WAGENINGEN UNIVERSITY & RESEARCH

MSc Minor Thesis

Plant Production Systems

Assessing on-farm performance of improved technology interventions on legume production by smallholder farmers in Sub-Saharan Africa.

Assessing on-farm performance of improved technology interventions on legume production by smallholder farmers in Sub-Saharan Africa.

Name of student:	Betty Rutendo Masamba
Registration number:	730121546050
Study programme:	MSc Plant Sciences – Specialization Natural Resource Management.
Chair group:	Plant Production Systems (PPS)
Course code:	PPS-80424
Date:	March 2019
Supervisor:	dr.ir. J. van Heerwaarden
Examiner:	dr.ir. Katrien Descheemaeker

WAGENINGEN UNIVERSITY & RESEARCH

Abstract

Grain legumes are an important component of smallholder farming in SSA, but yields are still below potential. Drought and poor soil fertility are the major causes of low productivity in the region. Farmers are also resource constrained and cannot afford to buy enough fertilizers to improve productivity. N2Africa, a project that aims to improve soil fertility and increase grain legume cultivation and productivity in SSA, supplied farmers with P-fertilizer, improved varieties, inoculant and agronomic practices recommendations. The aim of our study was to assess on-farm performance of these improved interventions. On-farm try outs in Bush bean, climbing bean, cowpea, ground nut and soya bean were assessed in Ghana, Nigeria, Tanzania and Uganda during the 2016 and 2017 growing seasons. Improved interventions performed better than farmers 'own interventions in all crops across countries but large yield and response variability existed between crops, farms and countries. Average crop yields and responses were consistent with the literature, although our estimates of the latter may have been lowered by the exclusion of control plots in our calculations. The effect of improved varieties on yield was more evident than that of P and inoculant, most likely due to the relative lack of appropriate, independent, on-farm contrasts for the latter two. Particularly, P comparisons were mostly across and not within farms and this could have affected the outcome.

Key words: improved intervention; Phosphorus; improved variety; inoculant; smallholder farmers

Table of Contents

List of figures

List of Tables

1 Introduction

Sub-Sahara Africa (SSA) is affected by food insecurity (Lipper *et al.,* 2014), and receives more food aid than other regions (Clover, 2003). In many parts of SSA, crop production remains the key agricultural activity, but productivity is very low, contributing to food insecurity and poverty (Cleland and Machiyama, 2017; Jeng, 2014). About 95% of low input agriculture is carried on highly weathered and low fertile sand soils (Jeng, 2014), under very low and unreliable rainfall (Muza *et al.*, 1996). Yields from rain fed maize (Van Ittersum *et al.,* 2016), as well as grain legumes (Ronner et al., 2016), are considerably below their potential. High costs of fertilizers (Mtambanengwe and Mapfumo, 2009), lack of improved varieties (Ronner et al., 2016) and poor market access (Ojiem et al., 2006a), have also contributed to low crop yields among the low input smallholder farmers. Increasing crop productivity per hectare (ha) and income among these farmers, is key to ensuring food security in SSA (Lipper et al., 2014; Van Ittersum et al., 2016).

Nitrogen (N) and phosphorus (P) availability are the major constraints to food production in SSA (Bationo et al., 2007; Okalebo et al., 2006). P is the most limiting major nutrient in crop production since no other element can replace its role in biochemical and physiological processes (Syers et al., 2008). It can be added to the soil through inorganic fertilizers, crop residues and manure (Bouwman et al., 2009; Sattari et al., 2012). P can become immobilized after application hence unavailable to plants (Jeng, 2014). N can be added to the soil through inorganic fertilizers, manure, crop residues and biological nitrogen fixation (BNF) (Cassman et al., 2002; Khan et al., 2007). Both nutrients can be lost through leaching, soil erosion and crop uptake (Giller *et al*., 2011; Matson *et al*., 1998; Rufino *et al*., 2006; Tilman *et al.*, 2002).

Most low input smallholder farmers fail to return lost N and P sufficiently to the soils, due to inadequate inorganic fertilizers and manure availability (Tittonell and Giller, 2013) leading to preferential application (Tittonell et al., 2005). This is when farmers apply fertilizer and manure to fields of main or staple crops and neglect minor crops due to insufficiency of the inputs. Manure is not available in large quantities to meet crop requirements (Giller *et al.*, 2011; Rufino *et al.*, 2006). Inorganic fertilizers are very expensive and farmers cannot afford them (Sanchez, 2002). Sustainable agricultural interventions such BNF (Giller et al., 2011) and fertilizer micro dosing, (Bielders and Gérard, 2015) can reduce fertilizer costs and improve crop yields in SSA.

BNF is an important alternative of inorganic N-fertilizer, and is central to sustainable agriculture intensification in low input farming systems of the SSA (Dakora and Keya, 1997; Giller, 2001). Legumes are a necessity for BNF in agroecosystems (Ledgard and Steele, 1992; Peoples et al., 1995). The amount of N fixed can meet more than half the amount required by the legume crop (Giller, 2001; Peoples et al., 2009; Peoples et al., 1995). This depends on legume type and variety (Mafongoya et al., 2006), availability of P (Adjei-Nsiah *et al.*, 2018), and environment (Franke et al., 2008). Legume residues left in the field increase soil nitrogen up to 140kg N/ha, although it depends on the type of legume crop (Giller, 2001). Grain legumes improve household food security, daily nutrition and income for smallholder farmers (Burstin et al., 2011; Ruganzu et al., 2014). Smallholder farmers typically grow grain legumes with little or no fertilizer and use local varieties (Franke et al., 2014; Van Vugt et al., 2017), leading to a yield gap with respect to potential water limited yields (Mueller et al., 2012; van Ittersum et al., 2013; Van Ittersum et al., 2016).

Some additional causes of legume yield gaps from previous studies on SSA are poor soil fertility, weed infestation, lack of access to chemical inputs and improved varieties. Improved technology interventions have been introduced in SSA to reduce grain legume yield gaps (Kamanga et al., 2010; Ronner et al., 2016). These interventions include, improved varieties (Buruchara et al., 2011), P-fertilizers (Kamanga et al., 2010; Kamara et al., 2007), inoculants and agronomic practices (Franke *et al.*, 2014; Ronner *et al.*, 2016). Examples of agronomic practices are weeding, time of sowing and pest and disease control, soil fertility management and soil and water conservation (Singh et al., 2012). Weeds, drought, pests and diseases reduce crop yields if controlled late or not controlled (Van Ittersum et al., 2016). P improves micronutrient uptake, nodulation, flower, fruit and seed development during legume production (Kamanga *et al.,* 2010; Karikari *et al.*, 2015; Ndakidemi and Dakora, 2007). P-fertilizers (30 kg/ha P) increased grain yield by 296, 527 and 390 kg/ha for cow pea, ground nut and soya bean grain respectively (Adjei-Nsiah *et al.*, 2018).
These results show that improved technology interventions have the potential to improve grain legume productivity among low input smallholder farming systems in SSA (Franke *et al.*, 2014; Giller, 2001).

Most researchers have assumed that improved legume technology interventions increase grain yields in SSA, yet this is not always the case. There is a lot of variability in on-farm performance as evidenced by recent studies on researcher managed on-farm trials. Lack of labour investment, adquate inputs and poor markets may lead to poor outcomes (Ojiem et al., 2006; Vanlauwe and Giller, 2006). Farmer's priority on certain crops entails neglecting others and results are affected. Yield variability across different farms implies that some farmers will not observe the benefits of improved technologies when evaluated without replication on their farms (van Heerwaarden et al., 2017). Variability at field level means that there is also variability of the benefits obtained by different farmers, yet this can be reduced by having multiple comparison plots (adaptation trials) on the farm. The plots' performance can then be compared to farmer's main fields, and this is rare in most literature studies. There was a lot of variability on on-farm soya bean performance due to location and field differences (van Heerwaarden et al., 2017).

The objectives of this study were to assess on-farm performance of improved grain legume interventions amongst smallholder farmers in SSA, and to establish the average grain yield increase is due to P-fertilizer application, improved varieties or intervention-specific management practices. Bush bean, climbing bean, cowpea, groundnut and soya bean were assessed for two growing seasons (2016 and 2017) in Ghana, Nigeria, Tanzania and Uganda under the N2Africa project, an improved intervention. To answer the objectives, the following research questions and hypotheses were defined.

Research questions

1. What is the yield and response to improved interventions per crop /country?

- How does this compare with existing literature?

2. Can the yield and responses be explained by P-fertilizer, improved variety, inoculant or management practices?

2 MATERIALS AND METHODS

2.1 Study areas

Fig. 1.Countries that participated in N2Africa adaptation trials in 2016 and 2017.

The data for analysis was collected from focal adaptation trials during 2016 and 2017 growing seasons. Focal adaptation trials are comparative experimental plots close to each other or within the farmer's fields. Assessed farmers were from Ghana, Nigeria, Uganda and Tanzania who participated in trials of bush bean, climbing bean, cowpea, groundnut and soya bean (Farrow *et al.*, 2015). Data came from two consecutive questionnaires on each farm, where the farmer used improved technology interventions on one plot (N2Africa plot) and his usual practices on another plot (Own plot), (Bravo, 2017; Franke *et al.*, 2014). Only farmers with own and N2Africa plots were selected. Plot sizes varied across farmers with 100m² being the standard.

A package of improved interventions (improved varieties, P-fertilizer and recommended agronomic practices) - or part of it - was used in N2Africa plots. In own plots, farmers used their own inputs (Farrow *et al.*, 2016). The plots were close to each other for easy monitoring and evaluation of on-farm performance of the improved technology interventions. The data collected included agronomic, climatic, geographical, socio-economic, and social data, but variables relevant to this study were only selected. These include country, crop species, input use, management practices and estimated grain yield.

2.2 Literature review

In this section, grain yield and response to N2Africa treatments were compared to literature studies to evaluate whether on-farm perfomance of improved interventions is similar to findings from literature. The analysis was based on the effect of P only. The duration of study (number of years taken for the study) and the presence of improved varieties and inoculant both in literature and in N2Africa plots were ignored. Crops assessed were bush bean, climbing bean, cowpea, ground nut and soya bean.

The literature data was from different countries in SSA, under a wide range of soil types, varying climatic conditions and different P-application rates. Only literature studies that had control and P treatments were selected for the analysis. Yield data which were over exaggerated and did not conform to Table 1 (section 2.3) were removed for analysis. For literature data, yield with P, control and response (P yield minus control yield) were averaged for all studies per crop using Excel.

For N2Africa, a mixed model was used to find the predicted yield means for each crop and own plots were excluded for this analysis. Yield data for 2016 and 2017 was used. Farms that did not receive P-fertilizer in the N2Africa package were considered as the control plots. The means for each crop, for the two years were added and then averaged for (P+, P- and response) in Excel. The standard error for each crop, both from literature and N2Africa plots were calculated in Excel and then plotted using R statistical package. The obtained literature data was then compared to N2Africa results to see whether improved interventions are in line with what has been documented in literature. Data from literature was put in appendix 8.1.

2.3 Data analysis

A descriptive statistical analysis was performed using R Studio in R version 3.4.3. Farms with two comparable plots (N2Africa and Own) were selected for analysis. Normal distribution of residuals was checked using Q-Q plots. Yield data greater than attainable yield (Table 1) were left out of analysis. Yield values of zero and non-reported data were considered as NAs. We assumed that all farmers used improved varieties in N2Africa plots in 2016 due to missing data.

Table 1. Attainable grain legume yields under rain fed conditions in SSA.

Crop	Attainable yield kg/ha	Reference
Climbing bean	4.0	(Atlas, 2015) & Prota4u,nd
Common bean	3.0	(Atlas, 2015) & Prota4u,nd
Cowpea	3.0	(Atlas, 2015) & Prota4u,nd
Groundnut	3.5	(Atlas, 2015; Kaizzi et al., 2012)& Prota4u,nd
Soya bean	3.0	Prota4u,nd

Mixed effects models were used to estimate average legume grain yield of both N2Africa and own plots. Analysis of variance (ANOVA) was done to evaluate whether there was a significant effect of each factor and interaction on yield with significant level at P=0.05. Mean yields were estimated using two main models. The types of models were used to answer the research questions.

We used the following model (yield ~ plot type + farm_id) to test the effects of improved interventions on yield per crop and per country. Yield was the response variable. Plot type and farm_id were fixed and random factors respectively. A random factor was necessary to cater for variability at field and farm level (Bates, 2010). No data subsetting was done for this analysis. Yield response was the difference between N2Africa and own yield. The package predict means (Welham et al., 2004), was used to estimate mean yields of the plots. Least significant difference (LSD) at P=0.05, was used to determine which means were significantly different from each other.

In order to test the specifc effects of P, improved variety (V) and inoculant (I), we used the model (yield ~ P * V * I + farm_id). Yield data was dissected into these factors for 2017 yield results only because data for improved variety in N2Africa plots was missing in 2016. We fitted an interaction where it was possible. Yield was the response variable while P, V and I were fixed effects and Farm id was the radom term for the model. P was common in all assessments.

We assumed that all own plots did not have improved varieties, since the varieties did not come from the N2Africa package. Data on the actual amounts of applied P was missing, we then assumed that the presence of P in the N2Africa package meant farmers used it. The model was also used to find the actual number of farmers that used certain input combinations per crop per country. An ANOVA was used to identify means that were significantly different at *p*=0.05.

Inorder to remove the effect of management on yield, a subset of N2Africa plots with either P-applied or improved variety only was done. Only 2017 data was used because it had effects of both P and improved variety. A simple linear model (yield ~ variety) was used with variety and P as fixed factors, and yield as the response variable. An ANOVA was used to check whether there were any significant differences between the means.

3 Results

The first part of the result section focused on how improved technology interventions (N2Africa plots) performed compared to farmer's own practices (own plots) per crop per country. The second part focused on individual effects of improved interventions on yield. The last part focused on the performance of improved technology interventions in comparison to literature findings.

3.1 Yield response to improved interventions

On-farm performance of improved technology interventions was assessed for bush bean, climbing bean, cowpea, ground nut and soya bean in 2016 and 2017 growing seasons. N2Africa plots had improved interventions and own plots had farmer's own interventions. Tables 2 and 3 summarized crop yield and response to improved technologies per crop per country for the two growing seasons. The Least significant difference (LSD) at p=0.05, was used to determine means that were significantly different from others.

Generally, for the two years, improved interventions increased yields in all crops except in bush bean in Uganda during the 2017 season (Table 3). Farmer's own interventions perfomed better than improved interventions in these adaptation trials although no significant differences were present. Yield response in bush bean in Uganda was not significant for the two years. The sample sizes for these bush bean adaptation trials were very small, (Tables 2 and 3) and could have affected the outcome.

In 2016, there were significant yield responses between improved and farmer's own interventions for all crops except in bush bean in Uganda (Table 2). Highest significant yield responses to improved interventions in 2016 (617 kg/ha, LSD = 78.24) were observed under soya bean adaptation trials in Nigeria, and the lowest (25 kg/ha, LSD = 244.15) was from bush bean trials in Uganda.

For 2017, significant yield response differences were observed in all crops across countries except in bush bean in Uganda. Highest yield responses to improved interventions (770 and 738 kg/ha) from Tanzania, cowpea and bush bean adaptation trials were very significant (Table 3).

Table 2. 2016 Average crop yield response to improved interventions (N2Africa minus own) (LSD=0.05).

				Yield (kg/ha)				
Country	Crop	N	Treatment	Mean	Response	LSD	SED	SE means
Nigeria	Soya bean	152	N2Africa	1597				
		152	Own	980	617	78.24	39.60	49.06
Ghana	Soya bean	74	N2Africa	1224				
		74	Own	843	381	66.22	33.22	59.94
Ghana	Ground nut	69	N2Africa	1382				
		69	Own	901	481	100.88	50.55	70.82
Nigeria	Ground nut	36	N2Africa	910				
		36	Own	650	260	203.27	100.13	112.40
Tanzania	Ground nut	34	N2Africa	865				
		34	Own	463	402	134.47	66.10	74.66
Tanzania	Bush bean	216	N2Africa	498				
		216	Own	339	159	37.42	18.99	21.17
Uganda	Bush bean	12	N2Africa	472				
		12	Own	447	25	244.15	94.98	217.16
Nigeria	Cowpea	38	N2Africa	834				
		38	Own	490	344	128.16	63.25	59.28
Tanzania	Cowpea	161	N2Africa	710				
		161	Own	360	350	41.05	20.79	37.96
Uganda	Climbing bean	52	N2Africa	1607				
		52	Own	1274	333	242.32	120.70	135.76

Table 3. 2017 Average crop yield response to improved interventions (N2Africa minus Own), (LSD=0.05).

				yield (kg/ha)				
Country	Crop	N	Treatment	Mean	Response	LSD	SED	SE means
Nigeria	Soya bean	43	N2Africa	1658				
		43	Own	1002	656	148.25	73.46	97.10
Ghana	Soya bean	69	N2Africa	1499				
		69	Own	943	556	84.53	42.36	74.77
Tanzania	Bush bean	77	N2Africa	1603				
		77	Own	865	738	82.92	41.63	45.11
Uganda	Bush bean	5	N2Africa	323				
		5	Own	425	-102	219.61	79.10	55.93
Tanzania	Cowpea	134	N2Africa	1185				
		134	Own	415	770	61.97	31.33	31.32
Ghana	Cowpea	39	N2Africa	1116				
		39	Own	686	430	82.58	40.79	83.86
Uganda	Climbing bean	24	N2Africa	2008				
		24	Own	1667	341	290.95	140.64	163.60

3.2 Yield response to P-fertilizer, improved variety and inoculant

In this section, the perfomance of improved interventions (N2Africa plots) was assessed.The effect of P-fertilizer, improved varieties, inoculant and their interaction were considered at field level. Yield estimates were calculated at p=0.05 significance.

3.2.1 P-fertilizer and variety interaction

Soya bean, climbing bean and cowpea adaptation trials were assessed for the efects of P and variety on grain yield. Only 2017 data was analysed as mentioned in section 2.3. Generally, improved varieties had significant effects on most crops (Table 4) except bush bean and climbing bean in Uganda.

Table 4. 2017 Observed crop response to P-fertilizer and improved variety with or without interaction. (significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.).

Country	Crop	Control yield kg/ha	Predicted difference between N2A and own	Response to P-fertilizer (kg/ha)		Response to improved variety (kg/ha)		Response to interaction (kg/ha)	
				Response	p-value	Response	p-value	Response	p-value
Ghana	S/bean	945	556	64	0.1485	400	<0.001***	125	0.4580
Nigeria	S/bean	-	656	-	-	-	-	-	-
Tanzania	B/bean	730	738	142	0.4524	738	<0.001***	-	-
Uganda	B/bean	401	-102	31	0.7726	-91	0.3701	-	-
Tanzania	cowpea	418	770	-219	0.3273	986	<0.001***	-	-
Ghana	cowpea	693	430	-127	0.4454	464	<0.001***	80	0.7048
Uganda	C/ bean	1684	341	-363	0.1871	676	0.0783	-164	0.8266

There were significant positive effects of improved varieties (p< 0.0001) on bush bean, cowpea and soya bean. Yield response to improved varieties was positive in climbing bean (table 4) even though no significant differences were present. Yield responses could not be estimated for soya bean in Nigeria because of missing levels for comparison (Table 5). No interactions were observed between P and improved variety under cowpea and bush bean trials in Tanzania due to missing data levels. The interaction for bush bean in Uganda could not be estimated because of few observations. Interaction did not have any significant yield differences on the assessed crops (Table 4). P-application resulted in negative yield responses in climbing bean and cowpea, although not significant.

Table 5. Number of farmers who used different in put combinations (reference to table 4). (P0 V0 = no P and no improved variety, P0 V1= only improved variety was used, P1 VO = P-fertilizer and local varieties used and P1 V1 = P-fertilizer and improved varieties used).

		Number of respondents							
		P0V0		P0V1		P1V0		P1V1	
Country	crop	N2Africa	Own	N2Africa	Own	N2Africa	Own	N2Africa	Own
Ghana	S/bean	-	62	13	-	1	7	55	-
Nigeria	S/bean	-	22	-	-	3	21	40	-
Tanzania	B/bean	-	3	-	-	1	74	76	-
Uganda	B/bean	-	5	2	-	1	-	2	-
Uganda	C/ bean	-	23	8	-	-	1	16	-
Ghana	Cowpea	-	37	5		-	2	34	-
Tanzania	Cowpea	-	132	-	-	-	2	134	-

3.2.2 P-fertilizer and inoculant interaction.

Only soya bean and bush bean adaptation trials had P-fertilizer and inoculant in both 2016 and 2017 (Table 6 and 8). Soya bean was grown in Ghana and Nigeria in the two years, and bush bean in Uganda, in the 2016 (Table 6). For Ghana, sample sizes were 74 and 69 while in Nigeria, they were 152 and 43 for 2016 and 2017 respectively. Bush bean sample size was very small, 5 farms. Tables 6 and 8 summerized the results. The effect of variety is embeded in the results. In general, inoculant did not have any significant effect on yield for all the crops assessed in the two years.

Table 6. 2016 Observed crop response to P-fertilizer and inoculant with interaction. (significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.).

Country	Crop	Control yield kg/ha	Response to P-fertilizer (kg/ha)		Response to inoculation (kg/ha)		Response to interaction (kg/ha)	
			Response	p-value	response	p-value	response	p-value
Ghana	S/bean	728	445	< 0.0001***	209	0.1569	-70	0.4107
Nigeria	S/bean	927	353	0.1001	1	0.8411	233	0.6816
Uganda	B/bean	493	198	0.8613	-325	0.4404	-348	0.2481

Table 7. Number of farmers who used different in put combinations (reference to table 1). (P0 I0 = no P-fertilizer and no inoculant, P0 I1= only inoculant was used, P1 I0 = P-fertilizer and no inoculant used and P1 I1 = P-fertilizer and inoculant used).

		Number of respondents									
		P0 I0		P0 I1		P1 I0		P1 I1		Total Farmers	
Country	crop	N2Africa	Own	N2Africa	Own	N2Africa	Own	N2Africa	Own	N2Africa	Own
Ghana	S/bean	5	24	8	50	19	-	42	-	74	74
Nigeria	S/bean	-	1	2	114	1	-	149	37	152	152
Uganda	B/bean	3	5	1	-	2	-	-	1	5	5

P had significant positive effects (p < 0.0001) on soya bean yield for both 2016 and 2017 seasons in Ghana (Table 6 and 8). There were no significant yield differences observed due to P or inoculant in Nigeria for soya bean in both years, and in bush bean in Uganda. The interaction of P and inoculant resulted in negative yields in soya bean in Ghana in both years, and in bush bean in Uganda (Tables 6 and 8). Inoculant had negative effects in bush bean in 2016 and in soya bean in 2017, although no significantly different from uninoculated treatments.

Table 8. 2017 Observed crop response to P-fertilizer and inoculant with interaction. (significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.).

Country	Crop	Control yield kg/ha	Response to P-fertilizer (kg/ha)		Response to inoculation (kg/ha)		Response to interaction (kg/ha)	
			Response	p-value	response	p-value	response	p-value
Ghana	S/bean	977	642	< 0.0001***	-6	0.6750	-120	0.4397
Nigeria	S/bean	1447	-109	0.5742	-448	0.4909	582	0.3710

Table 9. Number of farmers who used the above input combinations (reference to table 8). (P0 I0 = no P-fertilizer and no inoculant, P0 I1= only inoculant was used, P1 I0 = P-fertilizer and no inoculant used and P1 I1 = P-fertilizer and inoculant used).

		Number of respondents									
		P0 I0		P0 I1		P1 I0		P1 I1		Total Farms	
Country	crop	N2Africa	Own	N2Africa	Own	N2Africa	Own	N2Africa	Own	N2Africa	Own
Ghana	S/bean	11	19	2	43	10	2	46	5	69	69
Nigeria	S/bean	-	1	-	21	9	8	34	13	43	43

3.2.3 P-fertilizer, variety and inoculant interaction

In this section,only Ghana farmers received either P-fertilizer, improved variety, inoculant or a combination of them in the package. Data available was for 2017 only (Table 7). A total of 69 N2Africa fields were assessed.

Table 10. 2017 Observed crop response to P-fertilizer, variety and inoculant with interaction. (significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.).

Country	Crop	Control Yield kg/ha	Response to P-fertilizer kg/ha		Response to inoculant kg/ha		Response to variety Kg/ha		Response to Interaction Kg/ha	
			Response	P-value	Response	p-value	response	p-value	response	p-value
Ghana	S/bean	813	-130	0.8441	125	0.2516	357	< 0.0001***	-540	0.3070

Table 11. Number of farmers who used the above input combinations (reference to table 10). (P0 I0 V1= only variety used, P0 I1 V1= variety + inoculant minus P, P1 I0 V1=P + variety minus inoculant, P1 I1 V0= P + inoculant minus variety and P1 V1 I1= P+ variety + inoculant).

		Number of respondents												
		P0 I0 V0	P0 I0 V1		P0 I1 V0	P0 I1V1		P1 I0 V0	P1 I0 V1		P1 I1 V0		P1 I1 V1	
Country	crop	own	N2a	own	own	N2a	own	own	N2a	own	N2a	own	N2a	own
Ghana	s/bean	19	11	0	43	2	0	2	10	0	1	5	45	0

There were significant yield differences ($p < 0.0001$) between improved and local soya bean varieties in Ghana, during the 2017 season. Improved varieties increased yield by 357 kg/ha (Table 4), almost similar to variety effects in section 3.2.1. No significant yield differences were observed from P, inoculant or their interaction. P-application reduced yield by 130kg/ha (Table 4). The interaction of P, improved variety and inoculant decreased yield by 540 kg/ha although it was not significantly different from the control yield.

3.3 Comparison of N2Africa plots to exclude the effect of management on yield.

A subset of N2Africa plots with either P-applied or improved variety was made to remove the effect of management on the yield and response.

Generally, improved varieties performed better than local varieties in the presence of P, except in soya bean in Ghana (Table 12). Improved varieties performed better without P in climbing bean in Uganda and cowpea in Ghana.

There were significant negative yield differences (p=0.007) between P-fertilized and non-fertilized climbing bean improved varieties in Uganda (Table 12). Farmers who did not apply fertilizer were mostly from one district. In Ghana, local soya bean varieties yielded higher than improved varieties with P, and cowpea improved varieties gave higher yields without P. The responses were negative but not significanty differently from each other.

Table 12. 2017 Improved intervention yield response to improved varieties at significant level ('0.05'). P1V1=P and improved varieties used, P1VO= P used on local varieties, P0V1= only improved variety was used.

		Predicted difference between N2A and own			yield (kg/ha)			
Country	Crop		N	Treatment	Mean	Response	SED	p-value
Ghana	S/bean		13	P0V1	1280			
		556	55	P1V1	1533	253	221.9	0.259
Ghana	S/bean		1	P1V0	2510			
		556	55	P1V1	1533	-977	652.8	0.140
Nigeria	S/bean		3	P1V0	1547			
		656	40	P1V1	1666	119	340	0.727
Uganda	C/bean		8	P0V1	2632			
		341	16	P1V1	1697	-935	312.4	0.007
Tanzania	B/bean		1	P1V0	1240			
		738	76	P1V1	1608	368	422.3	0.387
Ghana	Cowpea		5	P0V1	1217			
		430	34	P1V1	1101	-116	291.8	0.694
Uganda	B/bean		1	P1V0	313			
		-102	2	P1V1	401	88	173.2	0.702
Uganda	B/bean		2	P0V1	250			
		-102	2	P1V1	400	150	111.8	0.312

3.1 Comparison between N2Africa plots and Literature yield response to P-fertilizer application.

In this section, grain yield and response to N2Africa treatments were compared to literature studies to evaluate whether on-farm perfomance of improved interventions were similar to findings from literature. The analysis was based on the effect of P only. The duration of study (number of years taken for the study) and the presence of improved varieties and inoculant both in literature and in N2Africa plots were ignored even if they were present.

For N2Africa data, farmers' own plots were excluded for this analysis. Farms that did not receive P-fertilizer in the N2Africa package were considered as the control plots. A mixed model was used to find the predicted yield means for each crop. The means for each crop, for 2016 and 2017 were added and then averaged for (P+, control and response) using Excel. The standard error for each crop, both from literature and N2Africa plots were calculated in Excel and then plotted using R statistical package. The obtained literature data was then compared to N2Africa results to see whether improved interventions were in line with what has been documented in literature.

The literature data was from different countries in SSA, under a wide range of soil types, varying climatic conditions and different P-application rates. Only literature studies that had control and P treatments were selected for the analysis. Yield data which were over exaggerated and did not conform to Table 1 (section 2.3) were removed for analysis. For literature data, yield with P, control and response were averaged for all studies per crop using Excel. Graphs were made in R using the ggplot function.

The average P-application rate for improved interventions was 20-30kg/ha (personal communication, van Heerwaarden 2018), but in literature, P rates varied per crop (15-35 kg/ha).

Soya bean.

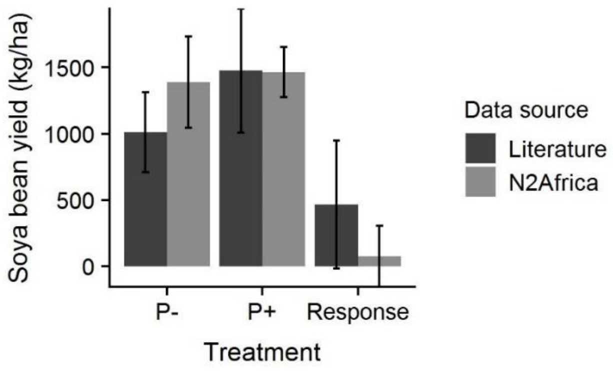

Fig. 2. Comparison of soya bean yield response to P application between literature and N2Africa. P- = no P-fertilizer, P+ = P-fertilizer application, response = difference between fertilizer and non-fertilizer application.

The average P application rate from literature was 33 kg/ha for soya bean. Soya bean performance from both Literature and N2Africa could be the same because of the large errors present (Fig. 2). The absolute yield difference (P-fertilizer application minus non P-ferilizer) could also be the same between literature and N2Africa trials because of huge errors.

Groundnut

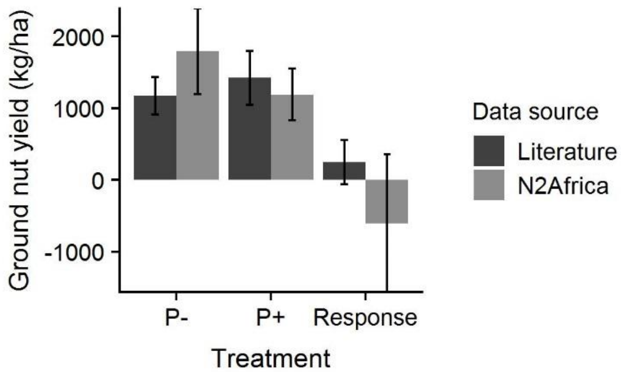

Fig. 3. Comparison of ground nut yield response to P application between literature and N2Africa. P- = no P-fertilizer, P+ = P-fertilizer application, response = difference between fertilizer and non-fertilizer application.

The average P-application rate for ground nut was 31 kg/ha, almost the same as N2Africa maximum application rate. There were huge errors present within both literature and N2Afica, hence performance could be the same (Figure 3).

Bush bean

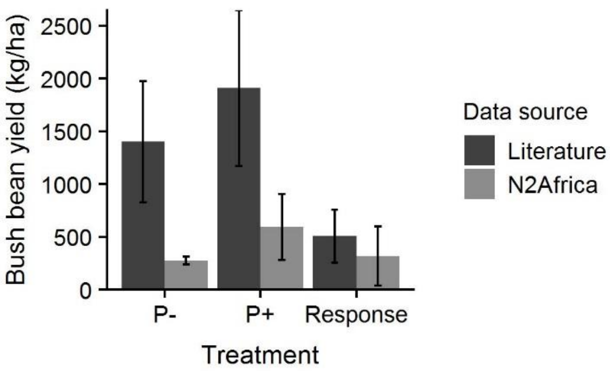

Fig. 4. Comparison of bush bean yield response to P application between literature and N2Africa. P- = no P-fertilizer, P+ = P-fertilizer application, response = difference between fertilizer and non-fertilizer application.

Although errors are huge, literature results were higher than N2Africa with and without P-fertilizer respectively (Fig. 4). The average literature bush bean P-application rate was 5.6 kg/ha higher than N2Africa. Both N2Africa yields were less than 1000 kg/ha. The response could be same because of the huge errors.

Cowpea

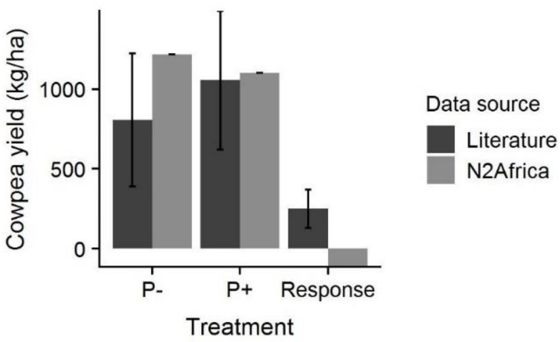

Fig. 5. Comparison of cowpea yield response to P application between literature and N2Africa. P- = no P-fertilizer, P+ = P-fertilizer application, response = difference between fertilizer and non-fertilizer application.

N2Africa yields seemed higher than literature in both cases, with differences of 45 and 410 kg/ha with or without P-fertilizer respectively (Fig 5), but performance could be the same due to errors present. Literature average P-application rate was 138.4% higher than that of improved interventions (25 kg/ha).

Climbing bean

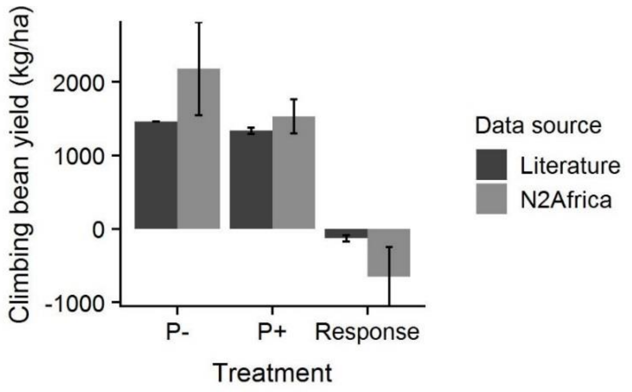

Fig. 6. Comparison of climbing bean yield response to P application between literature and N2Africa. P- = no P-fertilizer, P+ = P-fertilizer application, response = difference between fertilizer and non-fertilizer application.

N2Africa performed better than literature findings. Yield differences of 195 and 846 kg/ha were observed in climbing bean between literature and N2Africa with and without P-fertilizer respectively. The negative responses revealed that climbing bean performed better without fertilizer than with fertilizer. This showed that there is more to climbing bean yield increase other than P-fertilizer application.

4 Discussion

The purpose of this study was to assess on-farm performance of legume improved interventions, and to establish the individual effects of P-fertilizer, improved varieties, inoculant or management on yield and response where possible. We found out that there was a lot of yield and response variability within farms, across farms and within countries.

4.1 Yield response to improved interventions

We expected that improved interventions would increase grain yields on-farm. This was confirmed by the results we obtained for both 2016 and 2017 growing seasons (Tables 2 and 3). With the exception of bush bean in Uganda, yields from N2Africa plots were significantly higher than yields from farmers' own plots (LDS=0.05).

Generally, a large yield and response variability existed between crops within and across countries for both N2Africa and farmers' own plots. The highest yield responses (770 and 738 kg/ha) were obtained in 2017 in Tanzania, under cowpea and bush bean adaptation trials respectively. The lowest was obtained in Uganda in 2016 under bush bean adaptation trials.

Farmers in Tanzania applied P-fertilizer in all cowpea N2Africa plots, and NPK in bush bean adaptation trials. In 2017, drought was mild compared to 2016, weeds were a problem but most farmers weeded more than twice in their N2Africa plots. Farmers did sole cropping in their N2Africa plots, both cowpea and bush bean. Sole cropping leads to higher yields because there is no interference of management practices such as weeding, spraying and harvesting (Hüskens, 2015). Bush bean benefitted from the nitrogen present in NPK leading to a higher response. Nutrient uptake by plants was good because drought was not severe and moisture was available in the soil.

In Uganda, sample sizes for the bush bean were very small (Tables 2 and 3), and limited data could have affected the outcome. Despite small samples, yield response might have been reduced by the presence of severe drought, pest and diseases during the two growing seasons in Uganda.

Climbing bean had the highest yields in N2Africa plots during the two growing seasons even though there there was drought. The crop has a higher yield potential, and is more tolerant to drought, pests and diseases than other legumes, especially bush bean (Ruganzu et al., 2014). Climbing bean yields were almost three times more than bush bean in Uganda for 2016 and 2017 as acknowledged by (Musoni et al., 2014; Ruganzu et al., 2014; Wotmann et al., 1998). Most farmers in Uganda, weeded at least twice in the N2Africa plots and this could have contributed to higher yields, weeds compete with plants for nutrients, moisture, light and space (Muzari et al., 2012).

The highest yield response was obtained in Tanzania, in cowpea adaptation trials in 2017. All cowpea N2Africa plots received P. Ghana had the highest ground nut yield response compared to Nigeria and Tanzania.

In Tanzania, all farms that participated in the ground nut adaptation trials were from one district, grew the same improved variety as a sole crop. These farmers used all inputs received from N2Africa and weeded at least twice. Grain yields in this country were affected by drought which was severe in 2016. Most smallholder farmers in Tanzania have become vulnerable to climate change because they are situated in arid and semi-arid parts of the country, which are mostly hit by drought (Shemdoe, 2011). Location affects the performance of on-farm improved interventions, farmers depend on natural rainfall unlike where environmental conditions are controlled (Adjei-Nsiah et al., 2018).

4.2 Yield response to P-fertilizer, improved variety and inoculant

4.2.1 P-fertilizer and variety interaction

Improved varieties had significant positive effects ($p < 0.0001$), on all the crops except bush bean and climbing bean in Uganda (Table 4). P increased yield in soya bean and bush bean but the difference was not significant in any of the cases. In cowpea and climbing bean, P resulted in negative yield responses though not significant. There were more farmers who used improved varieties without P than those who used P without improved varieties in N2Africa plots (Table 5). Also, improved varieties were only used in N2Africa plots, yet P was assessed in both plots. This could have overshadowed the effect of P, resulting in improved varieties having a stronger apparent effect on most crops across countries.

The negative responses to P could have been caused by small sample sizes (Table 5, section 3.2.1). Small sample sizes gave little power to detect the actual P effects on yield. Also where P response was negative, only own plots used P without improved varieties in the countries involved. Low yields in fertilized plots could have been caused by P immobilization due to different on-farm management practices. P available to plants after fertilization can be limited by factors such as soil pH, soil organic matter content and soil microbial activities (Brady and Weil, 2008; Sattari, 2014). Very low or very high soil pH is not favourable for P absorption by plants (Brady and Weil, 2008; Jeng, 2014).

No results were estimated for soya bean in Nigeria due to lack of data for comparison (Table 5). The large difference between P and varietal effects on yield could be mainly due to the difficulties we faced in dissecting the data. In cases of bush bean and cowpea in Tanzania we estimated the variables without interaction, because of how the experiments were set up. The results we obtained could be different if the interaction was to be incorporated. On average P and improved varieties have positive effects on yield, (Abayomi et al., 2008; Devi et al., 2012; Magani and Kuchinda, 2009), our results did not confirm these results because it was difficult to disentangle the effects of P on yield due to small sample size and experiment set up.

4.2.2 P-fertilizer and inoculant interaction.

Soya bean and bush bean adaptation trials were assessed for P and inoculant interaction in 2016 and 2017 growing seasons. Soya bean was grown in Ghana and Nigeria in the two years and bush bean in Uganda in 2016 only. The effect of variety was embedded in the results obtained.

Generally, Only P improved yields except in Nigeria in 2017 under soya bean adaptation trials although the differences were not significant in both cases. P had significant effects ($p < 0.0001$) on soya bean yield in Ghana during both growing seasons.

Ghana had a comparable representation of farms in both seasons, and the effect of P was quite evident. This could have been caused by the possible effect of confounding with variety effect. In Nigeria and Uganda, for the two years, no adquate comparable data was present, and this could have lowered the effects of P and inoculant on yield. Sample size for bush bean was very small, and correct conclusions on the effects of P and inoculant could be difficult to draw.

In 2017, in Nigeria, P effects to soya bean yield were negative despite that a comparable number of farmers used P in both plots (Table 9). Negative P effects could have been due to management factors on the farm such as time and method of fertilizer application or soil properties on the farm. The presence of drought in some parts of Nigeria could have affected nutrient absorption by plants resulting in a negative response. Negative inoculant effects could have been caused by small sample size (only one farmer used inoculant in bush bean) or poor management of the inoculant at the time of application.

P and inoculant had strong positive individual and additive effects on soya bean yield, (Mpepereki et al., 2000; Ronner et al., 2016; Rurangwa et al., 2018; van Heerwaarden et al., 2017), and in chickpea (Wolde-meskel et al., 2018). These results differed from our findings, only P had an effect on soya bean yield in Ghana. The non-significant effect of inoculant on soya bean was also reported by van Heerwaarden et al., (2017), where they found a relatively modest 115 kg/ha effect of inoculant on yield. These results could have been caused by different on-farm management practices.

4.2.3 P-fertilizer, variety and inoculant interaction

Data for this assessment was only available in Ghana for soya bean in 2017. About two thirds of the farmers who participated in these trials where from one district.

Significant yield effects ($p < 0.0001$) were only observed from improved varieties (Table 7). P-application resulted in a negative yield response although not significant. Negative yield response to P could be due to a small sample size (2 farmers), unlike on improved varieties were 11 farmers participated. There was also a negative yield response (-540 kg/ha) from the interaction of P, improved variety and inoculant, but was not significant (Table 10, section 3.2.2). P and inoculant increase legume yield (Ndakidemi et al., 2006; Tairo and Ndakidemi, 2013). Our results could have been affected by management of P and inoculant at sowing which might have killed the inoculant or burn the seed.

4.3 Comparison of N2Africa plots to exclude the effect of management on yield.

A subset of the data of N2Africa (treatment) plots for plots were fertilizer or improved varieties was present or absent was analysed with the aim of removing the effects of management at field level that play a role when N2Africa and own plots are compared. Effect of P was evaluated on improved varieties and the effect of improved varieties was assessed on P-fertilized plots only.

Generally, improved varieties increased yields with P-application except in soya bean in Ghana, although the differences were not significant (Table 9). The effect of P on varieties was affected by small samples (Table 12). It became difficult to estimate the effects P on variety. This could have caused the negative response in soya bean in Ghana, and insignificant responses in bush bean. Others causes of yield insignificances could be varietal properties. Different soya bean varieties have different yield potentials and respond to P-application differently (OLANIYAN et al., 2016). Some of the improved varieties could have responded differently to P-application thus yielding insignificantly to local varieties. On the other hand, local varieties are well adapted to local growing conditions than improved varieties which have a higher nutrient requirement (Magani and Kuchinda, 2009).

Improved varieties had a positive effect, though not significant, on yield in most crops, when P was present, except for climbing bean in Uganda (Table 12). There were significant yield differences (p=0.007) in climbing bean in Uganda though negative (-935 kg/ha). Improved varieties performed better without P-application. Possible reasons could be geographical. Out of the 8 farmers that grew climbing bean improved varieties without P, seven of them were from one district (Kabale district). It could be possible that the soil properties and climatic conditions in the district could have affetced the yields.

The effects of P and improved varieties were variable and often not significant, showing the difficulty in estimating effects across farms, instead of estimating by treatment and control on-farm. On average, the effect of improved variety and P were 192 and 96 kg/ha respectively (Table 12), resulting in almost 300 kg/ha. When compared to the average N2Africa responses (460 kg/ha) in 2017 (Table 2) , we could speculate that management effects were likely to be slightly larger across farms and countries.

4.4 Comparison between N2Africa (improved technology intervention) and literature to P-fertilizer application.

Generally, the effect of P on crop yield was almost similar between improved interventions and literature, except for bush bean where yields for N2Africa where much lower than published yields (section 3.4). Response estimates for N2Africa were mostly lower, and highly variable, probably due to the fact that comparisons were made between treated plots only, wheras published studies typically used dierect comparisons between control and treatment plots. The idea of leaving own plots in the analysis discredited N2Africa results, which show a potential of perfoming better than Literature. Cowpea, ground nut and climbing bean improved interventions could have negative absolute yield responses despite errors present, but P is very necessary for legume productivity.

In SSA, fertilizer application has led to positive on-farm crop responses in many crops (Edmonds et al., 2009), yet in our results (section 3.4) higher yield responses were observed under P limited conditions. Yield variability could have been caused by different nutrient management practices or available soil fertility in the fields (Zingore et al., 2007).

5 Conclusion

In conclusion, improved interventions performed better than farmers' own interventions per crop for each country, with 2017 giving higher yields than 2016. Although there is a lot of variability amongst farmers and crops, the yield and responses were more or less the same with the expected from literature. Yield and response variability between literature and N2Africa could be accounted to soil properties, drought or on-farm management practices. Management practices such as land preparation, planting on time or early, timely fertilizer application and weeding on time can be rectified to increase the performance of improved interventions, but also this depends on labour availability. Delayed availability of seed and fertilizer can also bring yield variability amongst farmers.

Improved varieties seemed to have a greater effect in yield than P. It was difficult to dissect and estimate P effects on yield because of how the experiments were set up. Samples were small, variety had good comparison than P. P comparison was mostly across farms and not on the farm, this infuenced the out come. Improved climbing bean varieties performed better with P, this could be attributed to geographical factors, 88 % of the farms were in one district. On-farm fertility management practices could also contribute to yield variability.

5.1 Suggestions /Future researches

- Engaging competent people to do data collection so that all required information is captured. Ethiopia was excluded in the analysis due to lack of comparable data, In Uganda, bush bean samples were made small due to lack of yield data.

- Trying to include soil data in the analysis to have a better insight of causes of yield variability on on-farm performance of improved interventions.

- It could be interesting to check on the combined effect of P, improved varieties and manure on on-farm performance of improved interventions.

- Including intercropping in on-farm performance of improved interventions

6 Reference

Abayomi, Y., Ajibade, T., Sammuel, O., and Saadudeen, B. (2008). Growth and yield responses of cowpea (Vigna unguiculata (L.) Walp) genotypes to nitrogen fertilizer (NPK) application in the Southern Guinea Savanna zone of Nigeria. *Asian J. Plant Sci* **7**, 170-176.

Adjei-Nsiah, S., Alabi, B., Ahiakpa, J., and Kanampiu, F. (2018). Response of Grain Legumes to Phosphorus Application in the Guinea Savanna Agro-Ecological Zones of Ghana. *Agronomy Journal* **110**, 1089-1096.

Atlas, G. Y. G. (2015). Global Yield Gap Atlas.

Bationo, A., Kihara, J., Kimetu, J., and Waswa, B. (2007). "Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities," Springer.

Brady, N., and Weil, R. (2008). Soil colloids: seat of soil chemical and physical acidity. pp. 311-358. Pearson Education Inc.: Upper Saddle River, NJ, USA.

Bravo, S. P. (2017). N2Africa Project.

Burstin, J., Gallardo, K., Mir, R., Varshney, R., and Duc, G. (2011). 20 Improving Protein Content and Nutrition Quality. *Biology and breeding of food legumes*, 314.

Buruchara, R., Chirwa, R., Sperling, L., Mukankusi, C., Rubyogo, J. C., Mutonhi, R., and Abang, M. (2011). Development and delivery of bean varieties in Africa: the Pan-Africa Bean Research Alliance (PABRA) model. *African crop science journal* **19**, 227-245.

Cassman, K. G., Dobermann, A., and Walters, D. T. (2002). Agroecosystems, nitrogen-use efficiency, and nitrogen management. *AMBIO: A Journal of the Human Environment* **31**, 132-140.

Cleland, J., and Machiyama, K. (2017). The Challenges Posed by Demographic Change in sub-Saharan Africa: A Concise Overview. *Population and Development Review* **43**, 264-286.

Clover, J. (2003). Food security in sub-Saharan Africa. *African Security Studies* **12**, 5-15.

Dakora, F., and Keya, S. (1997). Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan Africa. *Soil Biology and Biochemistry* **29**, 809-817.

Devi, K. N., Singh, L. N. K., Devi, T. S., Devi, H. N., Singh, T. B., Singh, K. K., and Singh, W. M. (2012). Response of soybean [Glycine max (L.) Merrill] to sources and levels of phosphorus. *Journal of Agricultural Science* **4**, 44.

Edmonds, D. E., Abreu, S. L., West, A., Caasi, D. R., Conley, T. O., Daft, M. C., Desta, B., England, B. B., Farris, C. D., and Nobles, T. J. (2009). Cereal nitrogen use efficiency in sub Saharan Africa. *Journal of Plant Nutrition* **32**, 2107-2122.

Farrow, A., Ronner, E., Van Den Brand, G. J., Boahen, S. K., Leonardo, W., Wolde-Meskel, E., Adjei-Nsiah, S., Chikowo, R., Baijukya, F., and Ebanyat, P. (2016). From best fit technologies to best fit scaling: incorporating and evaluating factors affecting the adoption of grain legumes in Sub-Saharan Africa. *Experimental Agriculture*, 1-26.

Farrow, A., Wolde-Meskel, E., Adjei-Nsiah, S., Sangodele, E., Kamara, A., Kamai, N., Baijukya, F., and Ebanyat, P. (2015). "N2Africa Action Areas in Ethiopia, Ghana, Nigeria, Tanzania and Uganda in the N2Africa Project." N2Africa project.

Franke, A., Laberge, G., Oyewole, B., and Schulz, S. (2008). A comparison between legume technologies and fallow, and their effects on maize and soil traits, in two distinct environments of the West African savannah. *Nutrient Cycling in Agroecosystems* **82**, 117-135.

Franke, A., Van Den Brand, G., and Giller, K. (2014). Which farmers benefit most from sustainable intensification? An ex-ante impact assessment of expanding grain legume production in Malawi. *European Journal of Agronomy* **58**, 28-38.
Giller, K. E. (2001). "Nitrogen fixation in tropical cropping systems," Cabi.
Giller, K. E., Tittonell, P., Rufino, M. C., Van Wijk, M. T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., and Corbeels, M. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural systems* **104**, 191-203.
Jeng, A. S. (2014). Securing Crop Phosphorus Availability in the Humid Tropics: Alternative Sources and Improved Management Options–A Review. *In* "Challenges and Opportunities for Agricultural Intensification of the Humid Highland Systems of Sub-Saharan Africa", pp. 51-66. Springer.
Kaizzi, K. C., Byalebeka, J., Semalulu, O., Alou, I. N., Zimwanguyizza, W., Nansamba, A., Odama, E., Musinguzi, P., Ebanyat, P., and Hyuha, T. (2012). Optimizing smallholder returns to fertilizer use: Bean, soybean and groundnut. *Field Crops Research* **127**, 109-119.
Kamanga, B., Whitbread, A., Wall, P., Waddington, S., Almekinders, C., and Giller, K. (2010). Farmer evaluation of phosphorus fertilizer application to annual legumes in Chisepo, Central Malawi. *African journal of agricultural research* **5**, 668-680.
Kamara, A. Y., Abaidoo, R., Kwari, J., and Omoigui, L. (2007). Influence of phosphorus application on growth and yield of soybean genotypes in the tropical savannas of northeast Nigeria. *Archives of Agronomy and Soil Science* **53**, 539-552.
Karikari, B., Arkorful, E., and Addy, S. (2015). Growth, nodulation and yield response of cowpea to phosphorus fertilizer application in Ghana. *J. Agron* **14**, 234-240.
Khan, S., Mulvaney, R., Ellsworth, T., and Boast, C. (2007). The myth of nitrogen fertilization for soil carbon sequestration. *Journal of Environmental Quality* **36**, 1821-1832.
Ledgard, S., and Steele, K. (1992). Biological nitrogen fixation in mixed legume/grass pastures. *Plant and soil* **141**, 137-153.
Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., and Henry, K. (2014). Climate-smart agriculture for food security. *Nature Climate Change* **4**, 1068.
Magani, I., and Kuchinda, C. (2009). Effect of phosphorus fertilizer on growth, yield and crude protein content of cowpea (Vigna unguiculata [L.] Walp) in Nigeria. *Journal of Applied Biosciences* **23**, 1387-1393.
Matson, P. A., Naylor, R., and Ortiz-Monasterio, I. (1998). Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science* **280**, 112-115.
Mpepereki, S., Javaheri, F., Davis, P., and Giller, K. (2000). Soyabeans and sustainable agriculture: promiscuous soyabeans in southern Africa. *Field crops research* **65**, 137-149.
Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., and Foley, J. A. (2012). Closing yield gaps through nutrient and water management. *Nature* **490**, 254.
Muza, L., Dhliwayo, H., Twomlow, S., and Ransom, J. (1996). Dryland maize response to different combinations of tillage and weeding methods. *In* "Maize productivity gains through research and technology dissemination. Proc. of 5th Regional Maize Conf. for Eastern and Southern Africa", pp. 110-114.

Ndakidemi, P., Dakora, F., Nkonya, E., Ringo, D., and Mansoor, H. (2006). Yield and economic benefits of common bean (Phaseolus vulgaris) and soybean (Glycine max) inoculation in northern Tanzania. *Australian Journal of Experimental Agriculture* **46**, 571-577.
Ndakidemi, P. A., and Dakora, F. D. (2007). Yield components of nodulated cowpea (Vigna unguiculata) and maize (Zea mays) plants grown with exogenous phosphorus in different cropping systems. *Australian journal of experimental agriculture* **47**, 583-589.
Ojiem, J., De Ridder, N., Vanlauwe, B., and Giller, K. (2006). Socio-ecological niche: a conceptual framework for integration of legumes in smallholder farming systems. *International Journal of Agricultural Sustainability* **4**, 79-93.
Okalebo, J., Othieno, C. O., Woomer, P. L., Karanja, N., Semoka, J., Bekunda, M., Mugendi, D. N., Muasya, R., Bationo, A., and Mukhwana, E. (2006). Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling in Agroecosystems* **76**, 153-170.
OLANIYAN, A., Enoobong, U., and AFOLAMI, A. (2016). PERFORMANCE OF SOYBEAN (Glycine max L.) INFLUENCED BY DIFFERENT RATES AND SOURCES OF PHOSPHORUS FERTILIZER IN SOUTH-WEST NIGERIA. *AGROFOR* **1**.
Peoples, M., Brockwell, J., Herridge, D., Rochester, I., Alves, B., Urquiaga, S., Boddey, R., Dakora, F., Bhattarai, S., and Maskey, S. (2009). The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis* **48**, 1-17.
Peoples, M., Herridge, D., and Ladha, J. (1995). Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production? *Plant and soil* **174**, 3-28.
Ronner, E., Franke, A., Vanlauwe, B., Dianda, M., Edeh, E., Ukem, B., Bala, A., Van Heerwaarden, J., and Giller, K. E. (2016). Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria. *Field Crops Research* **186**, 133-145.
Rufino, M. C., Rowe, E. C., Delve, R. J., and Giller, K. E. (2006). Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. *Agriculture, ecosystems & environment* **112**, 261-282.
Ruganzu, V., Mutware, J., Uwumukiza, B., Nabahungu, N., Nkurunziza, I., and Cyamweshi, A. (2014). Farmers' Knowledge and Perception of Climbing Beans-Based Cropping Systems in Rwanda. *In* "Challenges and Opportunities for Agricultural Intensification of the Humid Highland Systems of Sub-Saharan Africa", pp. 39-49. Springer.
Rurangwa, E., Vanlauwe, B., and Giller, K. E. (2018). Benefits of inoculation, P fertilizer and manure on yields of common bean and soybean also increase yield of subsequent maize. *Agriculture, ecosystems & environment* **261**, 219-229.
Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science* **295**, 2019-2020.
Sattari, S. Z. (2014). "The legacy of phosphorus: agriculture and future food security," Wageningen University.
Singh, A. K., Bhatt, B., Singh, D., Gade, R., Singh, A. K., and Sangle, U. (2012). Good Agronomic Practices (GAP)-An efficient and eco-friendly tool for sustainable management of plant diseases under changing climate scenario. *Journal of Plant Disease Sciences* **7**, 1-8.
Syers, J., Johnston, A., and Curtin, D. (2008). Efficiency of soil and fertilizer phosphorus use. *FAO Fertilizer and plant nutrition bulletin* **18**.
Tairo, E. V., and Ndakidemi, P. A. (2013). Yields and economic benefits of soybean (Glycine max L.) as affected by Bradyrhizobium japonicum inoculation and phosphorus supplementation. *American Journal of Research Communication* **1**, 159-172.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature* **418**, 671.
Tittonell, P., and Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research* **143**, 76-90.
Tittonell, P., Vanlauwe, B., Leffelaar, P., Shepherd, K. D., and Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya: II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, ecosystems & environment* **110**, 166-184.
van Heerwaarden, J., Baijukya, F., Kyei-Boahen, S., Adjei-Nsiah, S., Ebanyat, P., Kamai, N., Wolde-Meskel, E., Kanampiu, F., Vanlauwe, B., and Giller, K. (2017). Soyabean response to rhizobium inoculation across sub-Saharan Africa: Patterns of variation and the role of promiscuity. *Agriculture, Ecosystems & Environment*.
van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., and Hochman, Z. (2013). Yield gap analysis with local to global relevance—a review. *Field Crops Research* **143**, 4-17.
Van Ittersum, M. K., Van Bussel, L. G., Wolf, J., Grassini, P., Van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., and Mason-D'Croz, D. (2016). Can sub-Saharan Africa feed itself? *Proceedings of the National Academy of Sciences* **113**, 14964-14969.
Vanlauwe, B., and Giller, K. E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture, ecosystems & environment* **116**, 34-46.
Welham, S., Cullis, B., Gogel, B., Gilmour, A., and Thompson, R. (2004). Prediction in linear mixed models. *Australian & New Zealand Journal of Statistics* **46**, 325-347.
Wolde-meskel, E., van Heerwaarden, J., Abdulkadir, B., Kassa, S., Aliyi, I., Degefu, T., Wakweya, K., Kanampiu, F., and Giller, K. E. (2018). Additive yield response of chickpea (Cicer arietinum L.) to rhizobium inoculation and phosphorus fertilizer across smallholder farms in Ethiopia. *Agriculture, ecosystems & environment* **261**, 144-152.
Zingore, S., Murwira, H. K., Delve, R. J., and Giller, K. E. (2007). Soil type, management history and current resource allocation: Three dimensions regulating variability in crop productivity on African smallholder farms. *Field Crops Research* **101**, 296-305.

7 Appendix

7.1 Literature Review

7.1.1 soya bean

Country	P source	Amount of fertilizer applied (kg/ha)	Amount of P (kg/ha)	Inoculation	Yield with P (kg/ha)	Yield control (kg/ha)	Absolute difference (P treatment – control)	NUE (yield difference/ amount P applied)	Crop variety	Additional information	Source
Ghana	TSP	65.22	30	yes	1350	970	380	12.67			Adjei-Nsiah et al., 2018
Malawi	TSP	43.48	20	no	2100	1600	500	25		Estimated from graph	Kamanga et al., 2010
Uganda	TSP	27.17	15	no	1750	830	920	61.3	Namsoy2,maksoy1N/2/4		Kaizzi et al., 2012
Uganda	TSP	54.35	30	no	1870	830	1040	34.67	Namsoy2,maksoy1N/2/5		Kaizzi et al., 2012
Uganda	TSP	81.52	45	no	1940	830	1110	24.67	Namsoy2,maksoy1N/2/6		Kaizzi et al., 2012
Kenya	TSP	27.17	12.5	no	1070	530	540	43.2	SB20 and SB25		Savini et al., 2016
Kenya	TSP	54.35	25	no	1470	530	940	37.6	SB20 and SB25		Savini et al., 2016
Kenya	TSP	108.67	50	no	1740	530	1210	24.2	SB20 and SB25		Savini et al., 2016
Tanzania	TSP	43.48	20	yes	837.5	745.7	91.8	4.59	Soya 2		Tairo & Ndakidemi, 2013
Tanzania	TSP	86.96	40	Yes	997.5	745.7	251.8	6.3	Soya 3		Tairo & Ndakidemi, 2013
Tanzania	TSP	173.91	80	yes		745.7	338	4.23	Soya 4		Tairo & Ndakidemi, 2013
Kenya	MPR		50	no	1720	530	1190	23.8			Savini et al., 2016
Tanzania	TSP	56.52	26	Yes	1937.5	607	1330.50	51.17	Bossier		Ndakidemi et al., 2006
Tanzania	TSP	56.52	26	no	956.5	607	349.50	13.44	bossier		Ndakidemi et al., 2006
Nigeria	TSP	50	10	no	968.6	846	122.59	12.26	TGX		Ikeogu and Nwofia, 2013
Nigeria	TSP	100	20	no	905.8	846	59.84	3	TGX		Ikeogu and Nwofia, 2013
Nigeria	TSP	150	30	no	931.4	846	85.35	2.84	TGX		Ikeogu and Nwofia, 2013
Nigeria	TSP	200	40	no	962.7	846	116.71	2.92	TGX		Ikeogu and Nwofia, 2013
Nigeria	SSP	111.11	20	no	1510	720	790	39.5	TGX1987-10F/TGX1987-62F		OLANIYAN et al., 2016
Nigeria	SSP	222.22	40	no	2280	720	1560	39	TGX1987-10F/TGX1987-62F		OLANIYAN et al., 2016
Nigeria	SSP	333.33	60	no	1680	720	960	16	TGX1987-10F/TGX1987-62F		OLANIYAN et al., 2016
Nigeria	SSP	444.44	80	no	1550	720	830	10.38	TGX1987-10F/TGX1987-62F		OLANIYAN et al., 2016
Nigeria	SSP	222.22	40	no	2480	1300	1183	29.58	TGX1987-10F/TGX1987-62F		OLANIYAN et al., 2016
Nigeria	SSP	111.11	20	no	1251	902	349	17.45	improved varieties	P (2011)	Ronner et al., 2016
Nigeria	SSP	111.11	20	Yes	1883	902	981	49.05	improved varieties	P +I (2011)	Ronner et al., 2016
Nigeria				yes	1330	902	428		improved varieties	I (2011)	Ronner et al., 2016
Nigeria	SSP	111.11	20	No	1423	1035	338	19.40	improved varieties	P (2012)	Ronner et al., 2016
Nigeria	SSP	111.11	20	Yes	1660	1035	625	31.25	improved varieties	P+I (2012)	Ronner et al., 2016
Nigeria	SSP			yes	1460	1035	425		improved varieties	I (2012)	Ronner et al., 2016
Kenya	TSP	150	30	no	2660	1140	1520	50.7	Gazelle	+5 tons manure	Verde et al., 2013
Kenya	TSP	150	30	no	1700	1140	560	18.7	Gazelle	+2 tons manure	Verde et al., 2013
Kenya	TSP	150	30	no	2620	1140	1480	49.3	Gazelle	+5 tons manure,2 tons lime	Verde et al., 2013

Kenya	TSP	300	60	no	1200	1140	60	1	Gazelle		Verde et al., 2013
South Africa	SP	285.7	30	no	777.5	739.5	38	1.3	Pan 520RR/Highveld Top/ LS555		Mabapa et al., 2010
South Africa	SP	571.4	60	no	827	739.5	88	1.5	Pan 520RR/Highveld Top/ LS555		Mabapa et al., 2010
Nigeria			13.2	no	1508.8	1518.8	-10.3	-0.8	TGX 1019 - 2EB/TGX 1448 - 2EB		Chiezey and Odunze, 2009
Nigeria			26.4	no	1833.5	1518.8	314.7	11.9	TGX 1019 - 2EB/TGX 1448 - 2EB		Chiezey and Odunze, 2009
Nigeria			39.6	no	2015.7	1518.8	496.9	12.6	TGX 1019 - 2EB/TGX 1448 - 2EB		Chiezey and Odunze, 2009
Ethiopia			23	no	1132.6	1145.8	-13.2	-0.6	Awassa 04		Shengu and Ademe 2017
Ethiopia			46	no	1247.9	1145.8	102.1	2.2	Awassa 04		Shengu and Ademe 2017
Ethiopia			69	no	1086.1	1145.8	-56.7	0.8	Awassa 04		Shengu and Ademe 2017
Ethiopia			23	no	1118.7	1141.1	-22.4	-1	Awassa 95		Shengu and Ademe 2017
Ethiopia			46	no	1243.6	1141.1	102.5	2.2	Awassa 95		Shengu and Ademe 2017
Ethiopia			69	no	1080.2	1141.1	-60.9	-0.9	Awassa 95		Shengu and Ademe 2017
Nigeria	SSP	166.67	30.00	no	1219	1163	56	1.9	TGX 536-02D		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1341.5	999	342.5	11.4	TGX 1019-2EN		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1155.5	1194.5	-39	-1.3	TGX 1485-1D		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1769.5	1298	471.5	15.7	TGX 923-2E		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1416.5	1287	129.5	4.3	TGX 1440-1E		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1409.5	853	556.5	18.6	Samsoy 2		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1480.5	1338	142.5	4.8	TGX 1830-20E		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1290.5	1457.5	-167	-5.6	TGX 1740-2F		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1275	1030.5	244.5	8.2	TGX 1871-12E		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	2387.5	1582.5	805	26.8	TGX 1448-2E		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1610	1576.5	33.5	1.1	TGX 1844- 18E		(Mahamood et al., 2009)
Nigeria	SSP	166.67	30.00	no	1127.5	1338	-210.5	-7	TGX 1869-31E		(Mahamood et al., 2009)
	Means	**154.7**	**32.8**		**1475.6**	**1010.4**	**465.2**	**14.1**			
	SD	**105.8**	**16.3**		**469.2**	**302.8**	**482.5**	**17.2**			

7.1.2 Climbing bean

Country	P source	Amount of fertilizer applied (kg/ha	Amount of P (kg/ha	Yield with P (kg/ha)	Yield control (kg/ha)	Absolute difference (P treatment – control)	NUE (yield difference/amount P applied)	Crop variety	Additional information	Source
Ethiopia	DP	23.8	10	1307	1463	-156	-15.6	813-BCB-28	used yield from 16 tons/ha of farm yard manure as control in a maize and climbing beans intercrop	Abera et al., 2005
Ethiopia	DP	47.62	20	1367	1463	-96	-4.8	813-BCB-28	used yield from 16 tons/ha of farm yard manure as control in a maize and climbing beans intercrop	Abera et al., 2005
	Means	**35.7**	**15**	**1337**	**1463**	**-126**	**-10.2**			
	SD	**16.8**	**7.1**	**42.4**	**0**	**42.4**	**7.6**			

7.1.3 Cowpea

Country	P source	Amount of fertilizer applied (kg/ha	Amount of P (kg/ha	Inoculation	Yield with P (kg/ha)	Yield control (kg/ha)	Absolute difference (P treatment – control)	NUE (yield difference/ amount P applied)	Crop variety	Additional information	Source
South Africa			40	Yes	758	483	275	6.9	Bengpilaa	2003	Ndakidemi and Dakora, 2007
South Africa			80	Yes	807	483	324	4.1	Bengpilaa	2003	Ndakidemi and Dakora, 2007
South Africa			40	Yes	924	626	298	7.5	Bengpilaa	2004	Ndakidemi and Dakora, 2007
South Africa			80	yes	979	626	353	4.4	Bengpilaa	2004	Ndakidemi and Dakora, 2007
Malawi	SSP	43.5	20	no	550	250	300	15		Estimated from graph	Kamanga et al., 2010
Mozambique			20	no	550	410	140	7	IT 18	with irrigation	Devi et al., 2012
Mozambique			40	no	900	410	490	12.3	IT 18	with irrigation	Devi et al., 2012
Mozambique			20	no	380	290	90	4.5	IT 18	without irrigation	Devi et al., 2012
Mozambique			40	no	450	290	160	4	IT 18	without irrigation	Devi et al., 2012
Nigeria	SSP		203.3	no	1851.1	1594.2	256.9	6.9	Sampea 6 /Sampea 7		Magani and Kuchinda, 2009
Nigeria	SSP		416.7	no	1911.5	1594.2	317.3	4.2	Sampea 6 /Sampea 7		Magani and Kuchinda, 2009
Nigeria	NPK	150	15	no	1340	1120	220	14.7	TVX 3636/ IT90K-102-6/IT84-124	2002	Abayomi et al., 2008
Nigeria	NPK	300	30	no	1190	1120	70	2.3	TVX 3636/ IT90K-102-6/IT84-124	2002	Abayomi et al., 2008
Nigeria	NPK	75	7.5	no	1210	1050	160	21.3	IT89KD-256/IR-48	2003	Abayomi et al., 2008
Nigeria	NPK	150	15	no	1340	1050	290	19.3	IT89KD-256/IR-48	2003	Abayomi et al., 2008
Nigeria	NPK	225	22.5	no	1410	1050	360	16	IT89KD-256/IR-48	2003	Abayomi et al., 2008
Nigeria	NPK	300	30	no	1480	1050	430	14.3	IT89KD-256/IR-48	2003	Abayomi et al., 2008
Nigeria	NPK	150	15	no	1020	916	104	6.9	IT97K-356-1/IT97K-499-38/IT98K-491-4/IT99K-1122/IT00K-901-5	2004	Abayomi et al., 2008
Nigeria	NPK	300	30	no	1020	916	104	3.5	IT97K-356-1/IT97K-499-38/IT98K-491-4/IT99K-1122/IT00K-901-5	2004	Abayomi et al., 2008
	Means	**210.3**	**34.6**		**1056.3**	**806.8**	**249.6**	**7.2**			
	SD	**111.4**	**21.9**		**435.2**	**417.1**	**120.1**	**5.9**			

7.1.4 Ground nut

Country	P source	Amount of fertilizer applied (kg/ha	Amount of P (kg/ha	Yield with P (kg/ha)	Yield control (kg/ha)	Absolute difference (P treatment – control)	NUE (yield difference/ amount P applied)	Crop variety	Additional information	Source
Uganda	TSP	32.6	15	1630	850	780	53	Red Beauty/Serenut2/ Serenut3/ Serenut4		Kaizzi et al., 2012
Uganda	TSP	65.2	30	1720	850	870	29	Red Beauty/Serenut2/ Serenut3/ Serenut4		Kaizzi et al., 2012
Uganda	TSP	97.8	45	1820	850	970	21.6	Red Beauty/Serenut2/ Serenut3/ Serenut4		Kaizzi et al., 2012
Tanzania	DSP	252	46.1	1177.6	1157.3	20.3	0.4	natal common		Anderson, 1970
Tanzania	DSP	252	46.1	1542.4	1429.3	113.1	2.5	Dodoma Bold		Anderson, 1970
Tanzania	DSP	63	11.5	1226.3	1199.3	27	2.3	natal common		Anderson, 1970
Tanzania	DSP	126	23.1	1303.9	1199.3	104.6	4.5	natal common		Anderson, 1970
Tanzania	Tororo.SP	126	11.5	1246.5	1199.3	47.2	4.1	natal common		Anderson, 1970
Tanzania	TororoSP	252	23.1	1434.4	1199.3	235.1	10.2	natal common		Anderson, 1970
Tanzania	MPR	189	11.5	1265.6	1199.3	66.3	5.8	natal common		Anderson, 1970
Tanzania	MPR	378	23.1	1312.9	1199.3	113.6	4.9	natal common		Anderson, 1970
Tanzania	DSP	252	46.1	1172	1157.3	14.7	0.3	natal common	126kg/ha Muriate of potash	Anderson, 1970
Tanzania	DSP	252	46.1	1179.3	1157.3	22	0.5	natal common	1260kg/ha lime	Anderson, 1970
Tanzania	DSP	252	46.1	1252.7	1157.3	95.4	2.1	natal common	lime and Muriate of potash (above rates)	Anderson, 1970
Tanzania	DSP	252	46.1	1548	1429.3	118.7	2.6	Dodoma Bold	126kg/ha Muriate of potash	Anderson, 1970
Tanzania	DSP	252	46.1	1578.4	1429.3	149.1	3.2	Dodoma Bold	1260kg/ha lime	Anderson, 1970
Tanzania	DSP	252	46.1	1671.8	1429.3	242.5	5.3	Dodoma Bold	lime and Muriate of potash (above rates)	Anderson, 1970
Ghana	SSP	144.4	26	1037	895	142	5.5	Chinese Spanish	Low density +fungicide	Naab et al., 2009
Ghana	SSP	144.4	26	1061	895	166	6.4	Chinese Spanish	High density +fungicide	Naab et al., 2009
Ghana	SSP	144.4	26	1029	895	134	5.2	Manipinter Virginia	Low density +fungicide	Naab et al., 2009
Malawi	SSP	43.5	20	2700	1900	800	40		estimated control results from graph	Kamanga et al., 2010
	Means	**182**	**31.5**	**1424.2**	**1175.1**	**249.1**	**10**			
	SD	**92**	**13.8**	**374.4**	**259**	**309.3**	**14.1**			

7.1.5 Common bean

Country	P source	Amount of fertilizer applied (kg/ha	Amount of P (kg/ha	Yield with P (kg/ha)	Yield control (kg/ha)	Absolute difference (P treatment – control)	NUE (yield difference/amount P applied)	Crop variety	Additional information	Source
Kenya	TSP	27.2	12.5	830	460	370	29.6	KK8		Savini et al., 2016
Kenya	TSP	54.4	25	960	460	500	20	KK8		Savini et al., 2016
Kenya	TSP	108.7	50	960	460	500	10	KK8		Savini et al., 2016
Kenya	MPR		50	980	460	520	10.4	KK8		Savini et al., 2016
Uganda	TSP	27.2	12.5	1670	1530	140	11.2	K131/K132/ NABE4/ Kanyebwa/Tanzania		Kaizzi et al., 2012
Uganda	TSP	54.4	25	1710	1530	180	7.2	K131/K132/ NABE4/ Kanyebwa/Tanzania		Kaizzi et al., 2012
Uganda	TSP	81.5	37.5	1750	1530	220	5.9	K131/K132/ NABE4/ Kanyebwa/Tanzania		Kaizzi et al., 2012
Tanzania	TSP	113	52	372	288	84	1.6			Smithson et al., 1993
Tanzania	TSP	56.5	26	1464.5	784	680.5	26.2	Bossier	With inoculant	Ndakidemi et al., 2006
Tanzania	TSP	56.5	26	1236.5	784	452.5	17.4	Bossier	No inoculant	Ndakidemi et al., 2006
Ethiopia	TSP	50	10	2478	1715	763	76.3	Hawassa Dume	23 kg/ha applied in all treatments	Dejene et al., 2015
Ethiopia	TSP	100	20	2744	1715	1029	51.5	Hawassa Dume	23 kg/ha applied in all treatments	Dejene et al., 2015
Ethiopia			20	2326	1922	404	20.2	Hawassa Dume/Ibbado/Nasir	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			40	2297	1922	375	9.4	Hawassa Dume/Ibbado/Nasir	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			20	2553.8	2090.5	463.3	23.2	Hawasa Dume	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			40	2483.7	2090.5	393.2	9.8	Hawasa Dume	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			20	2013.5	1762.7	250.8	12.5	Ibbado	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			40	1997.8	1762.7	235.1	5.9	Ibbado	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			20	2412.6	1916.5	496.1	24.8	Nasir	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia			40	2410.3	1916.5	493.8	12.4	Nasir	plus 30kg N on P treatments	Girma et al., 2014
Ethiopia	DP	23.8	10	2256	1558	698	69.8	Red Wolaita	60 kg N applied to all treatments	Gidago et al., 2011
Ethiopia	DP	47.6	20	2386	1558	828	41.4	Red Wolaita	60 kg N applied to all treatments	Gidago et al., 2011
Ethiopia	DP	71.4	30	2395	1558	837	27.9	Red Wolaita	60 kg N applied to all treatments	Gidago et al., 2011
Ethiopia	DP	95.2	40	2547	1558	989	24.7	Red Wolaita	60 kg N applied to all treatments	Gidago et al., 2011
Ethiopia	DP	119.1	50	2268	1558	710	14.2	Red Wolaita	60 kg N applied to all treatments	Gidago et al., 2011
Ethiopia	DP	142.9	60	2115	1558	557	9.3	Red Wolaita	60 kg N applied to all treatments	Gidago et al., 2011
	Means	**72.3**	**30.6**	**1908.3**	**1401.8**	**506.5**	**22.04**			
	SD	**35.5**	**14.5**	**740.2**	**573.5**	**253**	**18.8**			

7.2 Intercropping and row planting for 2016 & 2017

2016 Crops	Own				N2Africa			
	Intercropping		Row planting		Intercropping		Row planting	
	Yes	No	Yes	No	Yes	No	Yes	No
niso	21	131	135	17	3	149	151	1
ghso	3	71	55	19	1	73	66	8
ghgn	9	60	44	25	2	67	57	12
nign	10	26	27	9	9	27	30	6
tngn	0	34	11	23	0	34	34	0
tnbu	140	76	170	46	123	93	216	0
ugbu	6	0	5	1	2	4	6	0
nico	1	37	37	1	1	37	37	1
tnco	1	160	23	138	2	159	161	0
ugcb	26	26	33	19	23	29	48	4
2017 crops								
niso	0	43	41	2	0	43	43	0
ghso	0	69	65	4	0	69	68	1
tnbu	0	77	77	0	0	77	77	0
ugbu	0	5	5	0	0	5	5	0
ghco	0	39	30	9	0	39	39	0
tnco	0	134	134	0	0	134	134	0
ugcb	0	24	15	9	0	24	22	2