

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

3 Short title: Fertilizer profitability in sub-Saharan Africa

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24 **Abstract**

25 Sub-Saharan Africa (SSA) is plagued by low productivity and little research is available
26 on the attainable responses and profitability to applied nutrients under variable
27 environments. The objective of this study was to determine the attainable maize grain
28 response to and potential of profitability of N, P and K application in SSA using
29 boundary line approaches. Data from experiments conducted in SSA under AfSIS
30 project (2009-2012) and from FAO trials database (1969 to 1996) in 15 countries and
31 constituting over 375 different experimental locations and 6600 data points are used.
32 Both response to fertilizer and value cost ratio (VCR) are highly variable and no more
33 than 61% cases for N, 43% for P and 25% for K attain VCR of 2 or more. Also, based
34 on the recent AfSIS data, VCR exceeds 1 in just 67% (N), 57% (P) and 40% (K) of the
35 cases, even when best management practices are applied on a research farm, and
36 interest rates are zero. Chances for profitability are highest when soil organic carbon is
37 1 - 2% and control maize grain yield is 1 – 3 t ha⁻¹ but also depends on relatively static
38 soil properties (primarily texture and mineralogy) that are not under farmer control. We
39 conclude that return on investment of macronutrient fertilizer is highly variable and can
40 be substantially increased by helping farmers decide where to apply the fertilizers.
41 Consequently, farmers need access to information on factors influencing economic
42 returns of fertilizer use in order to make the right decisions.

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

44 **Introduction**

45 Sub-Saharan Africa (SSA) has the lowest production estimates for cereals especially
46 maize, when compared to other regions of the world (www.fao.org). The low
47 production is attributed to low soil fertility (Ngome et al. 2011; Tittonell and Giller
48 2012), and inappropriate management practices including continuous cropping with
49 little or no nutrient replenishment. The level of soil fertility varies across landscapes
50 and even within farms (Diwani et al. 2013; FAO 2003; Zingore et al. 2007). Nitrogen
51 (N), phosphorus (P) and potassium (K) are considered as the major limiting nutrients
52 for crop production in SSA (Adediran and Banjoko 1995). Variable yield increases
53 have been reported following fertilizer application of these nutrients, but a
54 comprehensive assessment of the economic benefit of the nutrients under the various
55 soils and climate regimes in SSA has not been undertaken. It is important to provide
56 the African decision-maker with information on the potential for profitability and an
57 assessment of thresholds that can be expected when key nutrients are applied at the
58 commonly recommended rates.

59 Huge yield gaps are often reported in Africa and experimental results often show higher
60 yields than those obtained with farmer practices even at the same level of fertilizer input
61 (Yanggen et al. 1998). The premise is that researchers use best agronomic practices,
62 resulting in the higher yields. Such experimental data therefore provide an opportunity
63 to construct boundaries of attainable yield for different production environments.
64 Recently, large datasets from across SSA have become available such as recent
65 diagnostic trial data from the Africa Soil Information Services (AfSIS) project
66 (<http://afsis-dt.ciat.cgiar.org/>) and older fertilizer response trials data from the Food
67 Agriculture Organization of the United Nations (FAO Fertibase). Boundary lines of
68 nutrient responses from such datasets can indicate the attainable response to applied

69 nutrients under variable environments. Boundary lines represent the yield ceiling for
70 the application of a given fertilizer or nutrient under investigation and they have been
71 used elsewhere (Imhoff et al. 2010; Tasistro 2012). In case of nutrient omission trials
72 they provide insight in the level to which the attainable yield is limited by omission of
73 a nutrient. In this study, the focus was on the most important macronutrients in SSA
74 namely, N, P and K.

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

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

92 **Methodology**

93 Description of study sites and data

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

101 Figure 1 here

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

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

120 Table 1 here

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

123
$$\text{VCR} = \frac{\text{Additional maize yield in kg due to nutrient application} \times \text{maize price (per kg)}}{\text{Amount of a nutrient applied in kg} \times \text{price of the nutrient (per kg)}}$$
, based on

124 the average nutrient and maize grain prices for the last 6 years (2008-2015). In
125 economic terms, a VCR value greater than 1 means that cost for fertilizer is recovered
126 while a VCR of 2 represents 100% return on the money invested in fertilizer. A VCR
127 of 2 is often considered as a minimum for deciding to invest in a technology and is
128 taken here to represent potentially profitable cases. Fertilizer price was obtained from
129 www.indexmundi.com accessed on 8th April 2013 as 0.81, 2.47 and 0.92 US\$ per kilo
130 of N, P and K, respectively, being an average over the last 5 years. Since Eastern Europe
131 Free On Board (FOB) prices of fertilizers are about 50% of farm gate prices within SSA
132 (Ariga et al. 2006), we multiplied each of the nutrient costs by 2 when deriving
133 thresholds of potential profitability. Maize price per kilogram was obtained from the
134 food security portal (www.foodsecurityportal.org, accessed on 15th April 2015) as the
135 median price of 0.39 US\$ (range was 0.11 - 0.97) based on monthly prices for February
136 2008 to February 2015 period from DR Congo, Ethiopia, Kenya, Malawi,
137 Mozambique, Niger, Nigeria and Uganda. Thus to cover the cost each kilogram of
138 applied nutrient should result in at least 4.8, 14.5 and 5.4 kg additional grain for N, P
139 and K, respectively. The above fertilizer and maize prices are used for the calculations
140 of VCR presented in the figures.

141 Because of variability in prices and costs of outputs and inputs expected from country
142 to country, country-specific values were used for the AfSIS dataset. Thus, in addition
143 to the above analyses, current costs of N and P for each of 5 AfSIS countries was used
144 to assess changes in profitability potential. Here, the cost of N is 0.65, 1.68, 1.13, 1.04
145 and 1.04 US\$ for Nigeria, Malawi, Mali, Kenya and Tanzania, respectively. Similarly,
146 the cost per kg P is 3.89, 4.50, 2.03, 3.21 and 3.21 US\$ for Nigeria, Malawi, Mali,
147 Kenya and Tanzania, respectively. Price of maize per kg also varied being 0.39, 0.307,
148 0.46, 0.345 and 0.32 US\$ for Nigeria, Malawi, Mali, Kenya and Tanzania, respectively.
149 These are averaged 6 year monthly maize prices.

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

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

159 Statistical analysis

160 Different approaches were used in the data analysis. First, scatter plots of treatment
161 yield against control yield, and value cost ratio against soil organic carbon (SOC) were
162 constructed. For these, boundary lines representing the maximum value of a dependent
163 variable that can be achieved at different values of the independent variable (Shater and
164 McBratney 2004) were added. To construct the boundary line the data was grouped

165 based on the control yield into classes of 0.5 t ha⁻¹ interval and the 5 observations with
166 highest treatment yield in each class averaged. These average values for each class were
167 used for boundary line fitting. The boundary lines were fit both for the treatment where
168 a nutrient was omitted and also where this nutrient was applied. The boundary lines
169 were fit to the data as non-linear 3-parameter log logistic models using package drc, a
170 general dose response curve fitting function in R (www.r-project.org). The graphs were
171 plotted using R. In all cases where the control yield is reported in the x-axis, this refers
172 to the absolute control. Similarly, to construct boundary line for the VCR against SOC,
173 VCR data points were arranged into SOC classes with a 0.2% interval and the 5
174 observations with highest VCR in each class averaged and boundary lines fitted as
175 explained for control yield.

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

180 **Results**

181 Maize response to fertilizer varied greatly at all levels of control yield (Figure 2).
182 Maximum yield level in case of the FAO data is around 8 t ha⁻¹ and slightly less in case
183 of the AfSIS data. As expected, the highest response to fertilizer, which is indicated by
184 the difference between the boundary line and the 1:1 line, is obtained at low control
185 yields. A maximum of 6 t ha⁻¹ yield increment over the control was obtainable at low
186 fertility (control yield of between 0.5 and 1.5 t ha⁻¹). From the analysis, very limited
187 response to fertilizer is expected when control yields are more than 6 t ha⁻¹. When

188 considering a response of less than 0.5 t ha^{-1} to be insignificant, then in 25% of the
189 cases for AfSIS and 20% of the cases for FAO the response is very poor to none.

190 ~~Figure 2~~ here

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

206 ~~Figure 3~~ here

207 The potential for profitability, assessed based on VCR, is variable for the 3 macro-
208 nutrients (Table 2 and Figure 4). Based on the 288 field trials in the case of AfSIS, in
209 33% of the cases the response to N is not enough to cover the cost of the fertilizer,
210 whereas only in 50% of the cases is some profit expected (VCR of 2 or higher; note:
211 with N application rate of 100 kg ha^{-1}). In case of P, in 43% of the cases no return on

212 investment is expected and in 40% investment in P fertilizers is considered profitable.
213 In the case of K application, 60% has a VCR of 1 or less and in 25% of the cases attain
214 a VCR of 2 or more. Overall, chances of profitability are reduced only 2 to 5 (data not
215 shown) and up to 14 to 20 percentage points when varying the price of maize and both
216 price of maize and cost of fertilizer by country, respectively. Disaggregating by the
217 individual sites, the percentages at which the VCR for K is at least 1 range from 30%
218 for Pampaida to 56% for Kasungu, and for VCR of 2 or more from 13% to 48%
219 (Mbinga) (Figure 4a and Table 2). Only three sites, i.e., Mbinga, Sidindi and Kasungu
220 had more than 30% of cases with a VCR of 2 or more for K. For P the percentage of
221 cases with a VCR of at least 1 or at least two ranges from 24% (Kiberashi) to 77% and
222 from 24% to 61% respectively, with most responsive sites being Pampaida, Sidindi and
223 Mbinga. In Kiberashi in Tanzania, only 24% of cases obtained a VCR at least 1
224 following P application. It was also the only site where N application resulted in less
225 than 30% of cases attaining a VCR of 1 or more. Profitability of N application was in
226 at least 50% of the cases in 4 of the 8 sites studied. Similar results are observed with
227 FAO dataset with generally more cases of N than of P attaining a VCR of 2 (Figure 4b).
228 Indeed, of the 3,999 data points of P application and the 1,490 data points of N
229 application in historical data from FAO, the cases with a VCR of at least 2 are 61% for
230 N and 43% for P (those with VCR of at least 1 are 74% for N and 60% for P).

231 ~~Figure 4~~ here

232 ~~Table 2~~ here

233

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

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

241

242 ~~Figure 5~~ here

243

244 Maximum VCR for P application is attainable on soils with a soil organic carbon
245 percentage of about 1.5% (Figure 6). The maximum attainable VCR decreases when
246 SOC is >2% indicating low response due to high control yield. The maximum attainable
247 VCR decreases sharply with SOC levels below 1%, indicating poor soils. For N
248 application the highest attainable VCR are observed when soil organic carbon is around
249 <1.5%, and like with P seems to decline sharply with decreasing SOC levels.

250 ~~Figure 6~~ here

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

257

258 **Discussion**

259 Yields and responses to N, P and K

260 The yields observed from researcher designed experiments in SSA as presented in this
261 study are in a majority of cases still lower than the average maize production in Asia
262 (4.9 t ha⁻¹), Europe and America (over 6.6 t ha⁻¹; www.fao.org, accessed on 10th April
263 2013). In a previous meta-analysis by Kihara and Njoroge (2013) in western Kenya, a
264 region that is perhaps most researched in SSA, they observed yields far below the yield
265 potential. The observed maximum yields from this data set stagnated at around 7-8 t/ha
266 regardless of the control yield, very similar to the results reported earlier for western
267 Kenya (Kihara and Njoroge 2013). The low maximum yields can be attributed to the
268 fact that the dataset used is derived from plots where no other nutrients (e.g., secondary
269 and micronutrients) had been applied apart from N, P and (to some extent) K. Others
270 have argued that yield potential of improved varieties in SSA is not realized because of
271 soil degradation that has also reduced rainfall effectiveness (Lal 2010). In our case, data
272 presented is generated under best management by researchers in the case of AfSIS, and
273 a similar assumption can be made for the FAO dataset. This study does not investigate
274 the causes of the large variation in response to nutrient application, but it does indicate
275 that opportunities to obtain high yields through the proper management of N, P and K
276 nutrients vary from one site to the other and that more insight is needed in the site
277 specific production constraints in order to achieve the potential. The wide yield gap in
278 SSA present a huge opportunity for yield improvement through integrated crop
279 production management.

280 Response to fertilizer by crops in high fertility fields is often lower compared to those
281 in low fertility fields (see also Tiftonell et al. 2008b; Zingore 2011). This means that

282 agronomic efficiency and chance of profitability are decreased in the high fertility fields
283 (i.e., those with high control yields) as observed in this study. Potassium has often not
284 been considered as a limiting nutrient by most researchers in SSA and as a result K has
285 received much less focus compared to P and N. Results from this study indicate,
286 however, that K becomes limiting at higher yield levels (above about 4.5 t ha⁻¹), and
287 that a clear response to K application is often observed, but that this is site specific
288 (large variation between sites and within sites). N is the most limiting macronutrient
289 for maize in SSA, in agreement with findings from other researchers (Adediran and
290 Banjoko 1995; Wopereis et al. 2006).

291 Majority cases of low crop response to N, P and K (see also Vanlauwe et al., 2011,
292 Kihara and Njoroge 2013) could result from uncorrected soil acidity (Ngome et al.
293 2011), unbalanced nutrition where micronutrients for example are limiting (Subedi and
294 Ma 2009), application methods and timing (Oloredo et al. 2013), low soil moisture or
295 drought (Holford and Doyle 1993), and where farmer conditions are considered, weeds
296 (Tittonel et al. 2008a) and other management factors. As noted by others, fertilizer
297 application must be in line with the specific niche and include adaptation to site-specific
298 conditions in order to realize the potential response of crops to fertilizer use (Tittonell
299 et al. 2008b; Ngome et al. 2010; Vanlauwe and Zingore 2011). The challenge here is
300 that not much is known about local soil condition and site specific nutrient limitations
301 (beyond N and P). Also, under farmer conditions, causes of sub-optimal crop stands,
302 mainly due to in-season plant losses (e.g., termites, Akinnifesi et al. 2010), stem borer
303 (with yield losses of up to 17%; Vitale et al. 2007) and low planting densities, identified
304 by Kihara et al. (2015) are key factors contributing to low yields. Higher incidences of
305 pest damage are linked to poor soil fertility (Wale et al. 2006) hence the need to focus
306 on overall fertility improvement as well. Proper agronomic management could reduce

307 the yield gaps observed in SSA (Chikoye et al. 2004; Kihara et al. 2015) while
308 continued soil degradation may widen the yield gaps further (Tittonell and Giller 2012).

309

310 Profitability of fertilizers

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

331 low to high plant-available soil P (see also Phiri et al., 2010), chances of profitability
332 (VCR>2) were low, being only 25-39%.

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

339 Note that the generally low profitability rates indicated in this paper (though varying
340 strongly between and within sites) are notwithstanding the assumed good management
341 practices and will be lower under farmer's practice. Perceived profitability of fertilizer
342 by farmers in SSA is important determinant of adoption rate (Donovan et al. 2002)
343 especially considering the current blanket recommendations (Xu et al. 2009). Also the
344 profitability are given for fixed nutrient application rates in case of the AfSIS data, and
345 that profitability may increase with lower application rates. In Zambia, Donovan et al.
346 (2002) observed profitability only with the low and medium doses, while Xu et al.
347 (2009) found timeliness of fertilizer availability, remoteness of farm location, family
348 social tragedies and the use of animal or mechanical draught power in land preparation
349 to significantly affect fertilizer profitability. From our analysis, the profitable options
350 cut across the whole range of control yields reported, which is a great opportunity for
351 SSA, although diminishing returns are expected as the yields approach the boundary
352 line (Koning et al. 2008).

353 This study is the first comprehensive report on potential of fertilizer profitability for
354 maize in SSA. The potential for profitability of a nutrient in this study is undertaken

355 when the other macronutrients are not limiting. More studies are needed to inform
356 stakeholders on profitability of fertilizers for specific locations and for other crops as
357 well, and especially under farmer practices. Also, as noted by Druilhe and Barreiro-
358 Hurlé (2012), input and output prices vary widely even across different locations within
359 a country depending on the remoteness hence the need for further profitability
360 assessments disaggregated by regions within countries.

361 **Conclusions**

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

379

380

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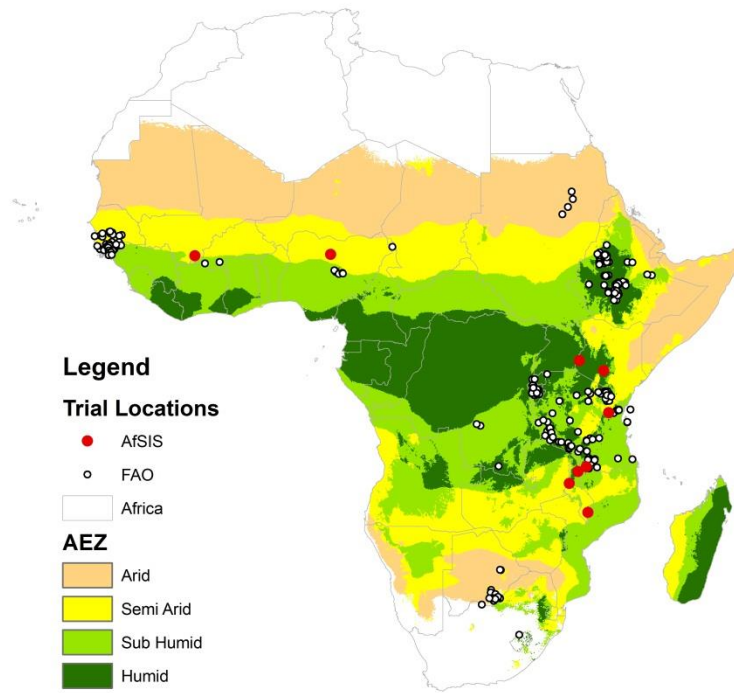
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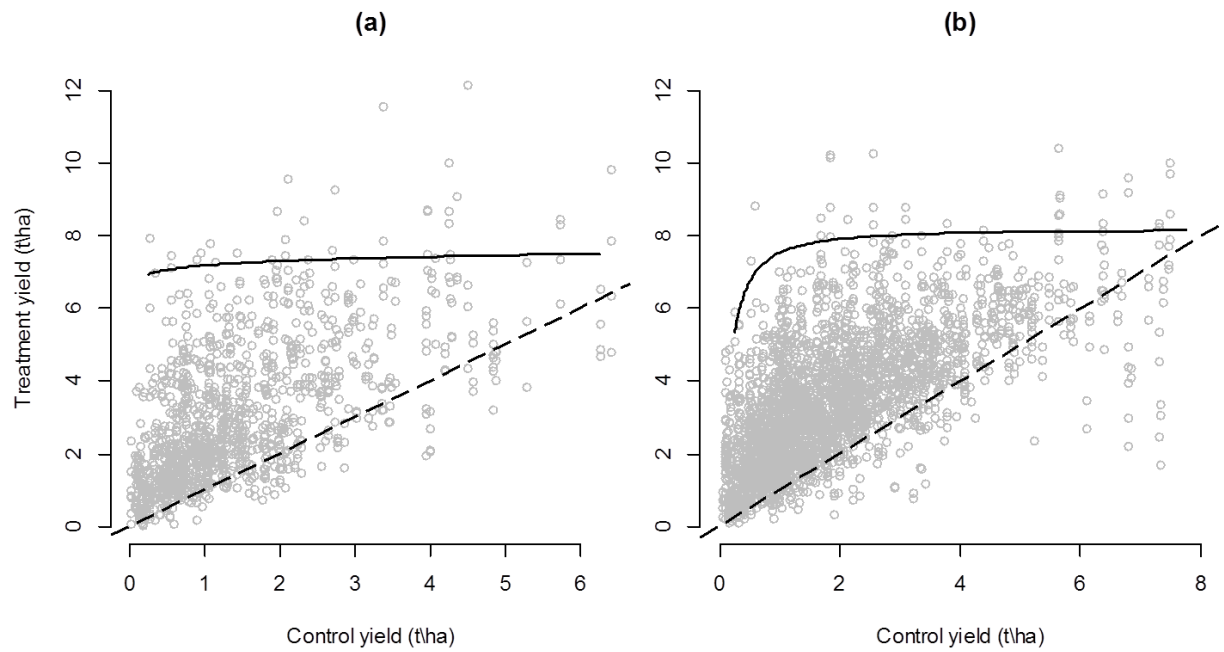
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547 Figure 1. Location of trials used for the FAO and AfSIS datasets

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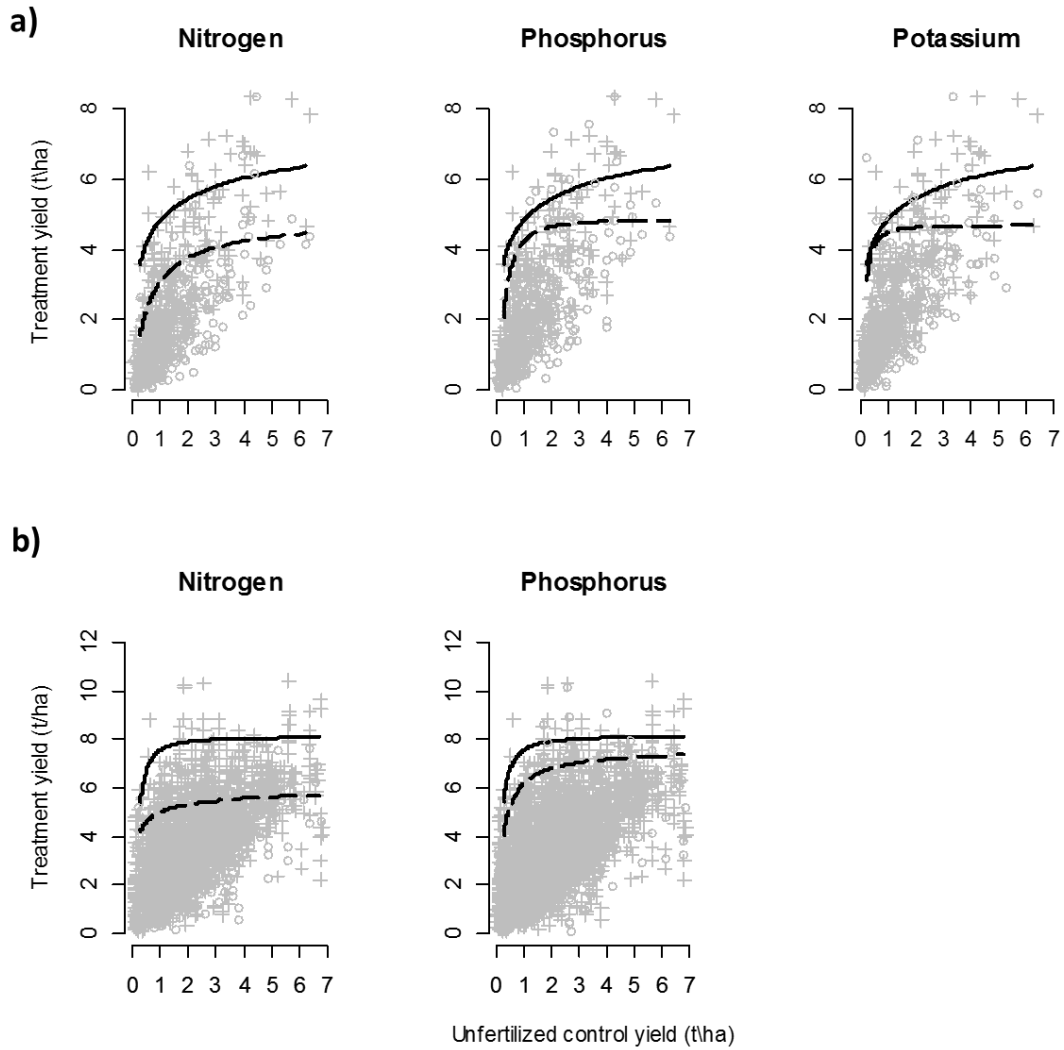
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550 Figure 2. Response to fertilizer at different levels of control yields in SSA with AfSIS

551 data (2009-2012; a) and FAO data (1969-1996; b). Only treatments where at least

552 NPK or NP were applied are used for AfSIS and FAO datasets, respectively

553



554

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

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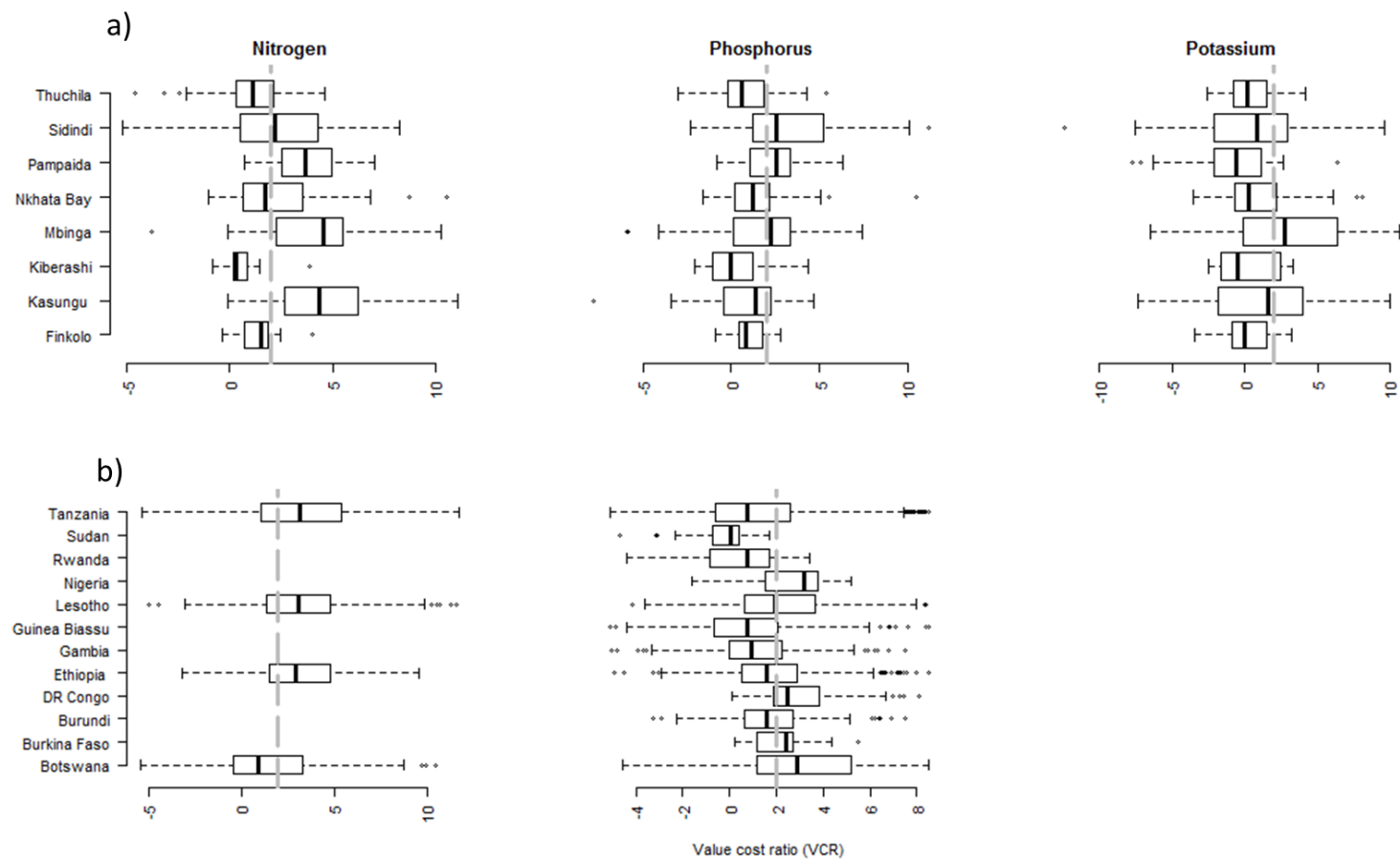
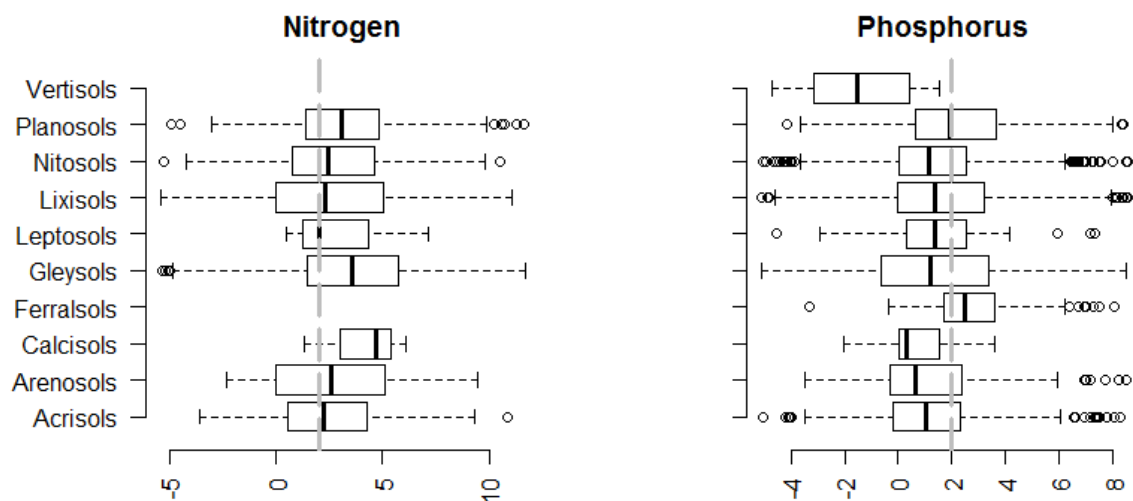


Figure 4. Distributions of value cost ratios for maize following application of N, P and K in (a) AfSIS trial sites and (b) elsewhere in SSA. Prices used are 0.81, 2.47 and 0.92 US\$ per kg of N, P and K, respectively, and a median price of maize grain of 0.39 US\$ per kg

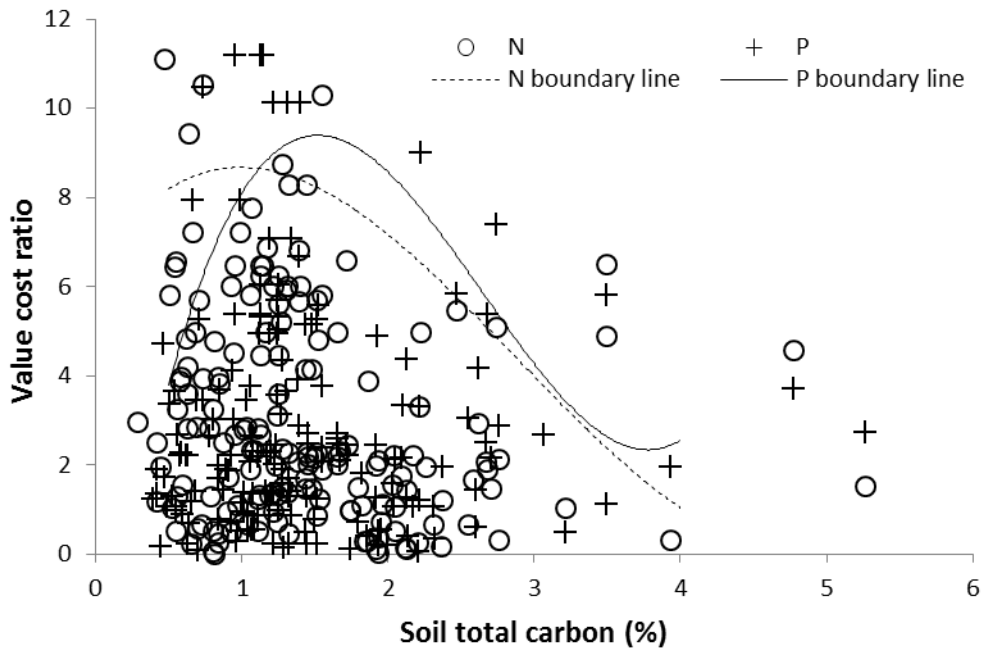


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2 Figure 5. Distributions of value cost ratios of N and P applied to maize under different soil
 3 types in SSA. Prices used are 0.81, 2.47 and 0.92 US\$ per kg of N, P and K, respectively, and
 4 a median price of maize grain of 0.39 US\$ per kg

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

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12

13 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

14 *from Ngwira et al. 2012.

15 [†]from Harmonized World Soil Database accessed on 7th June 2013

16

17 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)

18 values in bracket are percentages of cases where VCR is at least 1 or 2 based on specific input

19 costs and output prices for each country.