Maize response to macronutrients and potential for profitability in sub-Saharan Africa

Short title: Fertilizer profitability in sub-Saharan Africa

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Abstract

Sub-Saharan Africa (SSA) is plagued by low productivity and little research is available on the attainable responses and profitability to applied nutrients under variable environments. The objective of this study was to determine the attainable maize grain response to and potential of profitability of N, P and K application in SSA using boundary line approaches. Data from experiments conducted in SSA under AfSIS project (2009-2012) and from FAO trials database (1969 to 1996) in 15 countries and constituting over 375 different experimental locations and 6600 data points are used. Both response to fertilizer and value cost ratio (VCR) are highly variable and no more than 61% cases for N, 43% for P and 25% for K attain VCR of 2 or more. Also, based on the recent AfSIS data, VCR exceeds 1 in just 67% (N), 57% (P) and 40% (K) of the cases, even when best management practices are applied on a research farm, and interest rates are zero. Chances for profitability are highest when soil organic carbon is 1 - 2% and control maize grain yield is 1 – 3 t ha^{-1} but also depends on relatively static soil properties (primarily texture and mineralogy) that are not under farmer control. We conclude that return on investment of macronutrient fertilizer is highly variable and can be substantially increased by helping farmers decide where to apply the fertilizers. Consequently, farmers need access to information on factors influencing economic returns of fertilizer use in order to make the right decisions.

Keywords: boundary analysis, attainable yield, fertilizer profitability, macronutrients

Introduction

Sub-Saharan Africa (SSA) has the lowest production estimates for cereals especially maize, when compared to other regions of the world (www.fao.org). The low production is attributed to low soil fertility (Ngome et al. 2011; Tittonell and Giller 2012), and inappropriate management practices including continuous cropping with little or no nutrient replenishment. The level of soil fertility varies across landscapes and even within farms (Diwani et al. 2013; FAO 2003; Zingore et al. 2007). Nitrogen (N), phosphorus (P) and potassium (K) are considered as the major limiting nutrients for crop production in SSA (Adediran and Banjoko 1995). Variable yield increases have been reported following fertilizer application of these nutrients, but a comprehensive assessment of the economic benefit of the nutrients under the various soils and climate regimes in SSA has not been undertaken. It is important to provide the African decision-maker with information on the potential for profitability and an assessment of thresholds that can be expected when key nutrients are applied at the commonly recommended rates.

Huge yield gaps are often reported in Africa and experimental results often show higher yields than those obtained with farmer practices even at the same level of fertilizer input (Yanggen et al. 1998). The premise is that researchers use best agronomic practices, resulting in the higher yields. Such experimental data therefore provide an opportunity to construct boundaries of attainable yield for different production environments. Recently, large datasets from across SSA have become available such as recent diagnostic trial data from the Africa Soil Information Services (AfSIS) project (http://afsis-dt.ciat.cgiar.org/) and older fertilizer response trials data from the Food Agriculture Organization of the United Nations (FAO Fertibase). Boundary lines of nutrient responses from such datasets can indicate the attainable response to applied nutrients under variable environments. Boundary lines represent the yield ceiling for the application of a given fertilizer or nutrient under investigation and they have been used elsewhere (Imhoff et al. 2010; Tasistro 2012). In case of nutrient omission trials they provide insight in the level to which the attainable yield is limited by omission of a nutrient. In this study, the focus was on the most important macronutrients in SSA namely, N, P and K.

There is little, yet scattered information on profitability of fertilizer use in SSA. Further, results from experimentation are mainly reported as mean for a set of fields or trial locations (KARI 1994; Wokabi 1994), masking the variability inherent between those fields. It has been shown that response of crops to nutrient additions varies depending on the initial fertility status of the soil at a specific site (Zingore et al. 2007) and this has implications on profitability of fertilizer use. Yet in SSA, applications of macronutrients are mainly guided by blanket recommendations i.e., are usually given for regions not for specific sites or fields. The focus of this study was on potential for profitability of blanket fertilizer application to maize, which is one of the most important staple crops in SSA (www.fao.org), but the analysis can be applied to other cereals as well.

The objectives of this study were to (1) determine the attainable maize grain response to N, P and K application in SSA using boundary line approaches, and (2) determine the potential of profitability of N, P and K application to maize using VCR based on current and historic agronomic data for SSA. The study shows how return on investment is influenced by what and where fertilizer is applied, and provides some information that could be used to generate some explicit recommendations.

Methodology

Description of study sites and data

This work is based on data of maize response to fertilizers from experiments conducted in SSA under AfSIS project (www.africasoils.net; 2009-2012) and from FAO trials database (1969 to 1996). The trials represent a wide range of soils and climates in SSA, coming from 15 countries in the region namely Botswana, Burkina Faso, Burundi, DR Congo, Ethiopia, Gambia, Guinea Bissau, Kenya, Lesotho, Malawi, Mali, Nigeria, Rwanda, Sudan and Tanzania. These constitute over 375 different experimental locations (Figure 1).

Figure 1 here

For the AfSIS case, the dataset is from standard nutrient omission response trials conducted in Kenya, Malawi, Mali, Nigeria and Tanzania (Table 1). The AfSIS sites had been strategically selected to cover a wide range of biophysical conditions, ranging from semi-arid in northern Mali to more humid area in Tanzania, from fairly flat topographies of the Guinea Savanna in Nigeria to hilly sites in Malawi. Here, nutrients were added as 30 kg P ha^{-1}, and 60 kg K ha^{-1} as single dose at planting and 100 kg N ha^{-1} in 3 split applications (1/3rd each at planting, 3 weeks and 6 weeks after mergence). The trials were all conducted following similar experimental design and management, and data collection procedures were common across the regions (Huising et al. 2012). Data from FAO is derived from nutrient response trials with both N and P treatments and a control treatment without chemical fertilizer but with same management practices. The nutrients applied were in the form of Triple Super Phosphate (TSP), Urea and Muriate of potash and the seed used was hybrid maize. The applied nutrient rates ranged between 3.1 and 110 kg P ha^{-1}, and between 20 and 180 kg N ha^{-1} for the trials included in the FAO database. In total, the study included 2,537 data points from the

AfSIS sites and 4091 from FAO. For the FAO dataset, there were 3,999 data points of P application and 1,490 of N application. The response variables were observed yield and Value Cost ratio (VCR).

Table 1 here

In the absence of full cost data, VCR is often used to assess the profitability of the fertilizer (Xu et al., 2009). In this study, VCR was calculated as:

$$\mathrm{VCR} = \frac{\text{Additional maize yield in kg due to nutrient application X maize price (per kg)}}{\text{Amount of a nutrient applied in kg X price of the nutrient (per kg)}},$$ based on the average nutrient and maize grain prices for the last 6 years (2008-2015). In economic terms, a VCR value greater than 1 means that cost for fertilizer is recovered while a VCR of 2 represents 100% return on the money invested in fertilizer. A VCR of 2 is often considered as a minimum for deciding to invest in a technology and is taken here to represent potentially profitable cases. Fertilizer price was obtained from www.indexmundi.com accessed on 8th April 2013 as 0.81, 2.47 and 0.92 US$ per kilo of N, P and K, respectively, being an average over the last 5 years. Since Eastern Europe Free On Board (FOB) prices of fertilizers are about 50% of farm gate prices within SSA (Ariga et al. 2006), we multiplied each of the nutrient costs by 2 when deriving thresholds of potential profitability. Maize price per kilogram was obtained from the food security portal (www.foodsecurityportal.org, accessed on 15th April 2015) as the median price of 0.39 US$ (range was 0.11 - 0.97) based on monthly prices for February 2008 to February 2015 period from DR Congo, Ethiopia, Kenya, Malawi, Mozambique, Niger, Nigeria and Uganda. Thus to cover the cost each kilogram of applied nutrient should result in at least 4.8, 14.5 and 5.4 kg additional grain for N, P and K, respectively. The above fertilizer and maize prices are used for the calculations of VCR presented in the figures.

Because of variability in prices and costs of outputs and inputs expected from country to country, country-specific values were used for the AfSIS dataset. Thus, in addition to the above analyses, current costs of N and P for each of 5 AfSIS countries was used to assess changes in profitability potential. Here, the cost of N is 0.65, 1.68, 1.13, 1.04 and 1.04 US$ for Nigeria, Malawi, Mali, Kenya and Tanzania, respectively. Similarly, the cost per kg P is 3.89, 4.50, 2.03, 3.21 and 3.21 US$ for Nigeria, Malawi, Mali, Kenya and Tanzania, respectively. Price of maize per kg also varied being 0.39, 0.307, 0.46, 0.345 and 0.32 US$ for Nigeria, Malawi, Mali, Kenya and Tanzania, respectively. These are averaged 6 year monthly maize prices.

The probability to attain value cost ratio of at least 2 was calculated as the number of cases where yield increase over the control (due to N or P) was at least 2 times the cost of the fertilizer divided by the total number of cases. The probability was calculated for each of the control yield classes with a 0.5 t ha interval, whenever the total number of cases in a class was at least 10. For the AfSIS dataset, total data points beyond 4 t ha^{-1} of control yield were less than 10 so these were not included.

Soil samples from the 0-20 cm depth were taken from each individual plot of the AfSIS trials usually as a composite of 4 sampling points within a plot. The soils were analyzed for C, predicted from soil spectra using the ICRAF spectra prediction models.

Statistical analysis

Different approaches were used in the data analysis. First, scatter plots of treatment yield against control yield, and value cost ratio against soil organic carbon (SOC) were constructed. For these, boundary lines representing the maximum value of a dependent variable that can be achieved at different values of the independent variable (Shater and McBratney 2004) were added. To construct the boundary line the data was grouped based on the control yield into classes of 0.5 t ha^{-1} interval and the 5 observations with highest treatment yield in each class averaged. These average values for each class were used for boundary line fitting. The boundary lines were fit both for the treatment where a nutrient was omitted and also where this nutrient was applied. The boundary lines were fit to the data as non-linear 3-parameter log logistic models using package drc, a general dose response curve fitting function in R (www.r-project.org). The graphs were plotted using R. In all cases where the control yield is reported in the x-axis, this refers to the absolute control. Similarly, to construct boundary line for the VCR against SOC, VCR data points were arranged into SOC classes with a 0.2% interval and the 5 observations with highest VCR in each class averaged and boundary lines fitted as explained for control yield.

Secondly, in order to show the distributions of VCR for different sites, countries and soil types, boxplots of VCR were plotted in R. For all of the boxplots, a line indicating a VCR of 2 was added to indicate the point at which fertilizer use can be considered profitable.

Results

Maize response to fertilizer varied greatly at all levels of control yield (Figure 2). Maximum yield level in case of the FAO data is around 8 t ha^{-1} and slightly less in case of the AfSIS data. As expected, the highest response to fertilizer, which is indicated by the difference between the boundary line and the 1:1 line, is obtained at low control yields. A maximum of 6 t ha^{-1} yield increment over the control was obtainable at low fertility (control yield of between 0.5 and 1.5 t ha^{-1}). From the analysis, very limited response to fertilizer is expected when control yields are more than 6 t ha^{-1}. When considering a response of less than 0.5 t ha^{-1} to be insignificant, then in 25% of the cases for AfSIS and 20% of the cases for FAO the response is very poor to none.

Figure 2 here

Interesting patterns for attainable yields (here defined as highest observed yield at every class of control yield and indicated by boundary lines) are observed in the AfSIS and FAO datasets (Figure 3). First of all the attainable yield level based on the AfSIS data increases with increasing control yield and reached a maximum at around 6 t ha^{-1}, whereas for the FAO data the attainable yield level of around 8 t ha^{-1} is reached already with control yields of around 1 – 2 t ha^{-1}. The attainable yield following omission of N is consistently less by 2 t ha^{-1} than that with N application regardless of soil fertility (or control yield). Omission of P limited the attainable yields by about 1 to 1.7 t ha^{-1}, with the limitation becoming more pronounced in the fields with higher control yields in the case of AFSIS. The depression of attainable yield when K is omitted ranges from insignificant when control yields are below 1 t ha^{-1} to almost 2 t ha^{-1} when control yield are 6 t ha^{-1}. The fitted boundary lines with omission of K flattens when control yield are only 2 t ha^{-1}, which seems to suggest that K becomes limiting only at higher yield levels. Overall, N is the more limiting nutrient that is expressed at each level of control yield, followed by P and K.

Figure 3 here

The potential for profitability, assessed based on VCR, is variable for the 3 macro-nutrients (Table 2 and Figure 4). Based on the 288 field trials in the case of AfSIS, in 33% of the cases the response to N is not enough to cover the cost of the fertilizer, whereas only in 50% of the cases is some profit expected (VCR of 2 or higher; note: with N application rate of 100 kg ha^{-1}). In case of P, in 43% of the cases no return on investment is expected and in 40% investment in P fertilizers is considered profitable. In the case of K application, 60% has a VCR of 1 or less and in 25% of the cases attain a VCR of 2 or more. Overall, chances of profitability are reduced only 2 to 5 (data not shown) and up to 14 to 20 percentage points when varying the price of maize and both price of maize and cost of fertilizer by country, respectively. Disaggregating by the individual sites, the percentages at which the VCR for K is at least 1 range from 30% for Pampaida to 56% for Kasungu, and for VCR of 2 or more from 13% to 48% (Mbinga) (Figure 4a and Table 2). Only three sites, i.e., Mbinga, Sidindi and Kasungu had more than 30% of cases with a VCR of 2 or more for K. For P the percentage of cases with a VCR of at least 1 or at least two ranges from 24% (Kiberashi) to 77% and from 24% to 61% respectively, with most responsive sites being Pampaida, Sidindi and Mbinga. In Kiberashi in Tanzania, only 24% of cases obtained a VCR at least 1 following P application. It was also the only site where N application resulted in less than 30% of cases attaining a VCR of 1 or more. Profitability of N application was in at least 50% of the cases in 4 of the 8 sites studied. Similar results are observed with FAO dataset with generally more cases of N than of P attaining a VCR of 2 (Figure 4b). Indeed, of the 3,999 data points of P application and the 1,490 data points of N application in historical data from FAO, the cases with a VCR of at least 2 are 61% for N and 43% for P (those with VCR of at least 1 are 74% for N and 60% for P).

Figure 4 here

Table 2 here

In all soils, value cost ratio of at least 2 is observed following nitrogen application in a majority of cases, and there are no major differences attributable to the soil types (only

Calcisols have almost all cases (>75%) in the profitable range; Figure 5). For phosphorus, Vertisols are the only soils where all cases achieve VCR<2 while Ferralsols are the only soils where >50% of cases achieve VCR>2. With the exception of these two soil types (Vertisols and Ferralsols), distribution of VCR of P applied to maize is generally similar for most soil types.

Figure 5 here

Maximum VCR for P application is attainable on soils with a soil organic carbon percentage of about 1.5% (Figure 6). The maximum attainable VCR decreases when SOC is >2% indicating low response due to high control yield. The maximum attainable VCR decreases sharply with SOC levels below 1%, indicating poor soils. For N application the highest attainable VCR are observed when soil organic carbon is around <1.5%, and like with P seems to decline sharply with decreasing SOC levels.

Figure 6 here

The probability of obtaining a VCR of at least 2 was variable across the range of control yields; first, there is greater probability for profitability of N than of P and secondly, the probability of profitability for both N and P decreases at high control yields (> 3 t ha^{-1}) although it is also reduced at the very low yields of < 1 t ha^{-1} (data not shown). The 1 – 3 t ha^{-1} range for control yields seems to offer the greatest opportunity for fertilizer profitability.

Discussion

Yields and responses to N, P and K

The yields observed from researcher designed experiments in SSA as presented in this study are in a majority of cases still lower than the average maize production in Asia (4.9 t ha^{-1}), Europe and America (over 6.6 t ha^{-1}; www.fao.org, accessed on 10th April 2013). In a previous meta-analysis by Kihara and Njoroge (2013) in western Kenya, a region that is perhaps most researched in SSA, they observed yields far below the yield potential. The observed maximum yields from this data set stagnated at around 7-8 t/ha regardless of the control yield, very similar to the results reported earlier for western Kenya (Kihara and Njoroge 2013). The low maximum yields can be attributed to the fact that the dataset used is derived from plots where no other nutrients (e.g., secondary and micronutrients) had been applied apart from N, P and (to some extent) K. Others have argued that yield potential of improved varieties in SSA is not realized because of soil degradation that has also reduced rainfall effectiveness (Lal 2010). In our case, data presented is generated under best management by researchers in the case of AfSIS, and a similar assumption can be made for the FAO dataset. This study does not investigate the causes of the large variation in response to nutrient application, but it does indicate that opportunities to obtain high yields through the proper management of N, P and K nutrients vary from one site to the other and that more insight is needed in the site specific production constraints in order to achieve the potential. The wide yield gap in SSA present a huge opportunity for yield improvement through integrated crop production management.

Response to fertilizer by crops in high fertility fields is often lower compared to those in low fertility fields (see also Tittonell et al. 2008b; Zingore 2011). This means that agronomic efficiency and chance of profitability are decreased in the high fertility fields (i.e., those with high control yields) as observed in this study. Potassium has often not been considered as a limiting nutrient by most researchers in SSA and as a result K has received much less focus compared to P and N. Results from this study indicate, however, that K becomes limiting at higher yield levels (above about 4.5 t ha^{-1}), and that a clear response to K application if often observed, but that this is site specific (large variation between sites and within sites). N is the most limiting macronutrient for maize in SSA, in agreement with findings from other researchers (Adediran and Banjoko 1995; Wopereis et al. 2006).

Majority cases of low crop response to N, P and K (see also Vanlauwe et al., 2011, Kihara and Njoroge 2013) could result from uncorrected soil acidity (Ngome et al. 2011), unbalanced nutrition where micronutrients for example are limiting (Subedi and Ma 2009), application methods and timing (Olorede et al. 2013), low soil moisture or drought (Holford and Doyle 1993), and where farmer conditions are considered, weeds (Tittonel et al. 2008a) and other management factors. As noted by others, fertilizer application must be in line with the specific niche and include adaptation to site-specific conditions in order to realize the potential response of crops to fertilizer use (Tittonell et al. 2008b; Ngome et al. 2010; Vanlauwe and Zingore 2011). The challenge here is that not much is known about local soil condition and site specific nutrient limitations (beyond N and P). Also, under farmer conditions, causes of sub-optimal crop stands, mainly due to in-season plant losses (e.g., termites ,Akinnifesi et al. 2010), stem borer (with yield losses of up to 17%; Vitale et al. 2007) and low planting densities, identified by Kihara et al. (2015) are key factors contributing to low yields. Higher incidences of pest damage are linked to poor soil fertility (Wale et al. 2006) hence the need to focus on overall fertility improvement as well. Proper agronomic management could reduce the yield gaps observed in SSA (Chikoye et al. 2004; Kihara et al. 2015) while continued soil degradation may widen the yield gaps further (Tittonell and Giller 2012).

Profitability of fertilizers

The profitability of fertilizer is a key concern in SSA, a region that is struggling to increase fertilizer use. The percentage indicating profitable application of one of the macro-nutrients assumes that the other macro-nutrients are not limiting (e.g. in the case of AfSIS data). In practice the percentages will be lower when balanced nutrition is not observed.. In different studies, Tittonell et al. (2008b) and Ngome et al. (2010) showed that N and P should be the basis of optimizing fertilizer use for maximum yield and profitability. This is correct, since N and P limitations in soils are most severe and ubiquitous in Africa, however with the understanding that additional measures are needed to improve agronomic efficiencies and herewith the profitability of the N and P application. In Mbinga, K is as important as P for example. This requires site specific recommendations and locally adapted soil fertility management practices, taking into account seasonal rainfall, soil type and soil fertility including soil organic carbon as important determinants of profitability (see also Donovan et al., 2002). Soil organic carbon status is influenced highly by land degradation and soil texture but also responds to management. The identified positive impact of P on VCR for Ferralsols is interesting and is confirmed by physical processes but influences of other soil types are not so clear and should be further explored. The cases profitable for P in the different sites are also related to the level of plant-available soil P (e.g., both Pampaida and Sidindi which had more profitable cases than the other sites also had the lowest plant-available soil P of below 8 mg kg^{-1} soil; data not shown). For Malawi where each site is characterized by low to high plant-available soil P (see also Phiri et al., 2010), chances of profitability (VCR>2) were low, being only 25-39%.

While a solution need to be found to improve the agronomic efficiency of N and P (and K) fertilizers, the only way to make fertilizer use (more) profitable to the smallholder farmer in general is through regulation of the price the farmer has to pay for fertilizer input or that he/she receives for his/her crop. Fertilizer subsidies are common in countries in SSA, but not always effective and more structural and sustainable solutions need to be found.

Note that the generally low profitability rates indicated in this paper (though varying strongly between and within sites) are notwithstanding the assumed good management practices and will be lower under farmer's practice. Perceived profitability of fertilizer by farmers in SSA is important determinant of adoption rate (Donovan et al. 2002) especially considering the current blanket recommendations (Xu et al. 2009). Also the profitability are given for fixed nutrient application rates in case of the AfSIS data, and that profitability may increase with lower application rates. In Zambia, Donovan et al. (2002) observed profitability only with the low and medium doses, while Xu et al. (2009) found timeliness of fertilizer availability, remoteness of farm location, family social tragedies and the use of animal or mechanical draught power in land preparation to significantly affect fertilizer profitability. From our analysis, the profitable options cut across the whole range of control yields reported, which is a great opportunity for SSA, although diminishing returns are expected as the yields approach the boundary line (Koning et al. 2008).

This study is the first comprehensive report on potential of fertilizer profitability for maize in SSA. The potential for profitability of a nutrient in this study is undertaken when the other macronutrients are not limiting. More studies are needed to inform stakeholders on profitability of fertilizers for specific locations and for other crops as well, and especially under farmer practices. Also, as noted by Druilhe and Barreiro-Hurlé (2012), input and output prices vary widely even across different locations within a country depending on the remoteness hence the need for further profitability assessments disaggregated by regions within countries.

Conclusions

Nutrient response, and cases of profitability of fertilizer in SSA are highly variable. N is the most limiting nutrient and response to N application is found even on relatively fertile soils (represented by soils with high control yields) assuming no other limiting factors. Phosphorus limitations are also observed across soils of varying soil fertility status but less pronounced in general compared to N limitation. Potassium limitations are expressed especially at higher yield levels and on relatively fertile soils.. Even when farmers have access to inputs, labor and knowledge necessary to control the yield-reducing impacts of weeds and pests, and cheap credit, they would be likely to break even or make some money on fertilizer inputs in less than half of the time. This is because of a variety of factors such as 1) fertilizer prices and interest rates, 2) crop prices, and 3) poor crop response to fertilizer inputs because of static soil properties (primarily texture and mineralogy) and dynamic properties (e.g. organic matter, structure, that farmer do control to some extent) 4) weather, and 5) management of other yield-limiting factors. Consequently farmers need to have access to information on all of these factors and, ideally, decision support tools necessary to make the right decisions including support for site-specific fertilizer recommendations and management, with regard to where, what and how much fertilizers to apply.

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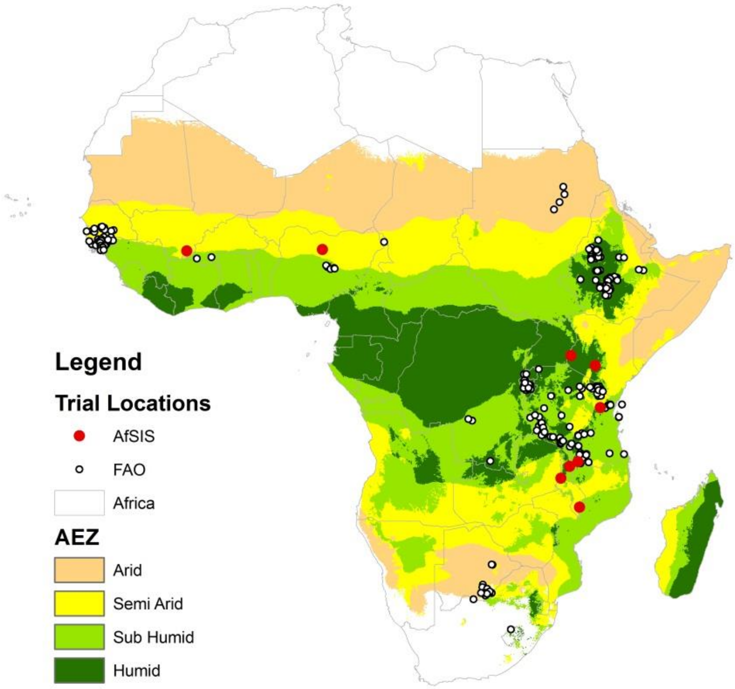

Figure 1. Location of trials used for the FAO and AfSIS datasets

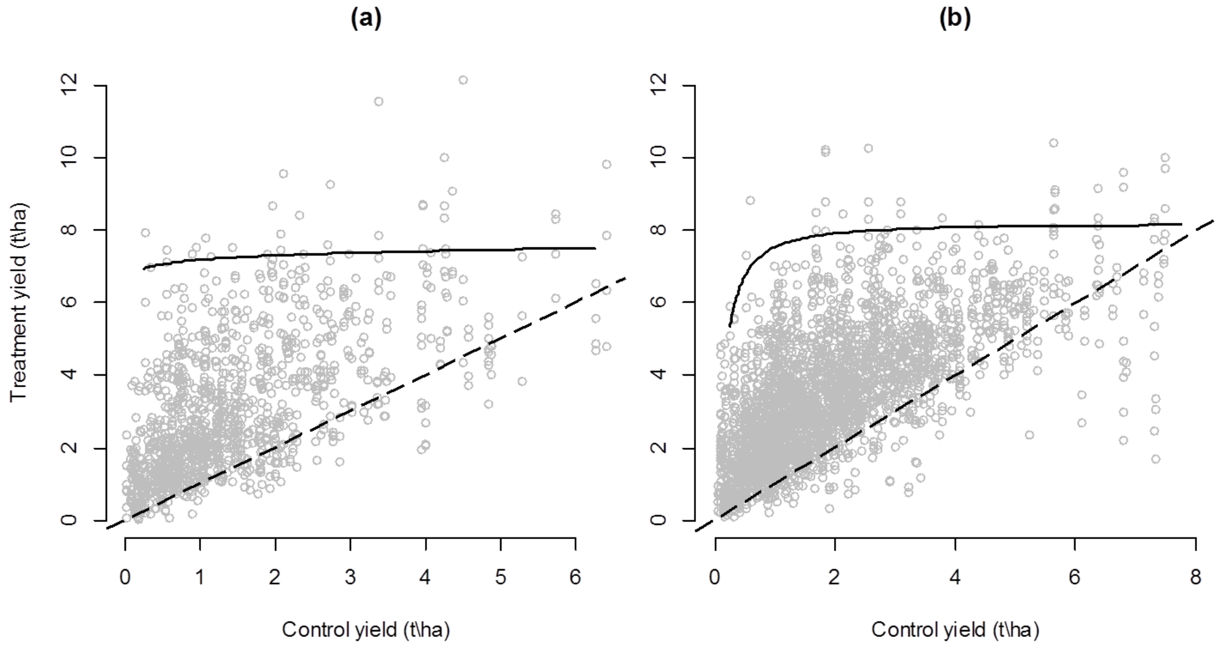

Figure 2. Response to fertilizer at different levels of control yields in SSA with AfSIS data (2009-2012; a) and FAO data (1969-1996; b). Only treatments where at least NPK or NP were applied are used for AfSIS and FAO datasets, respectively

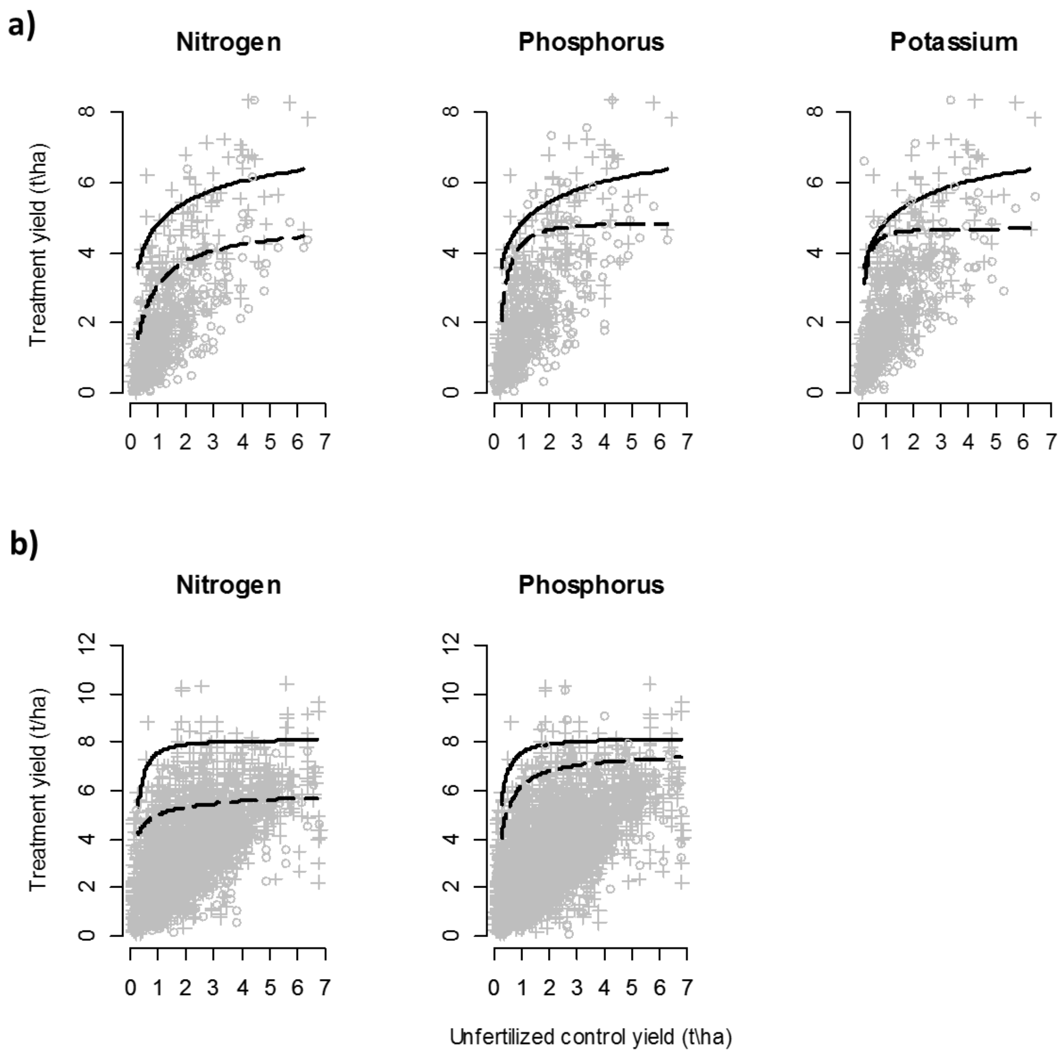

Figure 3. Effect of N, P and K omission on attainable yield at different levels of control yield in SSA based on (a) AfSIS and (b) FAO datasets. Open symbols are yields where either N, P or K are omitted and plus symbols where these nutrients are applied.

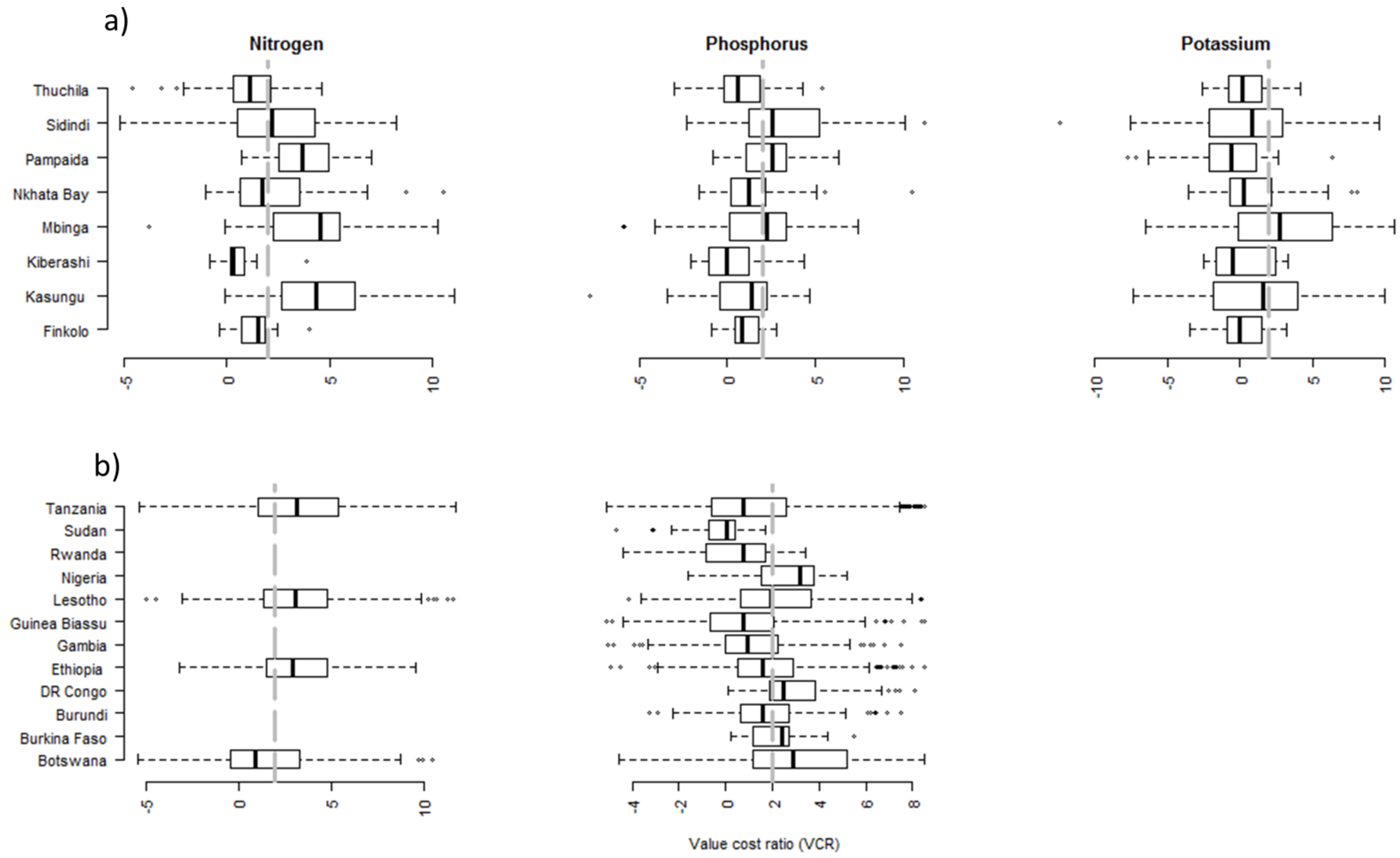

Figure 4. Distributions of value cost ratios for maize following application of N, P and K in (a) AfSIS trial sites and (b) elsewhere in SSA. Prices used are 0.81, 2.47 and 0.92 US$ per kg of N, P and K, respectively, and a median price of maize grain of 0.39 US$ per kg

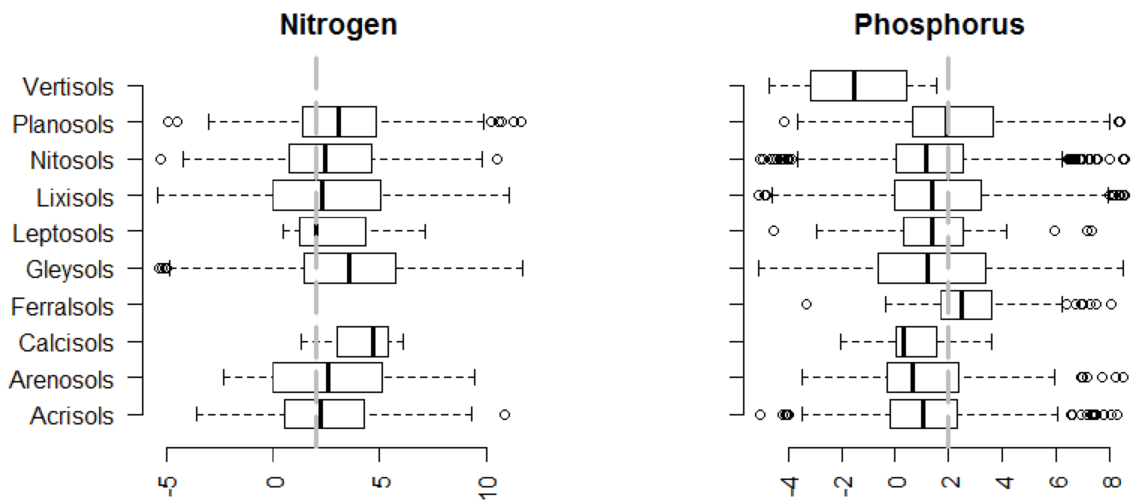

Figure 5. Distributions of value cost ratios of N and P applied to maize under different soil types in SSA. Prices used are 0.81, 2.47 and 0.92 US$ per kg of N, P and K, respectively, and a median price of maize grain of 0.39 US$ per kg

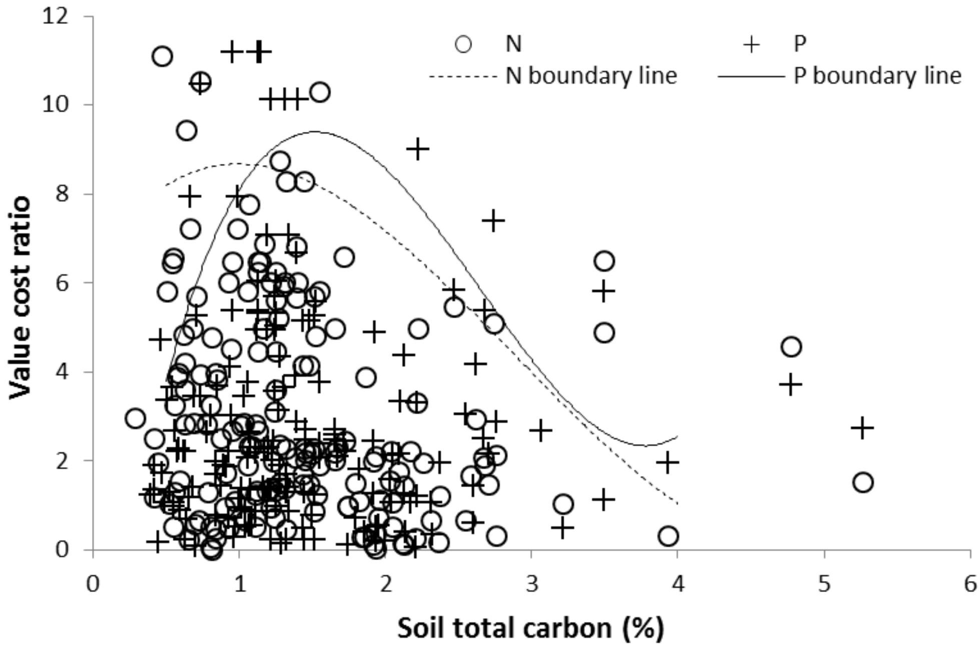

Figure 6. Effect of soil organic carbon on Value Cost Ratio of N and P fertilizers in AfSIS sites in SSA. Prices used are 0.81, 2.47 and 0.92 US$ per kg of N, P and K, respectively, and a median price of maize grain of 0.39 US$ per kg

Table 1: Description of the sites for the AfSIS trials

Site name	Seasonal rainfall	key soil conditions	Major farming system
Kiberashi, Tanzania	Bi-modal with 1000 mm of seasonal rainfall	Newly converted from forest land. Considered fertile. FAO soil group is Luvisols[†]	Maize/pigeonpea
Kasungu, Malawi	Uni-modal rainfall of 740mm during the season	Sandy loam soils mainly Luvisols and Gleysols [*]	Maize
Finkolo, Mali	Uni- modal with 1000 mm rainfall annually	Soils mainly Lixisols and Nitisols[†]	Maize
Mbinga, Tanzania	Uni-modal with 985 mm rainfall in the observation season	Cambisols and Acrisols[†]	Maize
Nkhata Bay, Malawi	870 mm in first season. Poorly distributed. 950 mm in second season and well distributed	Very variable soil texture, 50% of fields are acidic (pH <5.5), mainly Ferralsols[†]	Cassava/maize
Pampaida, Nigeria	790 mm well distributed.	Arenosols[†]	Maize/sorghum
Sidindi, Kenya	Bi-modal rainfall of 900 mm for first and 750 mm for second season. Average annual rainfall ranges from 900-1700 mm per annum.	Acidic soils with average pH of 5.1. Ferralsols and Acrisols[†] predominant	Maize/beans
Thuchila, Malawi	712 mm in season 1, poorly distributed.	Soils are mainly Lixisols[†]	Maize/pigeonpea

[*]from Ngwira et al. 2012.

[†]from Harmonized World Soil Database accessed on 7^{th} June 2013

Table 2. Percentage of cases with Value/Cost ratio of 1 and 2 in different AfSIS sites in SSA

	K % cases		P % cases		N % cases	
	V/C =1	V/C =2	V/C =1	V/C =2	V/C =1	V/C =2
Finkolo, Mali	33	14	43 (76)	24 (38)	76 (71)	33 (14)
Kasungu, Malawi	56	45	66 (33)	37 (07)	79 (68)	72 (42)
Kiberashi, Tanzania	35	30	24 (24)	24 (18)	31 (24)	6 (6)
Mbinga, Tanzania	55	48	52 (48)	48 (32)	77 (77)	74 (65)
Nkhata Bay, Malawi	35	26	55 (32)	39 (07)	66 (37)	43 (12)
Pampaida, Nigeria	30	13	77 (61)	61 (47)	91 (94)	84 (88)
Sidindi, Kenya	47	34	76 (68)	57 (45)	67 (65)	57 (38)
Thuchila, Malawi	34	17	47 (17)	25 (04)	53 (18)	33 (02)
Average	40	28	57 (43)	40 (23)	67 (53)	50 (30)

values in bracket are percentages of cases where VCR is at least 1 or 2 based on specific input costs and output prices for each country.