (0.8 plants per CAP) after 3 weeks of planting
Wheat HP	broadcast 97.4 kg DAP (2.7 m per 2-cm bottle) at planting and top-dress 59.3kg/ha urea (2.6 m per 2-cm bottle)
Wheat LP	broadcast 83.5 kg/ha DAP 3 m per 2-cm bottle at planting and topdress 80.5 kg/ha urea (2 m per 2-cm bottle)
Barley	48.6 kg/ha DAP broadcast at planting (6 m per 2-cm bottle)
Faba bean	93.8 kg/ha DAP band apply at planting (2.0 m per CAP)

The paper FOT is easy to use and it is expected that many farmers will learn to use it on their own. For example, one level 1 financial ability recommendation is 'Teff: broadcast 30 kg DAP (12.7 m per 2-cm bottle) at planting and topdress 42 kg/ha urea (7.3 m per 2-cm bottle)'. Therefore, 30 kg/ha DAP is to be applied at planting by broadcasting in 2-m wide passes. The farmer 'calibrates' his or her eye and feel using the 500 ml Highland brand water bottle cut to 2-cm height, which is enough for 12.7 m distance. Urea is topdress applied by broadcasting at 42 kg/ha; one 2-cm bottle is enough for 7.3 m with an application width of 2 m.

5.5.3 The fertilizer rate adjustment tool

Another aspect of optimizing fertilizer use is to consider soil test values and practices that reduce or increase the need for fertilizer such as timing, amount and quality of any recent manure application. If the previous crop was a legume, or there was a use of a green manure crop, one

Table 5.3: Adjustment of recommended fertilizer rates due to other practices or soil test information

ISFM practice	Urea	TSP/DAP	KCl/KSO_4
	Nutrient reduction, kg/ha or %		
Previous crop was a green manure crop	100%	100%	100%
Fresh vegetative material (e.g. pruning of lantana or tithonia) applied, per 1 t of fresh material	10 kg	4 kg	6 kg
Farmyard manure per 1 t of dry material	0 kg	4 kg	6 kg
Residual value of FYM applied for the previous crop, per 1 t	0 kg	2 kg	2 kg
Dairy or poultry manure, per 1 t dry material	10 kg	6 kg	10 kg
Residual value of dairy & poultry manure applied for the previous crop, per 1 t	4 kg	4 kg	2 kg
Compost per 1 t dry material applied	6 kg	6 kg	10 kg
Residual value of compost applied for the previous crop, per 1 t	6 kg	4 kg	2 kg
Rotation	0% reduction but more yield expected		
Cereal-bean intercropping	Increase DAP/TSP by 8 kg/ha, but no change in N and K compared with sole cereal fertilizer		
Cereal-other legume (effective in N fixation) intercropping	Increase DAP/TSP by 12 kg/ha, reduce urea by 20 kg/ha, and no change in K compared with sole cereal fertilizer		
If Mehlich III P >15 ppm	Apply no P		
If soil test K <100 ppm	Band apply 40 kg/ha K_2SO_4		

needs to consider nutrient credit from those practices and adjust nutrient application (Table 5.3). Soil test information may also provide helpful information to recommend optimal application rate.

Typically, these adjustment practices may not apply to all cropland of a farmer but only to one or a few, if any, parcels of land. There may be opportunities to reduce fertilizer application for some land parcels and to reallocate that fertilizer or money elsewhere (Table 5.3). For example, for each ton of farmyard manure applied, P_2O_5 and K_2O rates can be reduced by 2 and 3 kg/ha, respectively. With cereal-bean intercropping, however, fertilizer P rate should be increased. Soil test P is commonly low for smallholder fields and fertilizer P should be applied according to the FOT unless soil test P value is above 15 ppm by Mehlich III. Fertilizer K should be applied as recommended by the FOT unless the soil test K is less than 100 ppm when 40 kg/ha potassium sulphate should be applied, even if not recommended by the FOT.

5.6 Targeted crops by AEZ

Nutrient response functions of major crops were determined for the 13 recommendation domains (Table 5.4a-g) using results from past research and OFRA supported trials. The crops were maize, wheat, teff, sorghum, barley, rice, finger millet, Irish potato, bean, soybean and faba bean. Considering mostly unique characteristics of Ethiopian production conditions compared with agricultural areas elsewhere in Africa, few research results were considered from outside of Ethiopia.

Available results relevant to each AEZ were compiled and analyzed and used with other information, such as current recommendations (REC), in determining representative crop nutrient functions. In Table 5.4, crops targeted for an AEZ are listed in column 1 with AEZ differentiation by altitude or latitude (column 2). The nutrient and coefficients a, b, c of crop nutrient response functions are presented in columns 3-6. Expected average yield increases with increments of applied nutrient are in columns 7-10, followed by the EOR and recommended rate of nutrient application in columns 11-12.

All cereals, Irish potato and faba bean had economical responses to N in all AEZ where these were targeted (Table 5.4 a-g). Bean had

Table 5.4a: Tepid to cold moist mid-highland, differentiated by altitude. 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 recommendations (REC) in Ethiopia. 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

	Altitude range (masl)	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crops		**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
				t/ha			**t/ha**			**kg/ha**	
Faba bean	<2200	N	2.300	0.117	0.890	0.113	0.003	0.000	0.000	14	18
Rice	<2200	N	3.363	1.112	0.975	0.592	0.277	0.130	0.061	98	69
Teff	<2200	N	2.735	1.235	0.948	0.986	0.199	0.040	0.008	61	69
Bean	<2200	N	2.100	0.230	0.890	0.223	0.007	0.000	0.000	20	18
Maize	<2200	N	5.443	2.945	0.980	1.339	0.730	0.398	0.217	102	69
Sorghum	<2200	N	3.176	0.744	0.989	0.210	0.151	0.108	0.078	36	18
Barley	>2000	N	1.811	0.546	0.975	0.291	0.136	0.064	0.030	40	41
Faba bean	>2000	N	2.400	0.100	0.963	0.068	0.022	0.007	0.002	11	18
Wheat HP>3t	>2000	N	3.777	1.279	0.974	0.699	0.317	0.144	0.065	83	69
Wheat LP<3t	>2000	N	2.497	1.229	0.978	0.598	0.307	0.157	0.081	89	69
Irish potato	>2000	N	23.175	13.646	0.980	6.203	3.383	1.846	1.007	184	92
						0-5	**5-10**	**10-15**	**15-20**		
Faba bean	<2200	P	2.23	0.594	0.920	0.203	0.133	0.088	0.058	28	20
Rice	<2200	P	2.743	0.285	0.850	0.159	0.070	0.031	0.014	15	20
Teff	<2200	P	1.006	0.840	0.900	0.344	0.203	0.120	0.071	28	20
Bean	<2200	P	2.510	0.405	0.885	0.185	0.101	0.055	0.030	19	20
Maize	<2200	P	4.498	1.117	0.918	0.389	0.253	0.165	0.108	30	20
Faba bean	>2000	P	2.387	0.751	0.825	0.464	0.177	0.068	0.026	18	20
Barley	>2000	P	3.194	0.945	0.880	0.446	0.236	0.124	0.066	20	20
Wheat HP>3t	>2000	P	4.023	1.458	0.812	0.943	0.333	0.118	0.041	18	20
Wheat LP<3t	>2000	P	2.320	0.683	0.940	0.182	0.133	0.098	0.072	29	20
Irish potato	>2000	P	21.486	2.745	0.825	1.696	0.648	0.248	0.095	21	20

†The following grain values and fertilizer costs were used to calculate EOR values. Grain values used were (EtB/kg): bean, 12; faba bean, 12; tef, 12; wheat, 8; barley, 6; sorghum, 5.5; maize, 4; finger millet, 10; soybean, 9; Irish potato, 6. Fertilizer use costs for 50 kg were (EtB/kg): 700 for urea; 850 for DAP; and 1500 for KCl.

a profitable response to N only in the tepid to cold moist mid-highland <2200 masl and soybean did not have a response to N. All targeted crops had an economic response to P except sorghum in the tepid to cold moist and sub-moist mid-highlands <2200 masl. The only economical responses to applied K were determined for hot to warm moist lowlands for maize and teff.

The EOR for N averaged over all crops in all AEZ was 63 kg/ha compared with 51 kg/ha for the average of the RECs with a standard error (SE) of 3.3 (Table 5.4a-g). High EOR of N determined for Irish potato compared with REC N contributed much to difference and SE. The EOR for P averaged over all crops in all AEZ was 18 kg/ha compared with 20 kg/ha for average of recommended rates with a SE of difference of 2.1. The REC P rate was 20 kg/ha in most cases while the EOR P determined from the results of field research was much more variable.

Table 5.4b: Tepid to cold humid mid-highland, differentiated by altitude

Crops	Altitude range (masl)	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
		Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC
				t/ha			t/ha			kg/ha	
Maize	>1700	N	5.596	2.256	0.961	1.572	0.477	0.144	0.044	61	69
Sorghum	<2200	N	4.880	0.870	0.975	0.463	0.217	0.101	0.047	53	41
Teff	<2200	N	2.753	1.049	0.955	0.785	0.197	0.050	0.012	63	69
Barley	>1700	N	2.053	0.753	0.979	0.355	0.188	0.099	0.053	52	41
Faba bean	>1700	N	2.350	0.100	0.900	0.096	0.004	0.000	0.000	20	18
Wheat HP>3T	>2000	N	4.009	1.698	0.940	1.433	0.224	0.035	0.005	54	41
Wheat LP<3T	>2000	N	2.238	0.947	0.977	0.476	0.237	0.118	0.059	57	41
						0-5	**5-10**	**10-15**	**15-20**		
Maize HP>5t	>1700	P	6.928	2.832	0.833	1.696	0.680	0.273	0.109	20	30
Maize LP<5t	>1700	P	3.521	1.515	0.940	0.403	0.296	0.217	0.159	30	20
Sorghum	<2200	P	4.645	1.550	0.850	0.862	0.383	0.170	0.075	17	10
Teff	<2200	P	1.401	0.514	0.898	0.214	0.125	0.073	0.043	19	20
Barley	>1700	P	2.687	0.438	0.901	0.178	0.106	0.063	0.037	15	10
Faba bean	>1700	P	2.753	1.392	0.850	0.774	0.344	0.152	0.068	21	20
Wheat HP>3T	>2000	P	4.154	1.415	0.867	0.722	0.354	0.173	0.085	23	20
Wheat LP<3T	>2000	P	2.313	0.576	0.930	0.175	0.122	0.085	0.059	24	20
Wheat	>2000	K	2.369	0.056	0.899	0.023	0.014	0.008	0.005	0	0

5.7 Conclusion

Nutrient management is very critical to maximize crop yield and to sustain soil productivity. Poor farmers need to achieve high net returns on their investment with little risk while wealthier farmers may strive to maximize profit per hectare. Profit potential from fertilizer use varies greatly with crop-nutrient choices. The profit potential is generally much greater with application of N and P compared with K and the secondary and micro nutrients. Consistent with findings elsewhere worldwide, farmers need adequate access to single nutrient and di-nutrient compound fertilizers to maximize profit. Evidence-based FOTs were developed for optimization of fertilizer use by Ethiopian farmers of any economic class. The EOR determined from the results of field research often differed from RECs.

5.8 References

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Table 5.4c: Tepid to cold sub-humid mid-highland, differentiated by altitude

	Altitude range (masl)	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crops		Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC
				t/ha			t/ha			kg/ha	
Sorghum	<2200	N	4.770	0.611	0.973	0.342	0.151	0.066	0.029	41	41
Teff HP>2t	<2200	N	2.877	1.220	0.955	0.913	0.230	0.058	0.014	66	69
Teff LP<2t	<2200	N	1.015	0.458	0.963	0.310	0.100	0.032	0.010	49	41
Maize HP>5t	<2200	N	6.306	3.025	0.975	1.610	0.753	0.352	0.165	88	87
Maize LP<5t	<2200	N	4.082	1.400	0.971	0.821	0.340	0.140	0.058	55	64
Barley	>2000	N	1.811	0.546	0.975	0.291	0.136	0.064	0.030	40	32
Wheat HP>3t	>2000	N	3.777	1.279	0.974	0.699	0.317	0.144	0.065	83	87
Wheat LP<3t	>2000	N	2.350	1.229	0.978	0.598	0.307	0.157	0.081	89	64
Faba bean	>2000	N	2.400	0.100	0.963	0.068	0.022	0.007	0.002	11	18
Irish potato	>2000	N	23.176	13.646	0.980	6.203	3.383	1.846	1.007	184	110
						0-5	**5-10**	**10-15**	**15-20**		
Sorghum	<2200	P	4.766	1.166	0.882	0.544	0.290	0.155	0.083	20	20
Teff	<2200	P	1.401	0.514	0.898	0.214	0.125	0.073	0.043	20	20
Maize HP>5t	<2200	P	6.865	2.761	0.819	1.744	0.642	0.237	0.087	17	20
Maize LP<5t	<2200	P	4.195	1.219	0.94	0.324	0.238	0.175	0.128	23	20
Barley	>2000	P	3.194	0.945	0.880	0.446	0.236	0.124	0.066	18	10
Wheat HP>3t	>2000	P	4.023	1.458	0.812	0.943	0.333	0.118	0.041	17	20
Wheat LP<3t	>2000	P	2.320	0.683	0.940	0.182	0.133	0.098	0.072	24	20
Faba bean	>2000	P	2.387	0.751	0.825	0.464	0.177	0.068	0.026	16	20
Irish potato	>2000	P	21.486	2.745	0.825	1.696	0.648	0.248	0.095	19	20

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Table 5.4d: Tepid to cold sub-moist mid-highland, differentiated by altitude

	Altitude range (masl)	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crops		**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
				t/ha			**t/ha**			**kg/ha**	
Bean	<2200	N	2.000	0.015	0.930	0.013	0.002	0.000	0.000	0	0
Faba bean	<2200	N	2.148	0.376	0.966	0.243	0.086	0.030	0.011	46	18
Maize	<2200	N	3.385	1.601	0.973	0.897	0.394	0.174	0.076	64	64
Teff	<2200	N	1.602	0.989	0.988	0.300	0.209	0.146	0.101	107	64
Sorghum	<2200	N	3.107	0.654	0.966	0.422	0.150	0.053	0.019	41	41
Barley	>2000	N	1.811	0.546	0.975	0.291	0.136	0.064	0.030	40	64
Wheat HP>3t	>2000	N	3.777	1.279	0.974	0.699	0.317	0.144	0.065	83	64
Wheat LP<3t	>2000	N	2.350	1.229	0.978	0.598	0.307	0.157	0.081	89	64
Faba bean	>2000	N	2.400	0.100	0.963	0.068	0.022	0.007	0.002	11	18
Irish potato	>2000	N	23.176	13.646	0.980	6.203	3.383	1.846	1.007	184	110
						0-5	**5-10**	**10-15**	**15-20**		
Bean	<2200	P	2.509	0.404	0.88	0.191	0.101	0.053	0.028	17	0
Faba bean	<2200	P	2.238	0.902	0.922	0.301	0.201	0.134	0.089	30	20
Maize	<2200	P	4.498	1.117	0.918	0.389	0.253	0.165	0.108	19	20
Teff	<2200	P	1.148	0.212	0.955	0.044	0.035	0.028	0.022	10	20
Sorghum	<2200	P	2.664	0.232	0.97	0.033	0.028	0.024	0.021	0	20
Barley	>2000	P	3.194	0.945	0.880	0.446	0.236	0.124	0.066	18	20
Wheat HP>3t	>2000	P	4.023	1.458	0.812	0.943	0.333	0.118	0.041	17	20
Wheat LP<3t	>2000	P	2.320	0.683	0.940	0.182	0.133	0.098	0.072	24	20
Faba bean	>2000	P	2.387	0.751	0.825	0.464	0.177	0.068	0.026	16	20
Irish potato	>2000	P	21.486	2.745	0.825	1.696	0.648	0.248	0.095	19	20
Maize	<2200	K	3.659	0.120	0.800	0.081	0.026	0.009	0.003	0	0

Table 5.4e: Hot to warm moist lowlands, differentiated by latitude

	Altitude range (masl)	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crops		**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
				t/ha			**t/ha**			**kg/ha**	
Maize <9ºN	N	3.462	1.782	0.978	0.868	0.445	0.228	0.117	71	32	
Maize >9ºN	N	2.600	0.384	0.955	0.288	0.072	0.018	0.005	74	32	
Sorghum <9ºN	N	4.400	1.714	0.979	0.807	0.427	0.226	0.120	86	32	
Sorghum >9ºN	N	2.504	0.297	0.920	0.273	0.022	0.002	0.000	89	32	
Rice, lowland paddy	N	3.006	0.787	0.958	0.570	0.157	0.043	0.012	62	64	
Bean	N	2.000	0.015	0.950	0.012	0.003	0.001	0.000	0	0	
Teff	N	1.912	1.013	0.962	0.696	0.218	0.068	0.021	30	64	
					0-5	**5-10**	**10-15**	**15-20**			
Maize <9ºN	P	2.923	0.344	0.95	0.078	0.060	0.047	0.036	7	20	
Maize >9ºN	P	2.800	0.559	0.897	0.234	0.136	0.079	0.046	4	20	
Sorghum <9ºN	P	4.696	0.913	0.8	0.614	0.201	0.066	0.022	30	20	
Sorghum >9ºN	P	2.419	0.089	0.900	0.036	0.022	0.013	0.008	13	20	
Bean	P	2.497	0.392	0.940	0.104	0.077	0.056	0.041	22	20	
Teff	P	1.564	0.155	0.750	0.118	0.028	0.007	0.002	8	20	
Soybean	P	1.476	0.346	0.880	0.163	0.086	0.046	0.024	13	10	
					0-5	**5-10**	**10-15**	**15-20**			
Maize	K	3.383	0.282	0.85	0.157	0.070	0.031	0.014	12	0	
Teff	K	1.595	0.157	0.700	0.131	0.022	0.004	0.001	9	0	

Table 5.4f: Hot to warm sub-moist and drier lowlands, differentiated by altitude

	Altitude range (masl)	Response coefficients, Yield = $a - bc^r$; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crops		**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
				t/ha			**t/ha**			**kg/ha**	
Rice	>1000	N	4.579	1.822	0.979	0.858	0.454	0.240	0.127	132	110
Sorghum	>1000	N	4.229	0.810	0.957	0.593	0.159	0.042	0.011	42	64
Maize	>1000	N	3.654	1.674	0.985	0.610	0.388	0.246	0.157	80	64
Teff	>1000	N	1.912	1.013	0.962	0.696	0.218	0.068	0.021	71	64
Maize	<1000	N	4.272	2.025	0.963	1.372	0.443	0.143	0.046	61	64
Sorghum	<1000	N	4.159	0.619	0.890	0.600	0.018	0.001	0.000	22	18
Rice	<1000	N	2.779	1.162	0.973	0.651	0.286	0.126	0.055	95	87
Finger millet	<1000	N	1.528	0.282	**0.904**	**0.268**	**0.013**	**0.001**	0.000	22	18
Teff	<1000	N	2.735	1.235	0.948	0.986	0.199	0.040	0.008	61	64
						0-5	**5-10**	**10-15**	**15-20**		
Rice	>1000	P	2.500	0.300	0.700	0.250	0.042	0.007	0.001	8	20
Sorghum	><1000	P	4.037	0.715	0.830	0.433	0.171	0.067	0.026	12	20
Maize	>1000	P	3.892	0.711	0.700	0.592	0.099	0.017	0.003	7	20
Teff	>1000	P	0.916	0.044	0.800	0.030	0.010	0.003	0.001	2	20
Maize	<1000	P	3.803	1.267	0.910	0.476	0.297	0.185	0.116	20	20
Rice	<1000	P	3.790	0.556	**0.947**	**0.133**	**0.101**	**0.077**	0.059	31	20
Finger millet	<1000	P	1.559	0.325	0.937	0.090	0.065	0.047	0.034	16	20
Soybean	<1000	P	1.827	0.352	0.750	0.268	0.064	0.015	0.004	9	20
Teff	<1000	P	1.118	0.250	0.795	0.171	0.054	0.017	0.005	10	20

Table 5.4g: Cold to very cold sub-Afro alpine.

	Altitude range (masl)	Response coefficients, Yield = $a - bc^r$; r = elemental nutrient rate				Elemental nutrient rate change, kg/ha				Recommended nutrient rate	
Crops		**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC**
				t/ha			**t/ha**			**kg/ha**	
Barley	N	2.179	0.625	0.982	0.263	0.152	0.088	0.051	44	73	
Faba bean	N	2.550	0.060	0.940	0.051	0.008	0.001	0.000	16	18	
Wheat	N	3.284	1.303	0.964	0.869	0.289	0.096	0.032	69	73	
					0-5	**5-10**	**10-15**	**15-20**			
Barley	P	3.525	0.881	0.871	0.439	0.220	0.110	0.055	18	30	
Faba bean	P	3.040	1.434	0.847	0.809	0.353	0.154	0.067	22	20	
Wheat	P	4.656	1.468	0.837	0.865	0.355	0.146	0.060	20	30	