9. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Malawi

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9.1 Agricultural systems of Malawi

9.1.1 Agro-ecological zones (AEZ)

There are four AEZ in Malawi based on altitude: the highlands; the mid-elevation and upland plateau; lakeshore, middle and upper Shire Valley; and the lower Shire Valley (Figure 9.1). The sub-humid tropical agro-ecosystems of Malawi are characterised by a long dry season, with a unimodal rainfall pattern between November and April (Table 9.1) (MoAFS 2012).

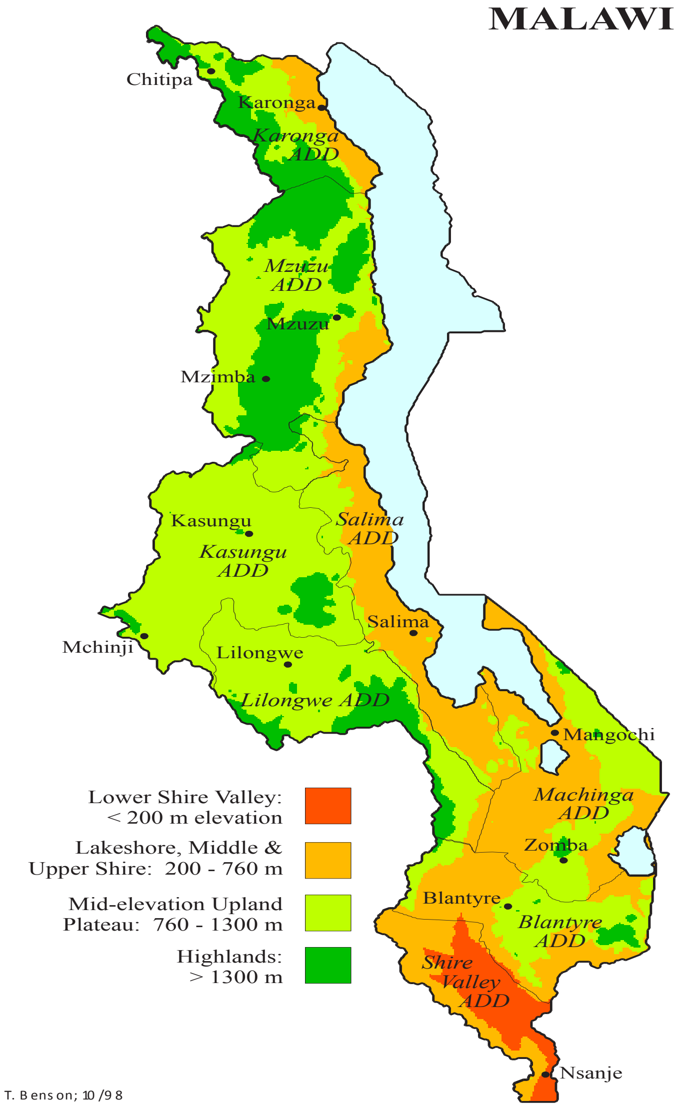

Figure 9.1: Agro-ecological zones of Malawi.

The highlands AEZ, lying between 1320 and 3000 m above sea level (masl), consist of isolated mountains with extensive highland plateaus found in Nyika, Viphya and Mulanje, while Dedza and Zomba are more isolated. The climate is sub-humid with 84% of the rainfall occurring during December to March. The minimum and maximum mean temperatures range is 9 to 16 and 19 to 25°C, respectively (Table 9.1). The predominant soils are the leached Latosols, Alfisols and Utilsols. The major crops include maize, pigeonpea, tea, coffee, bananas, pineapples, cassava, potatoes and many more.

The mid-elevation and upland plateau AEZ lies between 760 and 1300 masl. This zone consists of escarpments and plateaus running from Karonga in the north to Nsanje in the south. The plateaus have a flat to rolling topography with scattered rock inselbergs. The climate is semi-arid with monthly rainfall range of 1 to 221 mm; and minimum and maximum mean temperatures range of 8 to 17 and 24 to 30°C, respectively (Table 9.1). The escarpment soils are predominantly shallow latosols. Soils higher in the plateau catenas are deep well drained latosols while poorly drained sand and clay soils dominate in the valleys, locally called dambos. Other important soil groups include Ferrasols, Luvisols, Lixisols, Lithic and Leptosols. The major crops include maize, tobacco, cassava, rice and pulses.

The lakeshore, middle and upper Shire Valley AEZ lies between 200 and 760 masl. It is flat to gently undulating, with deep calcimorphic soils in the valleys and the shorelands of Lake Malawi. The Upper Shire River flows through a broad flat valley from the south of Lake Malawi. Mopanosols are found in some areas of the Shire River Valley. The climate is semi-arid. Monthly rainfall ranges from 0 to 339 mm and mean monthly minimum and maximum

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Table 9.1: Mean monthly rainfall (mm) and maximum and minimum temperature (°C; Tmax; Tmin) for representative locations of AEZs of Malawi

	J	F	M	A	M	J	J	A	S	O	N	D
Highlands (Dedza 1632 m)												
Rainfall	289	234	180	67	11	4	4	1	4	12	74	231
Tmax	23	23	23	23	21	19	19	21	23	25	25	24
Tmin	16	15	15	14	12	10	9	11	13	15	16	16
Mid-elevation, upland plateau (Chitedze-Lilongwe)												
Rainfall	202	221	195	149	47	11	2	1	0	2	11	81
Tmax	27	27	27	27	27	26	24	24	26	28	30	30
Tmin	17	17	17	16	15	11	9	8	9	12	15	17
Lakeshore, middle and upper Shire (Salima)												
Rainfall	339	266	254	93	11	2	0	0	0	6	44	250
Tmax	29	29	30	29	28	26	26	28	31	33	32	30
Tmin	21	21	21	21	18	16	16	17	19	21	22	22
Lower Shire Valley (Makhanga)												
Rainfall	157	127	111	38	15	17	17	7	5	29	61	167
Tmax	33	33	33	31	30	28	28	30	34	36	36	34
Tmin	23	23	22	20	17	14	14	16	19	22	23	23

Source: http://www.malawi.climatemps.com

temperatures range from 16 to 22 and 26 to 33°C, respectively. Important food crops include maize, rice, cassava, sorghum and millet.

The lower Shire Valley AEZ is below 200 masl and extends from Kapachira Falls to Nsanje District. The climate is semi-arid with a monthly mean rainfall range of 5 to 167 mm and minimum and maximum mean monthly temperatures of 14 to 23 and 28 to 36°C, respectively. The soils of the marsh lands are hydromorphic. Medium to coarse textured alluvial and colluvial soils are most common to the east of the Shire River and vertisols are common to the west of Shire River to the escarpment. The common food crops are maize, sorghum, cassava and Irish potato.

9.1.2 Current soil fertility management in Malawi

Soil degradation and inherently low soil fertility contribute to the unsustainable low productivity of existing production systems and threaten long-term food insecurity in sub-Saharan Africa. In Malawi, agriculture is dominated by production of maize, the main staple crop, with 1.2 million hectares of production annually, occupying about 80% of cultivated land. Most production is by smallholder farmers with limited access and use of fertilizer, improved seed and other inputs due to high costs and low financial ability.

Low-cost good agricultural practices (GAP) for enhancing soil nutrient availability have been studied including crop residue management; agro-forestry; maize-legume rotations; area-specific maize fertilizer recommendations to improve nutrient use efficiency; conservation agriculture; climate smart practices; and use of compost. Integration of organic resources and N fixing legumes in rotations with fertilizer use has been well studied. However, adoption of such GAP is low and the perceived profit potential of fertilizer use in maize production is unattractive to many smallholders at current maize price to fertilizer cost ratios relative to other uses of available finance.

Traditional practices affecting soil fertility have variable effects on soil fertility and crop productivity. Shifting cultivation is no longer feasible for soil fertility restoration due to land use pressure. Ridging of the soil for cereal production across the field slope using hand hoes is very common for soil aeration, water conservation and easy root development. There is little incorporation of crop residues in Central and Northern Malawi as the crop residue is harvested by uprooting and used for fuel and livestock feed, or often burnt to ease land preparation. Animal manure is a common nutrient source in the north where cattle density is high compared with other AEZ. In parts of central Malawi, tobacco residues are used to enhance soil fertility. In the Central and Northern Regions, sole crop production prevails with rotation of maize with tobacco, groundnut, bean, soybean, velvet bean and other crops. Some farmers intercrop legumes with other legumes in what is known as 'doubled-up legume technology'.

In the Southern Region, intercropping cereals with legumes is traditional and up to 10 crops can be found in a field. Pigeonpea is often intercropped with maize. Crop residue is incorporated soon after harvesting to recycle nutrients. Relay cropping is practised to take advantage of the residual soil water, especially in the Thyolo Escarpment area. Some farmers in southern Malawi apply manure, homestead wastes and compost.

9.1.3 Fertilizer use and recommendations

Most of the soils in Malawi are highly weathered, low in organic matter (OM) with low pH and low availability of P, K, S, B and Zn; over 40% are Oxisols and Ultisols (Saka et al., 2006).

In early 1970s, 20:20:0 was recommended as a basal dressing followed by top dressing with sulphate of ammonia or calcium ammonium nitrate (CAN). Later, in the 1980s, the government introduced urea and DAP which were cheaper. Later DAP was replaced with 23-21-0+4S as a basal dressing fertilizer followed by top dressing with urea or CAN. However, recently, K is also becoming a more common deficiency, especially on soils that are continuously and intensively cultivated. Much

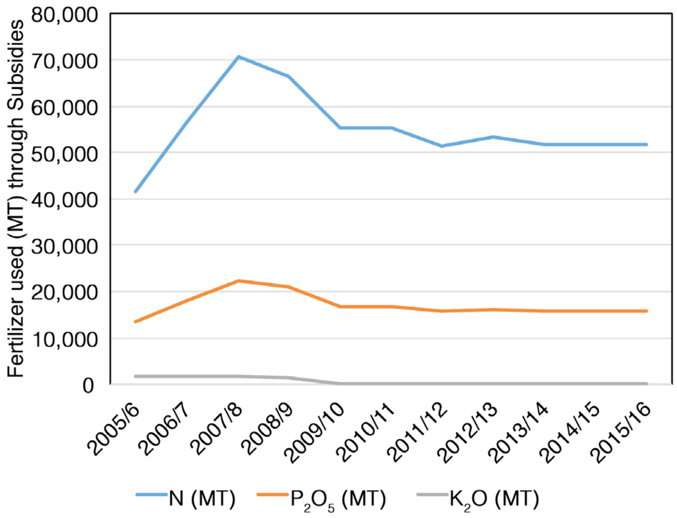

Figure 9.2: Fertilizer use components (NPK) of Fertilizer Input Subsidy Program (FISP) in Malawi from 2005 to 2016 (Source: NSO 2005; Nakhumwa, 2006; MoAFS 2012).

K is removed in crop harvest and soil K has been mined; some recent studies have shown crop yield response to applied K (Chilimba and Liwimbi 2008). Soil S deficiency is nearly as important as N deficiency in many places and 23-21-0+4S has proven appropriate for maize production but usage has been inadequate relative to the importance of S deficiency.

Overall, current fertilizer use in Malawi was estimated at 43 kg per arable hectare in 2015, up from 31 kg/ha in 2003. This rate of use is high compared with mean rates for many African countries; however, it is very low considering the intensity of land use.

The prevailing poverty of smallholder farmers prevents many from using fertilizer. Fertilizer use is constrained by the financial ability of farmers. The profit potential of fertilizer use needs to be increased such as by reducing fertilizer use costs through more efficient fertilizer supply with reduced transport costs, subsidizing fertilizer use, higher commodity prices and better access to low cost and accessible financing. All of these factors have been difficult to achieve. A government subsidy program has contributed

Table 9.2: Common fertilizer recommendations (kg/ha) for cereal production in Malawi although there is area specificity for maize recommendations

Crop	Maize	Millet	Sorghum	Rainfed rice	Irrigated rice
Nutrient type					
N	92 kg	46 kg	46 kg	83 kg	83 kg
P_2O_5	42 kg	42 kg	42 kg	25 kg	25 kg
S	8 kg	8 kg	8 kg	4.8 kg	4.8 kg

to increased fertilizer use and also seed of improved varieties, but primarily targeting fertilizer N (Figure 9.2). There has been a strong focus on fertilizer use for maize production with little attention to other, generally higher value, crops such as pulses.

There are many fertilizer recommendations made for different crops in the country based on the type of the crops grown and agro-ecological zones. The fertilizer recommendations are in three categories that include: 1) general recommendations mostly based on 23:21:0+4S plus N fertilizer (Table 9.2); 2) area specific recommendations; and 3) based on soil and plant tissue analysis. Even though fertilizer recommendations are made for different crops for optimum economic returns, less than 50% of smallholders in the country use any fertiliser and about 70% use less than 50 kg/ha. Mean maize yield is below 2.5 t/ha (MOAFS 2012). A fertilizer blend of 23-10-5+3S+1Zn is now marketed to respond to more frequent occurrence of K and Zn deficiencies. Liming use is recommended for amendment of acid soils.

Efficient fertilizer use requires well managed crops. Fertilizer use can complement organic nutrient sources from manure application and nitrogen fixation by green manure crops, agro-forestry and cereal-legume rotation and intercropping. The value of such integration of practices has been validated through research but there has been little adoption of such practices among smallholder farmers.

9.2 Soil diagnosis and diagnostic trials in Malawi

Mapping soil resources and better targeting of soil amendment practices is ongoing but challenged by the extreme variability in soil fertility conditions. Sixteen OFRA-Malawi trials were conducted on-station or on-farm between 2013/14 and 2014/15 seasons in the mid-altitude and lake shore AEZ of Malawi for different legumes and maize. Fertilizer treatments included a diagnostic nutrient package of Mg, S, Zn and B in addition to N, P, K (P, K for legumes) that was directly comparable to an N, P, K treatment.

The results were inconsistent across sites and years within AEZ (Figure 9.3). There was a mean yield increase of more than 10% with

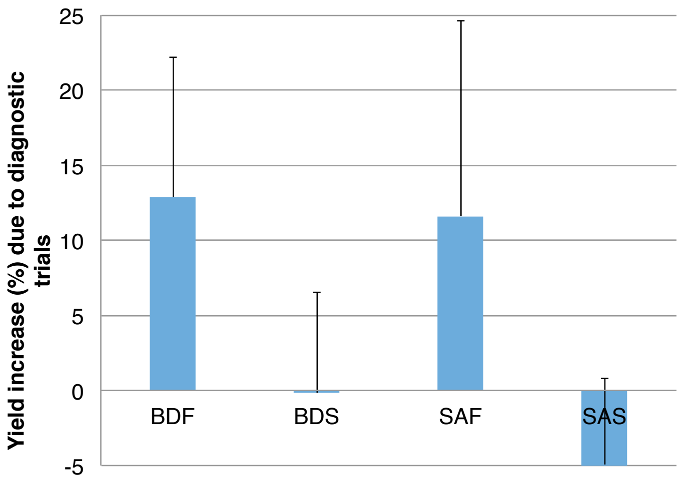

Figure 9.3: The percent yield increase due to application of a diagnostic treatment of N, P, K, Mg, S, Zn and B compared with N, P, and K averaged over maize, groundnut and soybean for 16 on-station or on-farm trials conducted during the 2013/14 and 2014/15 growing seasons. BDF = Bunda on-farm; BDS = Bunda on-station; SAF = Salima on-farm; SAS = Salima on-station. The bars represent standard errors of the mean.

the diagnostic treatment applied for on-farm trials but the mean effect was greater than the standard error of the mean only for the mid-altitude AEZ trials. There was no yield increase due to the diagnostic package of nutrients for on-station trials. The mean response to the diagnostic treatment was similar for all test crops which included cowpeas, soybean and maize. The results suggest more research is needed to better determine if the response was to Zn alone or at least partly due to Mg, S or B.

9.3 Optimizing fertilizer use in Malawi

Fertilizer use optimization in this chapter is considered to be maximization of farmer profit from fertilizer use. It assumes that farmers with adequate financial ability will want to maximize profit per hectare from fertilizer use while financially constrained farmers will want to maximize net returns on their limited investment in fertilizer use. The magnitude and nature of a crop response to an applied nutrient in a given AEZ is important to profitability for both the financially able and the financially constrained farmer. Also very important to the financially constrained farmer is the relative profit potential associated with specific nutrients applied to specific crops, that is, of the crop-nutrient choice.

Crop response to applied nutrients varies with the crop, the nutrient and site-season, and

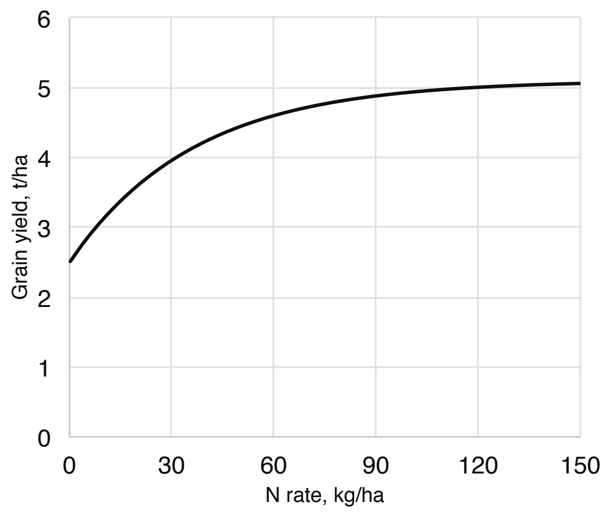

Figure 9.4: A curvilinear yield response maize to applied N for the Highland AEZ of Malawi (Y = 5.1 – 2.6 * 0.973N).

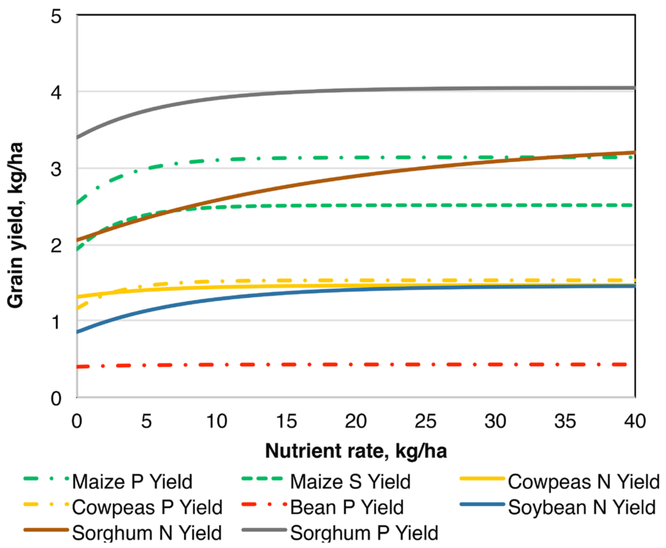

Figure 9.5: Yield nutrient functions for different crops for highlands in Malawi, >1300 masl.

may include no or negative response, a linear response, a quadratic response with yield loss at higher rates of application, and others. However, the response considered over numerous site-seasons of results is typically a curvilinear to plateau as shown for maize response to N in the highland AEZ of Malawi (Figure 9.4) with yield on the vertical axis (y-axis) and rate of applied N on the horizontal axis (x-axis). With such a response, there is a steep yield increase with increasing N at low rates, a smaller rate of yield increase at higher N rates, until yield reaches a plateau with no more yield increase. Such responses can be mathematically represented by the asymptotic equation of: Yield (t/ha) = $a - bc^r$ where a is yield at the plateau, b is the maximum gain in yield due to application of the nutrient of interest, c determines the shape of the curve, and r is the nutrient application rate. Such response curves are typical for most crops and nutrients in the highland AEZ (Fig. 9.5). The financially able farmer wants to apply a nutrient until the point where the value of the

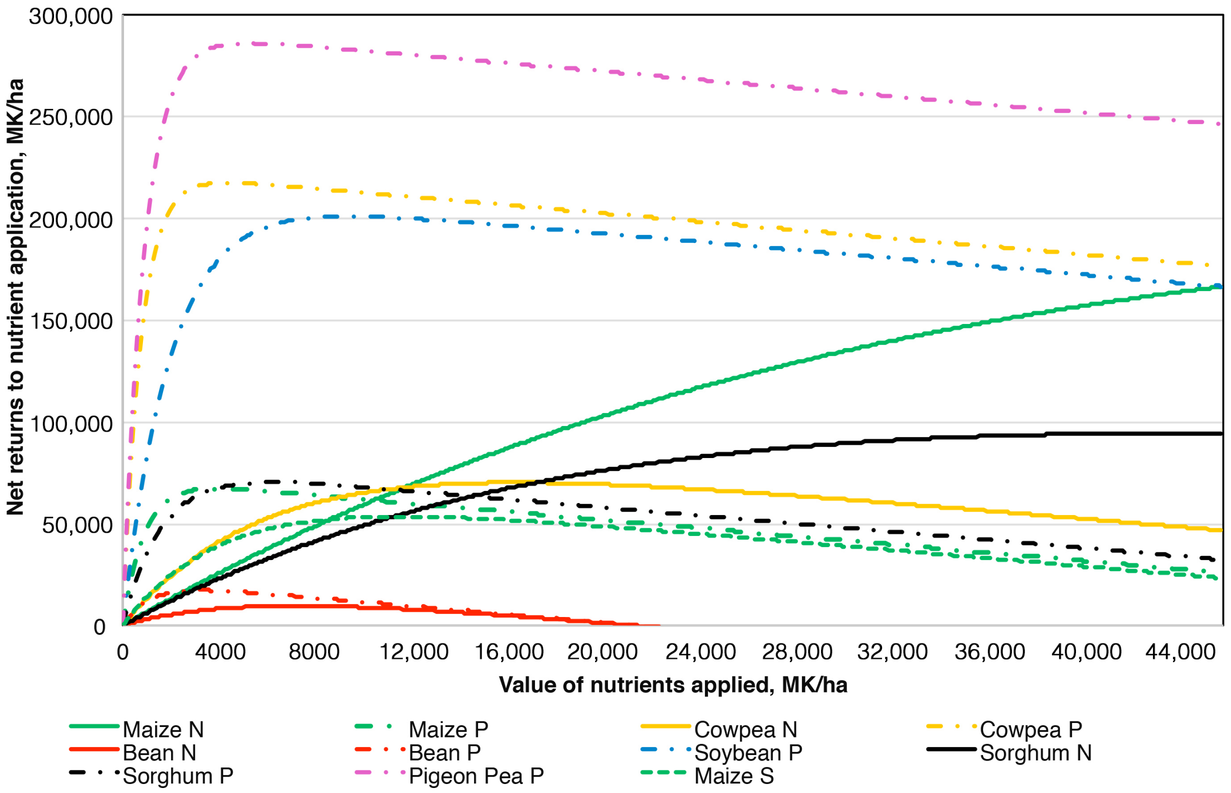

Figure 9.6: Net returns to investment in a crop-nutrient for Highlands AEZ in Malawi (>1300 masl). The assumed fertilizer use cost for 50 kg were: MK 23,000 for NPS and urea, and MK 25,000 for KCl and TSP. Commodity values (MK/kg) were: maize 120; cowpea 600; bean 350; soybean 350; sorghum 300 and pigeon pea 600.

yield increase equals the cost of an additional increment in nutrient rate. This is considered to be the economical optimal rate (EOR). The financially limited farmer, however, should strive to apply at a rate at which yield is still increasing and may choose to apply no more than 30 or 40 kg/ha N for the highland maize response of Figure 9.4, but not more than 5 kg/ha elemental nutrient for several of the crop-nutrient responses displayed in Figure 9.5 and no application of P to bean and N to cowpea.

Some nutrients applied to some crops have much more profit potential than other nutrients applied to the same or other crops (Figure 9.6). Financially constrained farmers need to consider this opportunity to achieve high profit from fertilizer use. The x-axis represents the amount of money invested in one nutrient applied to one crop. The y-axis shows the net returns to investment in application of a nutrient to a crop. Each curve represents the profit potential of a nutrient applied to a crop. The steeper the slope of the curve, the higher the net returns of the investment. As the amount invested increases, the slope decreases but if the response is still increasing, profit is increasing. Where curves reach a peak and the slope is flat, the point of maximum profit per hectare (EOR) is reached. When slopes decline, profit declines.

The financially constrained farmer wants first to take advantage of the crop-nutrient combinations that will give the most profit. The greatest profit potential on a small investment was with a small amount of P applied to legume crops, partly because of their high grain value, and especially for pigeonpea, compared with maize or sorghum. Also, a small amount of P applied to maize and sorghum was very profitable although these responses may only occur if some N is applied. Application of N to maize, sorghum and cowpea, and of S to maize, also have good profit potential although less with small investments compared to other options. Therefore, the financially constrained farmer needs to take advantage of the best profit opportunities according to their ability and, hopefully, use some of the increased profits to gradually become less financially constrained and eventually apply fertilizer to all cropland at rates to maximize profit per hectare.

Consideration of the nature of different crop nutrient response functions together with the farmer's land allocation, the expected value of the commodity, the fertilizer costs and the farmer's budget constraint is very complex. To deal with this complexity, easy to use fertilizer use optimization tools (FOTs) were developed using Excel Solver © (Frontline Systems Inc., Incline Village, NV, USA) which use complex mathematics of linear optimization to integrate the economic and agronomic information and give a solution (https://agronomy.unl.edu/OFRA).

Use of the Excel FOT requires that the add-in Solver is activated and macros are enabled; step-by-step instructions are given in the 'Help and Instructions' worksheet of the FOT (Figure 9.7). More detailed instructions are in Extension Materials and FOT Manual at the same website.

The data input screen is where the farmer needs to estimate how much land will be planted to each crop of interest, the farm-gate value per kg at harvest considering that some is for home consumption (the most valuable) and that the surplus will be marketed, and the cost of using different fertilizers (Figure 9.7). The farmer's available money for fertilizer use is also entered as the budget constraint.

The results are displayed as in Figure 9.8, 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. In this example, the farmer has only NPS and urea as available fertilizers. The budget constraint of Malawi kwacha (MKW) 150,000 is not sufficient to apply fertilizer at EOR but gives recommendations of more than 25 kg/ha for urea and NPS applied to maize and NPS applied to cowpea and pigeonpea. The recommended rates of less than 25 kg/ha are too low for feasible application and it is suggested that these fertilizers or the money be allocated elsewhere such as to increase the fertilizer applied to cowpea and pigeonpea. The expected average total return to MKW 150,000 invested in fertilizer use is MKW 918,133. If, however, TSP were available for a cost of MKW 30,000 per 50 kg, the expected average total net return is MKW 1,1012,746 increasing the farmer's profit potential by over 10%. Restricted availability of fertilizer types requires farmers to buy and apply nutrients that give no or less return compared to other nutrient application options.

DARS

above 1300 M

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

Crop Selection and Prices		
Crop	Area Planted (Ha)*	Expected Grain Value/kg †
Maize	3	120
Cowpea	1	600
Bean	1	700
Soybean	1	350
Sorghum	1	120
Pigeon pea	1	600
Total	8	

Fertilizer Selection and Prices					
Fertilizer Product	N	P2O5	K2O	S	Costs/50 kg bag ¶*
Urea	46%	0%	0%	0%	25,000
TSP	0%	46%	0%	0%	0
NPS	23%	21%	0%	4%	25,000
	0%	0%	0%	0%	0
	%	%	%	0%	0

Budget Constraint	
Amount available to invest in fertilizer	150000

Figure 9.7: The input screen of the FOT for the Highlands AEZ in Malawi (>1300 masl).

Fertilizer Optimization					
	Application Rate - kg/Ha				
Crop	Urea	TSP	NPS	xx	
Maize	29	0	30	0	0
Cowpea	0	0	46	0	0
Bean	0	0	0	0	0
Soybean	0	0	7	0	0
Sorghum	22	0	0	0	0
Pigeon pea	0	0	47	0	0
	0	0	0	0	0
Total fertilizer needed	109	0	191	0	0

Expected Average Effects per Ha		
Crop	Yield Increases	Net Returns
Maize	1,494	149,688
Cowpea	410	223,193
Bean	0	181
Soybean	47	12,966
Sorghum	519	51,579
Pigeon pea	341	181,150
	0	0

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer	918,133

Figure 9.8: The output screen of the FOT for the Highlands AEZ in Malawi (>1300 masl).

Table 9.3: Malawi Fertilizer Use Optimizer: paper version, Mid-elevation, upland and plateau (760-1300 m)

The below assumes:
Calibration measurement unit: a water bottle cap (CAP, 8 ml) for 5.6 g urea, 8 g of NPS.
Row spacing: maize, 75 cm; bean, soybean, cowpea all 50 cm; pigeonpea 75 cm.
Application point spacing: maize and cowpea, 25 cm; groundnut 20 cm; pigeonpea 75 cm.
Grain prices: per kg (MK): 120 maize; 350 bean; 120 rice; 300 sorghum; 600 pigeonpea; 600 cow pea; 700 groundnut; Fertilizer use costs per 50 kg bag (MK): 25,000 urea; 23,000 NPS.
Weeks after planting (WAP).

Level 1 financial ability.	
Maize	point apply 69 kg NPS, 8 WAP (1 CAP for 5.8 plants or 2.9 points)
Cowpea	point apply 55 kg NPS at planting (1 CAP for 7.9 plants or 4 points)
Bean	band apply 33 kg urea at planting (1 CAP for 2.2 m)
Soybean	band apply 66 kg NPS at planting (1 CAP for 1 m)
Pigeonpea	point apply 85 kg NPS at planting (1 CAP for 5.1 plants or 2.5 points)
Level 2 financial ability.	
Maize	137 kg NPS at 2 WAP (1 CAP for 3.1 plants and 1.5 points); point apply 45 kg urea, 8 WAP (1 CAP for 6.2 plants and 3.1 points)
Cowpea	point apply 72 kg NPS at planting (1 CAP for 6.5 plants and 3.2 points)
Bean	band apply 30 kg Urea at planting (1 CAP for 9.4 m) at planting
Soybean	band apply 90 kg NPS at planting (1 CAP for 0.7 m)
Pigeonpea	point apply 98 kg NPS at planting (1 CAP for 4.4 points)
Sorghum	52 kg NPS, 2 WAP (1 lid for 8.2 plants and 4.1 points); point apply 28 kg urea, 8 WAP (1 lid for 10 plants and 5 points)
Level 3 financial ability (maximize profit per acre).	
Maize	150 kg NPS at 2 WAP (1 CAP for 2.9 plants and 1.5 points); point apply 121 kg urea, 8 WAP (1 CAP for 2.4 points)
Cowpea	point apply 89 kg NPS at planting (1 CAP for 4.8 plants and 2.4 points)
Bean	band 71 kg NPS at planting (1 CAP for 1.5 m)
Soybean	point apply 142 kg NPS at planting (1 CAP for 0.4 m)
Pigeonpea	point apply 125 kg NPS at planting (1 CAP for 3.5 plants and 1.7 points)

A consequence of the very restricted fertilizer availability is that for the farmer to apply P to pigeonpea, cowpea, and soybean, three very profitable options in Figure 9.6, they also must pay for N and S in the compound fertilizer, even though there is no evidence of these crops having a response to these nutrients; therefore the benefits to fertilizer use for these crops is, in this example, much less than the potential indicated in Figure 9.6.

Farmers and their advisors often do not have ready access to a computer for use of the Excel Solver © FOT. A paper-based FOT has therefore been developed for each Excel Solver© FOT for the mid-elevation, upland and plateau AEZ (Table 9.3). The paper FOT is constructed for three financial levels: 1) for the farmer who is poor and has no more money than one-third the amount required to apply fertilizer to all cropland at EOR; 2) for the farmer with more money but has no more money than two-thirds the amount required to apply fertilizer to all cropland at EOR; and 3) for the farmer with enough money to apply fertilizer to at least some of the 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; and expected commodity values on-farm at harvest, considering the value both for home consumption and for market.

Table 9.4: Fertilizer use within an ISFM Framework: fertilizer substitution and soil test implications

ISFM practice	**Urea or CAN**	**DAP or TSP**	**NPK 23-21-0+4S or 23:10:5+6S+1.0Zn**
	Fertilizer reduction, % or kg/acre		
	N	**P**	**K**
Previous crop was a green legume manure (Mucuna, Crotalaria and Lablab) crop	100%	8 kg	28 kg †
Early incorporation of a green legume manure (Mucuna, Crotalaria and Lablab) crop	57 kg	3 kg	11 kg †
Use of agroforestry technologies (e.g. leaf prunings of Gliricidia, Leucaena, Sesbania, *Senna spectabilis*) applied, per 1 t of fresh material	10 kg	1 kg	6 kg††
Farmyard manure per 1 t of dry material	2 kg	1 kg	1 kg
Residual value of FYM applied for the previous crop, per 1 t	1 kg	0.4 kg	0.4 kg
Dairy or poultry manure, per 1 t dry material	24 kg	7 kg	14 kg
Residual value of dairy and poultry manure applied for the previous crop, per 1 t	5 kg	1.4 kg	3 kg
Compost, per 1 t/ha dry wt	20 kg	1 kg	20 kg
Doubled-up legume-technology (pigeonpea/groundnuts etc)	In the following year, reduce urea by 50 kg/ha †††		
Cereal-bean intercropping	Increase DAP/TSP by 18 kg/ha, but no change in N & K compared with sole cereal recommendations		
Cereal-other legume (effective in N fixation) intercropping	Increase DAP/TSP by 20 kg/ha, reduce urea by 30 kg/ha, and no change in K compared with sole cereal recommendations		
If Mehlich III P >18 ppm	Do not apply P		
If soil test K < 0.25 cmol/kg	Apply 20 kg KCl/ha		

†Saka et al. 2006
††Akinnifesi et al. 2006
†††Njira et al. 2012

The paper FOT tables address the 4Rs of fertilizer use advising on the right product, rate, time and method of application. It also advises on calibration, that is, the distance along the band or the number of points per measuring unit for the recommended fertilizer rate. A constraint of the paper FOTs is that these need to be revised, maybe annually, if significant changes occur in the costs of fertilizer use relative to the commodity values.

The paper FOT is easy to use (Table 9.3). Consider the recommendation for maize under Level 2 financial ability "Maize: 137 kg NPS at 2 WAP (1 CAP for 4.4 plants); point apply 45 kg urea, 8 WAP (1 CAP for 12.5 points)".

Therefore, 137 kg/ha of NPS is to be point applied at 2 weeks after planting. One 8 ml water bottle cap is sufficient for 4.4 plants. In addition, 45 kg/ha
urea is to be applied at eight weeks after planting. The farmer learns to apply this rate by applying one water bottle lid to 12.5 plants.

Another aspect of fertilizer use optimization is to adjust fertilizer rates according to other practices when these are applied to a parcel of land and to soil test values. After getting the results of the FOT, the farmer considers parcels of land where practices of Table 9.4 have been or will be applied. Some of the practices have fertilizer substitution value and fertilizer rates can be decreased. Intercropping calls for an increase in some fertilizer. Soil test P is considered with the assumption that most fields have sufficiently low soil test P that the probability of response is high but if soil test results indicate adequate P, then the P application should be withheld from that land parcel and applied elsewhere or the money reallocated. The soil test K assumes that generally soil K availability is adequate and the FOT recommendation is followed, but if soil test results find very low K availability, some application of KCl is advised.

9.4 Targeted crops and cropping systems by AEZ

For Malawi, maize, bean, pigeonpea, soybean, cowpea and sorghum were considered for the highlands and all of these crops except sorghum were considered for the other AEZ (Table 9.5a-c). The lakeshore and all of the Shire Valley were considered as one recommendation domain in the development of FOTs.

In this series of tables, column 1 and 2 give the crop and nutrient, columns 3-5 give a, b and c coefficients of the curvilinear to plateau response function, columns 6-9 give the yield increases asssociate with incremental changes in nutrient rate, column 10 and 11 give EOR determined from field research results and the recommended elemental nutrient application rates (REC).

In the highland AEZ, with the exception of bean, crops had good responses to applied N and P (Table 9.5a). Maize responded well to applied K and S. In the mid-elevation and upland plateau AEZ and in the lakeshore and the Shire River Valley AEZ, maize again responded well to N, P and S but not to K (Table 9.5b,c). Bean was more responsive to N than in the highlands.

Table 9.5a: Highlands >1300 masl - Response functions, expected yield increases (t/ha) for crop-nutrients, and OFRA economically optimal rate (EOR) to maximize profit per hectare compared to current or recent (REC) recommendations P_2O_5 = P x 2.29; K_2O = K x 1.2. Some functions have zero response 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			**t/ha**			**kg/ha**	
Highlands (above 1300 m) AEZ										
Maize	N	5.100	2.600	0.973	1.456	0.641	0.282	0.124	81	69-92
Cowpea	N	1.465	0.154	0.835	0.153	0.001	0.000	0.000	16	0
Bean	N	0.429	0.031	0.798	0.031	0.000	0.000	0.000	7	23
Sorghum	N	3.377	1.326	0.951	1.032	0.229	0.051	0.01Y	43	58
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.137	0.600	0.756	0.452	0.112	0.028	0.007	8	3-18
Cowpea	P	1.529	0.371	0.720	0.299	0.058	0.011	0.002	11	20†
Bean	P	0.429	0.031	0.798	0.021	0.007	0.002	0.001	4	9
Soybean	P	1.457	0.607	0.883	0.281	0.151	0.081	0.043	20	9-18
Sorghum	P	4.047	0.651	0.856	0.352	0.162	0.074	0.034	11	9
Pigeonpea	P	2.538	0.487	0.758	0.365	0.091	0.023	0.006	15	20†
Maize	K	4.863	0.563	0.896	0.238	0.137	0.079	0.046	19	6-8
Cowpea	K	1.563	0.081	0.898	0.034	0.020	0.011	0.007	16	0
Soybean	K	0.837	0.019	0.908	0.007	0.004	0.003	0.002	0	0
Pigeonpea	K	2.535	0.127	0.666	0.110	0.014	0.002	0.000	10	0
Maize	S	2.510	0.577	0.738	0.451	0.099	0.022	0.005	12	4

†Kamanga et al. 2010. EOR was determined with the cost of using 50 kg NPS at MK 23,000, urea, KCl and TSP at MK 25,000. Commodity values (MK/kg) used were: maize 120; cowpea 600; bean 350; soybean 350; sorghum 300 and pigeonpea 900

Table 9.5b: Mid-elevation and upland plateau (760-1300 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			**t/ha**			**kg/ha**	
Mid-elevation and upland plateau (760-1300m) AEZ										
Maize	N	4.906	2.572	0.982	1.081	0.627	0.363	0.211	78	69-92
Bean	N	0.838	0.293	0.862	0.290	0.003	0.000	0.000	21	23
Soybean	N	1.131	0.046	0.929	0.041	0.004	0.000	0.000	0	23-50
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	2.853	1.794	0.972	0.237	0.206	0.179	0.155	24	3-18
Cowpea	P	1.529	0.371	0.72	0.299	0.058	0.011	0.002	10	20†
Bean	P	0.884	0.058	0.869	0.029	0.014	0.007	0.004	4	9
Soybean	P	1.359	0.608	0.868	0.308	0.152	0.075	0.037	16	9-18
Pigeonpea	P	2.538	0.487	0.758	0.365	0.091	0.023	0.006	13	20†
Maize	K	4.084	0.097	0.9	0.040	0.023	0.014	0.008	2	6-8
Cowpea	K	1.563	0.081	0.898	0.034	0.020	0.011	0.007	16	0
Soybean	K	1.402	0.508	0.781	0.360	0.105	0.030	0.009	16	0
Pigeonpea	K	2.535	0.127	0.666	0.110	0.014	0.002	0.000	10	0
Maize	S	2.555	0.400	0.761	0.298	0.076	0.019	0.005	11	4

Table 9.5c: Lakeshore, middle and upper Shire (200-760 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			**t/ha**			**kg/ha**	
Lakeshore, Shire River valley (200-760 m) AEZ										
Maize	N	4.905	2.571	0.982	1.080	0.626	0.363	0.211	87	69-92
Bean	N	0.838	0.293	0.862	0.290	0.003	0.000	0.000	22	23
Soybean	N	1.131	0.046	0.929	0.041	0.004	0.000	0.000	0	23-50
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	2.853	1.794	0.972	0.237	0.206	0.179	0.155	30	3-18
Cowpea	P	1.529	0.371	0.720	0.299	0.058	0.011	0.002	10	20†
Bean	P	0.884	0.058	0.869	0.029	0.014	0.007	0.004	5	9
Soybean	P	1.359	0.608	0.868	0.308	0.152	0.075	0.037	17	9-18
Pigeonpea	P	2.538	0.487	0.758	0.365	0.091	0.023	0.006	14	20†
Maize	K	4.084	0.097	0.900	0.040	0.023	0.014	0.008	2	6-8
Cowpea	K	1.563	0.081	0.898	0.034	0.020	0.011	0.007	16	0
Soybean	K	1.402	0.508	0.781	0.360	0.105	0.030	0.009	16	0
Pigeonpea	K	2.535	0.127	0.666	0.110	0.014	0.002	0.000	10	0
Maize	S	2.555	0.400	0.761	0.298	0.076	0.019	0.005	11	4-10

All crops had profitable response to P and all except for bean had profitable responses to K.

In 28% of 42 comparisons of EOR with REC, the REC was an average of 60% less. In 38% of the comparisons, the REC was on average 96% higher than EOR. For K applied to soybean, pigeonpea and cowpea, and for N applied to cowpea in the highlands, EOR were determined while the RECs were for no K application to these crops.

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