Quantifying the impact of the N2Africa project on Biological Nitrogen Fixation

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N2Africa

Putting nitrogen fixation to work for smallholder farmers in Africa

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Introduction

This report addresses Milestone 1.4.2 (a baseline report quantifying the current level of BNF and its contributions to rural livelihoods) together with the baseline report (Franke & de Wolf, 2011, and also links to Milestones 1.6.1 (A report on the impact of N2 fixation technologies on farmers' livelihoods),and 2.6.1 (Household benefits from specific BNF interventions quantified for the four major grain legumes in the impact zones). It contains an evaluation of the available information on the current amount of nitrogen fixed by grain legumes in the action sites where N2Africa works, as well as a first preliminary assessment of the potential impact that N2Africa technologies have on N-fixation at field and farm level. Information for this report was largely collected from results found in literature, as well as data collected as part of the N2Africa activities:

- farm characterisations
- baseline survey
- agronomy trials
- dissemination trials

Detailed biological nitrogen fixation (BNF) assessments by legumes in the project are limited to the agronomy trials and farm characterisations. Accurate BNF assessments at a field and farm level are difficult to achieve because of inaccuracies related to quantifications of the fraction or percentage of plant N derived from air (%N from N_2-fixation) in legumes, of total N accumulation by legumes, and of the exact area covered by legumes on a smallholder farm. Therefore, in most crop data collection activities for N_2Africa, grain yield or total aboveground biomass yield is measured and not BNF. However, biomass yield is a strong indicator of BNF and with the help of estimates of plant N concentration and %N from N_2-fixation from literature, BNF can be estimated.

In Part 1 of this report we provide an overview of the variables that determine BNF at a field and farm level, as well as the variables that determine rotational effects of legumes. Moreover, we present results from literature to estimate the values of parameters necessary to assess BNF for bush bean, climbing bean, soybean, groundnut and cowpea, as well as the rotational effects of legumes. In Part 2 we bring the data generated so far (as per April 2012) by N2Africa activities together to establish a baseline for BNF and do a first *ex-ante* assessment of the potential project impact on BNF at a field and farm level.

1. Factors influencing nitrogen fixation

1.1 Which factors influence %N from N_2-fixation and BNF?

The percentage of N_2 fixed from the air at field level is determined by two important factors (Giller, 2001): the potential of N_2-fixing plants to establish an effective symbiosis with rhizobia, and the relative ability of the established symbiosis to fix N_2. The latter depends on the genetic potential of the bacteria, the crop and the symbiosis. In controlled experiments, %N from N_2-fixation could be as high as 100%, and as a general rule legumes fix 15-25 kg shoot N for every tonne of shoot dry matter accumulated. Common bean is an exception, with often only 10 kg shoot N per tonne of shoot dry matter (Unkovich et al., 2008). In farmers' fields, however, environmental and management factors often limit an effective legume / rhizobia symbiosis and lower the potential %N from N_2-fixation.

Main environmental stress factors are (Giller, 2001):

- Physical:
  - Moisture (the number of rhizobia in the soil decreases with drought; N_2-fixation rates decrease with a reduction in soil moisture, faster than other processes and even in drought tolerant species; N_2-fixation is sensitive to waterlogging).
  - Temperature (too high or too low temperatures prevent or slow down nodulation; adaptation differs for different rhizobia and plant species).
- Chemical:

- Toxicities (particularly aluminium toxicity in acidic soils prevents rhizobia survival and decreases nodule initiation).
- Nutrient deficiencies (cause reduction in number and size of nodules and in amount of N_2-fixed; rhizobia have difficulties to survive with low P concentrations, and in plants P-deficiency can prevent nodulation; calcium deficiency decreases the ability of rhizobia to infect legumes; K and S have no direct role in nodulation, but addition of S can increase nodulation on deficient soils.
- Plant available N in the soil (soil N is used in preference to N_2 fixation. Especially common bean and soybean are sensitive to this, groundnut to a lesser extent) (Unkovich et al., 2008).

In addition to environmental factors, agricultural management factors influence %N from N_2-fixation as well:

- Inoculation – the need for inoculation depends on the presence of compatible rhizobia in the soil and their effectiveness. If a legume is promiscuous, rhizobium strains with which it can form effective nodules are often present, and it will rarely respond to inoculation (e.g. cowpea or groundnut). In grain legumes, a response to inoculation is most commonly seen in soybean: many varieties are highly specific and do not always nodulate with indigenous rhizobia in Africa (Giller, 2001).
- Choice of variety – some varieties are more specific than others, or are better adapted to local environmental circumstances. In general, long duration, indeterminate species fix more N_2 due to their longer period of growth than determinate, short-duration varieties.
- P-fertilization – improves nodulation and plant growth where P is limiting.
- Cropping system (mono- or intercropping). Legumes in intercropping often show a higher %N from N_2-fixation, since cereals like maize or sorghum, grown as main crops, have a high N demand. With less N available in the soil, legumes in intercropping rely more on N_2-fixation (Vesterager et al., 2008), (Rusinamhodzi et al., 2006).
- Plant density (either positive for %N from N_2-fixation due to increased competition for soil N, or negative as a result of competition for other nutrients and moisture (Naab et al., 2009) (Makoi et al., 2009).

To increase the total amount of N_2 fixed from the air per ha, an increase in %N from N_2-fixation usually provides only a limited contribution. BNF (in kg ha^{-1}) is largely determined by the total amount of biomass produced, since:

BNF (kg N ha^{-1}) = biomass yield x total N concentration x %N from N_2-fixation

A wide range of environmental stress factors (e.g. water and nutrient deficits) and management factors (plant density, weeding, cropping system, pests and diseases, etc.), which may not directly affect the %N from N_2-fixation, determine legume biomass production and therefore associated BNF as well. To increase the input from BNF by legumes in Africa, therefore, both %N from N_2-fixation as well as total biomass production should be increased.

Finally, an increase in BNF at a farm level can be achieved by an increase in the area planted with legumes. An important indicator to assess the impact of N2Africa is therefore:

BNF (kg N $farm^{-1}$) = biomass yield x total N concentration x %N from N_2-fixation x area planted with legumes

1.2 Range of %N from N_2-fixation and BNF values for grain legumes in Africa

The factors that constrain or promote BNF, and to which extent, differ widely between locations. Therefore, a wide range of values on %N from N_2-fixation and total N-fixed is found in literature for common bean, groundnut, soybean and cowpea in Africa. An overview of the range of values found for %N from N_2-fixation and N fixation is given in Table 1.

Table 1: Range of values %N from N_2-fixation and total N_2 fixed in studies in Africa

	Adapted from Giller et al. (1997)		Literature review 2000-2012*	
	N from N_2-fixation (%)	**N_2 fixed (kg N ha^{-1})**	**N from N_2-fixation (%)**	**N_2 fixed (kg N ha^{-1})**
Cowpea	8-89	11-201	20-89	12-266
Soybean	65-89	159-227	5 to 74	3 to 166
Groundnut	38-62	20-70	19-83	10-124
Common bean	10-51	2-58	14 to 73	5 to 31

*Sources: (Sanginga, 2003, Okogun et al., 2005, Osunde et al., 2003b, Thuita et al., 2012, Van Jaarsveld et al., 2002, Yusuf et al., 2009, Ebanyat et al., 2010, Ojiem et al., 2007, Osunde et al., 2003a, Adjei-Nsiah et al., 2008, Bado et al., 2006, Belane et al., 2011, Belane and Dakora, 2009, Chikowo et al., 2004, Makoi et al., 2009, Naab et al., 2009, Ncube et al., 2007, Pule-Meulenberg et al., 2010, Rusinamhodzi et al., 2006, Vesterager et al., 2008, Snapp et al., 1998)

In the studies referred to in Table 1, N_2-fixation is assessed in the aboveground plant parts only. One study conducted in Africa (Nigeria) assessed the N contribution of a legume crop (soybean) belowground up to a depth of 30 cm (Laberge et al., 2009). In this study, belowground plant-derived N in the recoverable roots and the rhizodeposits was found to constitute 16-23% of the total soybean N. The estimated amount of belowground N_2 fixed equalled 8-37 kg N ha^{-1}. These results were in line with studies outside Africa (Wichern et al., 2008) and indicated that fixed N_2 in the roots and rhizodeposits can provide a substantial but often neglected contribution to total plant N_2 fixation, which should actually be included when assessing the total contribution of legumes to BNF.

Extremes in the ranges in Table 1 are determined by the factors mentioned in Section 1.1. In most studies, the impact of e.g. variety, inoculation or fertilizer application is compared to a control situation, often representing farmers' current practices. The difference between the control and the treatment with inputs represents the impact of a certain treatment. The impact of different varieties on N2-fixation is most widely studied (Table 2). For the four legumes, a change in variety (e.g. from local varieties to improved varieties, from determinate to indeterminate, or from selectively to freely nodulating varieties) often has an important influence on both %N from N_2-fixation and total N-fixed. In cowpea, the choice of a different variety even increased N-fixed by 120 kg ha^{-1} in one study. The application of P (in the studies referred to: 30 kg P ha^{-1}) can greatly improve %N from N_2-fixation and N-fixed, e.g. in cowpea up to an increase of 58 kg N ha^{-1} compared to 0 kg P ha^{-1} in the control. The effect of intercropping seems to be contrasting: on the one hand, %N from N_2-fixation can be increased by 4-12% as compared to mono-cropping due to increased competition for soil N. However, the total amount of N_2-fixed was found to decrease by up to 70 kg N ha^{-1}, as a result of lower total legume biomass compared to mono-cropping. Interaction effects of e.g. a good soils or varieties combined with P-fertilization enhance the impact on %N from N_2-fixation and N_2-fixed even further.

1.3 Rotational effects of legumes

Mono-cropping of cereals often results in declining soil fertility given the low use of external inputs by smallholder farmers in sub-Saharan Africa (SSA). Rotation with legumes potentially improves yields for the following crop, due to the N-fixed from the air which is added to the system as leaves and roots decay. An important criterion for the amount of N that actually becomes available for subsequent crops is the way crop residue are used: are they left in the field or removed to serve other purposes? And if they are removed, is N returned in the form of animal or farmyard manure? Generally, if residues are not returned to the soil, the aboveground N-balance of a field with legumes is negative (Giller, 2001). But even when stover is left in the field or N in residues are returned to the field as manure, there are several losses in N: losses of residue biomass from the field before residues are worked into the soil, N volatilisation and leaching from residues, N losses during storage of crop residues for feeding, N uptake by livestock, N losses from manure during storage and application, etcetera.

Table 2: Potential increase in %N from N_2-fixation and N_2-fixation compared to 'control'

	Cowpea		Soybean		Groundnut		Common bean	
	N from N_2-fixation (%)	**N_2-fixed (kg ha^{-1})**	**N from N_2-fixation (%)**	**N_2-fixed (kg ha^{-1}**	**N from N_2-fixation (%)**	**N_2-fixed (kg ha^{-1}**	**N from N_2-fixation (%)**	**N_2-fixed (kg ha^{-1}**
Variety	3 to 44	7 to 120	1 to 55	1 to 34	19	22	21 to 38	
Inoculation			0 to 55	10 to 20				
Rhizobia strain			0 to 55					
P (30 kg ha^{-1})		16 to 58	-3 to -4	-14 to 38		-17 to 21	23 to 29	
Soil fertility (poor vs good)	11	42 to 84	0 to 30	0 to 43		0 to 45		1 to 19
Management (plant density, weeding)	-12 to 7	7 to 15	6	32				
Intercropping	4 to 12	-10 to -70						
Rainfall (high vs low)	-2	-4	45		-27 to 12	26	19	
Manure application	30	26						
Interactions								
Good soil + 30 kg P ha^{-1}		100		0 to 66		21		
Variety + 30 kg P ha^{-1}							43 to 60	

Sources: (Sanginga, 2003, Okogun et al., 2005, Osunde et al., 2003b, Thuita et al., 2012, Van Jaarsveld et al., 2002, Yusuf et al., 2009, Ebanyat et al., 2010, Ojiem et al., 2007, Osunde et al., 2003a, Adjei-Nsiah et al., 2008, Bado et al., 2006, Belane et al., 2011, Belane and Dakora, 2009, Chikowo et al., 2004, Makoi et al., 2009, Naab et al., 2009, Ncube et al., 2007, Pule-Meulenberg et al., 2010, Rusinamhodzi et al., 2006, Vesterager et al., 2008, Snapp et al., 1998)

1.3.1 Field N-balance at harvest

For the field N-balance at harvest an important factor is the N-harvest index: the benefit of legumes in terms of soil N-enrichment largely depends on amount of N harvested in the grain relative to the N content of the stover. The N content in grain, or generally the N harvest index, is often increased by breeding, however. Soybean for instance allocates a large part of its N to grain as a result of breeding (Table 3). So even when residues are returned to the soil there could be a net N removal from the field, especially when belowground N is not taken into account.

Table 3: Total N in stovers and N harvest index (%)

	N in stover (kg N ha^{-1})[1]	N harvest index (%)[1]	N-balance with stovers left in field (kg N ha^{-1})[2]
Cowpea	20-94	29-66	6 to 31
Soybean	50	52[3]-80	-27 to 39
Groundnut	52-154	30-70	-8 to 89
Common bean	3-38	44-70	-25 to -1

Sources: 1. Giller et al. (1997); 2. Bado et al. (2006), Adjei-Nsiah et al. (2008), Osunde et al. (2003a), Ojiem et al. (2007); 3. Yusuf et al. (2009)

Groundnut and cowpea have relatively low N harvest indices and provide the largest potential benefits in terms of soil N-enrichment. Dual-purpose species (with a lower harvest index) of e.g. soybean or cowpea generally contribute more N to soils than grain varieties with a high harvest index. However, biomass production is often not regarded as an important criterion by farmers in selection of a variety and should only be regarded as an 'additional benefit' (Adjei-Nsiah et al., 2008).

Even with net N-depletion, benefits of rotation with legumes for subsequent crops are nevertheless often found. Osunde et al. (2003a) report maize grain yields of 3 t ha^{-1} after two years soybean, compared to 0.5 t ha^{-1} after fallow, even when stovers were removed. Comparably, Yusuf et al. (2009) found a negative N-balance for soybean and cowpea at harvest, but increases in maize yield of 30-40% compared to maize after maize or maize after fallow. These benefits are often attributed to the 'sparing-effect' of legumes (they extract less N from the soil than cereals, so that more N is available for subsequent crops) or to 'other benefits' from rotation (see paragraph 1.4). In addition, belowground N could play an important role, as most studies only compare the N-content of aboveground biomass. An experiment with soybean in Nigeria shows that the N-balance was negative when grains and stover were removed from the field, but around 0 when belowground N was taken into account (Laberge et al., 2009).

1.3.2 N carry-over rates over the dry season

When stovers are left in the field, losses between harvest and the next cropping season reduce the amount of N available to subsequent crops. In general, losses are higher when the residues are left on the soil surface, rather than incorporated into the soil soon after grain harvest. N can be lost during the dry season due to volatilisation, leaching, animal grazing and termite activities, strong winds, etc. A study of Franke et al. (2008) with soybean and cowpea in Nigeria shows that in two sites where about 40 kg N ha^{-1} was left in the field as crop residues on the soil surface, in one site only 5 kg N ha^{-1} was measured at the beginning of the next cropping season. In another site, N in the aboveground plant parts had increased to 60 kg N ha^{-1} over the dry season, due to the uptake of soil N by weeds.

If legume stovers are fed to livestock, several factors determine how much N is finally returned to the field as manure. Part of the N originally available in the feed is consumed by livestock, and internally N is partitioned to milk, meat and excreta. Generally, 70 to 80% of N is recovered in livestock via excreta. Collection and handling of feed and manure are other major factors determining N-losses. In zero grazing systems, almost all N in excreta could be recycled, whereas in free grazing systems excreta can only be partially, or not at all, collected for application to arable land. During manure storage, N is lost through volatilization and leaching. The amount lost depends on the way manure is stored afterwards: left in the stall throughout the dry season (after which N-recovery could be less than 10%), composted in a heap, mixed with other waste, or mixed with straw (Rufino et al., 2006).

1.3.3 N-availability for subsequent crops

When applied to the soil, N release from manure is determined by the C:N ratio as well as the way manure is applied (e.g. incorporated in the soil reducing ammonia volatilization or left on the soil surface). The uptake by subsequent crops depends on the plant's N demand, the timing of mineralization and subsequent losses through leaching, and the frequency of N-application. All in all, Rufino et al. (2006) conclude that N-recovery from harvest to availability for subsequent crops through manure application varies from less than 1% to 44%, although the latter will rarely be achieved.

As with the N-recovery from manure, only part of the N in legume stovers is mineralized and becomes available for uptake by plants. Important factors determining the amount of N that is finally taken up by subsequent crops is the C:N ratio of stovers and their lignin content. Legume stovers often have relatively low lignin contents, and C:N ratios of <20:1, which means they decompose rapidly and generally release N rather than immobilize it. This also means, however, that 40% or more of the N in legume residues is released two weeks after it is added to the soil, which is often too early for the next crop to benefit from it (Giller, 2001). N-recovery from legumes and availability for subsequent crops is found to be 6 to 28% for the first crop, and possibly an additional 2 to 15% for a second crop (Rufino et al., 2006).

1.4 Other non-N benefits of legumes

Apart from an improved N availability, legumes could provide other benefits to subsequent crops. These 'other benefits' are rather location or cropping system specific. The inclusion of legumes in cereal-based systems, for instance, could lead to a reduction in biotic stresses for cereals. Most studies do not quantify these 'other benefits'. Yusuf et al. (2009) did attempt to separate rotational benefits from N_2-fixation benefits. They compared the increase in maize yield following cowpea and soybean, with maize following maize. The increase in maize yield after cowpea ranged from 9 to 37%, of which 16 to 56% could be attributed to rotational benefits unrelated to N. After soybean, maize yields increased by 33 to 43%, of which 30 to 44% as a result of rotation.

2. Estimation of baseline BNF and an *ex-ante* impact assessment of BNF in N2Africa

In this second part of the report, data from agronomy and dissemination and development (D&D) trials and from detailed farm characterizations collected in the N2Africa project so far (as per April 2012) is used to establish a baseline estimation of the amount of N-fixed per crop in each of the countries. In addition, the data from the agronomy and dissemination trials is used to make a preliminary assessment of the impact of inoculation and P-fertilizer on the amount of nitrogen fixed.

2.1 Baseline of N_2-fixation on farmers' fields

To estimate the current amount of nitrogen fixed by farmers in the N2Africa countries, the average grain and stover yields obtained in the control treatments of the agronomy trials (no inoculation, no fertilizer) were calculated. These trials are researcher managed and therefore do not entirely reflect farmers' management. However, these trials were implemented on farmers' fields, and they give an indication of the yields obtained by farmers. The agronomy trials in Mozambique were an exception in the sense that they were all implemented on-station. In Malawi, Rwanda and Zimbabwe, detailed farm characterizations were carried out, in which on-farm grain yields of locally grown crops were measured. In addition, results from D&D trials in Ghana in 2011 and DRC and Nigeria in 2010 are available. D&D trials are researcher-designed trials implemented by farmers on their own fields.

Grain and stover yields for cowpea were highest in Ghana, and they were about double the yields found in Malawi and Nigeria for the same crop (Table 4). Also the yields achieved in the D&D trials were higher than in the other two countries. In both Malawi and Nigeria, however, the data set was limited to one or two trials. DRC and Mozambique achieved the highest soybean yields. In Mozambique the trials were carried out on-station on fertile soils, which may not be representative for farmers' average conditions, whereas trials in the other countries were mostly on-farm. In Zimbabwe, average soybean yields were very low. This was largely the result of the poor sandy soils on which the trials were carried out.

Groundnut grain yields in the agronomy trials were relatively low, but in both Malawi and Zimbabwe yields found in the farm characterizations were much higher. This yield may be higher than commonly found on farmers' fields, however, as wealthier farmers may have been overrepresented due to the sampling methodology applied in these characterizations. Bush bean grain yields in DRC and Rwanda were on average more than double the yields in Kenya. For climbing beans, yields in the agronomy trials in Rwanda were even three times as high as in Kenya, and the yields found in the farm characterization were twice as high.

Table 4: Average grain and stover yields (kg ha^{-1}) (range in parentheses) and number of trials (n) in agronomy trials, detailed farm characterizations or D&D trials

	Agronomy trials			Detailed farm characterisations			D&D trials	
	n	Grain	Stover	n	Grain	Stover	n	Grain
Cowpea								
Ghana	5	0.98 (0.30-.187)	4.43 (3.55-6.05)				68	0.87 (0.07-3.00)
Malawi	1	0.41	2.24					
Nigeria	1	0.52	1.10	4	2.70 (1.90-3.30)	3.60 (2.20-4.40)		
Soybean								
DRC	6	1.58 (1.22-2.13)					66	0.97 (0.09-3.33)
Ghana	2	1.37 (57-2.17)	3.83				105	0.88 (0.01-3.60)
Kenya	10	1.00 (0.39-2.96)	1.53 (0.80-2.13)					
Malawi				3	0.54 (0.375-0.81)			
Mozambique	3	2.32 (2.20-2.53)						
Nigeria	2	0.78 (0.57-0.99)	1.30 (1.02-1.59)	4	2.20 (1.20-2.90)	2.10 (1.20-2.70)	41	1.05 (0.15-2.53)
Rwanda	4	0.76 (0.56-1.04)	0.77 (0.40-1.22)					
Zimbabwe	2	0.29 (0.03-0.55)	0.45 (0.15-0.75)					
Groundnut								
Ghana	5	0.47 (0.04-1.67)	1.12 (0.36-1.70)				86	0.65 (0.02-2.60)
Malawi	1	0.31	0.25	9	1.76 (0.64-4.46)			
Nigeria	1	0.57	2.02	6	1.30 (0.50-2.20)	3.23 (0.70-5.20)		
Zimbabwe				2	2.12 (1.81-2.42)			
Bush bean								
DRC	2	1.73 (1.46-1.99)						
Kenya	8	0.78 (0.13-1.58)	0.54 (0.10-1.15)					
Rwanda	3	1.60 (1.44-1.84)	0.97 (0.93-1.01)					
Climbing bean								
Kenya	6	0.60 (0.22-1.41)	0.91 (0.16-1.74)					
Rwanda	4	2.13 (1.06-2.75)	0.93 (0.39-2.09)	4	1.88 (1.14-2.27)			

Data on BNF assessments in the agronomy trials are not yet available. Samples for BNF assessments are currently being processed. Only in the farm characterizations in Rwanda and Nigeria direct measurements of N_2-fixed were taken. For the other data, therefore, N_2-fixation can only be estimated based on values found in other studies. Both grain and stover contain a certain percentage of nitrogen. Appendix 1 gives an overview of the average values of the N-content of the legumes as found in studies in Africa. The average N-content of grain and stover was applied to the yields presented in Table 4. Next, an assumption of %N from N_2-fixation was made based on the values found in part 1 of this report. The range in %N from N_2-fixation is very wide, but for this purpose an average value for the different crops was assumed:

- Soybean: 50% %N from N_2-fixation without inoculation, 70% with inoculation
- Cowpea and groundnut: 70% %N from N_2-fixation
- Bush bean: 40% %N from N_2-fixation without inoculation, 50% with inoculation
- Climbing bean: 50% %N from N_2-fixation without inoculation, 60% with inoculation

Table 5 gives an overview of the amount of N-fixed per country, without the use of fertilizer or inoculants. The differences in N-fixed between the countries are related to the differences in yield. The differences between crops are partly also explained by yield differences. For instance, even though %N from N_2-fixation for groundnut was assumed to be the same as for cowpea, groundnut shows lower amounts of N-fixed due to lower yields (except for groundnut in Nigeria). On the other hand, cowpea and soybean tend to have higher amounts of N-fixed than beans, which is a result of both differences in N-content and %N from N_2-fixation for the crops.

Table 5: Baseline of N-fixed in grain and stover (kg N ha^{-1}) on farmers' fields in N2Africa countries

	Agronomy trials			Detailed farm characterisation			D&D trials
	N-fixed in grain	N-fixed in stover	Total N-fixed	N-fixed in grain	N-fixed in stover	Total N-fixed	N-fixed in grain
Cowpea							
Ghana	25	97	122				22
Malawi	10	49	59				
Nigeria	13	24	37	74	30	104	
Zimbabwe				12	8	20	
Soybean							
DRC	47	26	73				
Ghana	41	48	89				27
Kenya	30	19	51				
Mozambique	70	37	107				
Nigeria	23	16	39	49	9	60	
Rwanda	23	10	33				
Zimbabwe	9	6	15	13	10	23	
Groundnut							
Ghana	13	17	30				19
Malawi	9	4	13	51		-	
Nigeria	16	31	47	40	12	53	
Zimbabwe				87	69	156	
Bush bean							
DRC	30		30				
Kenya	14	8	22				
Rwanda	28	15	43				
Zimbabwe	30		30	0.011	0.005	0.016	
Climbing bean							
Kenya	12	19	31				
Rwanda	44	19	63	23	47	70	

The range of N_2-fixed for the different crops lies within the range found in other studies in Africa (Table 1). Soybean N_2-fixation in the agronomy trials appears to be relatively low, however. This is probably because Table 1 includes many studies in which inoculation was tested, as well as experiments carried out on-station on more fertile soils, whereas Table 5 shows N_2-fixation on-farm, without inoculation. Also cowpea and groundnut are on the lower side of the range. For climbing beans, N-fixation in the agronomy trials in Rwanda is slightly higher than found in literature. The values in Table 5 only represent total aboveground N_2-fixed. When roots and rhizodeposition are taken into account as well, the amount of N_2-fixed is higher.

2.2 N_2-fixed per farm

The baseline study conducted in each of the N2Africa countries (Franke and De Wolf, 2011) shows that legumes play an important in all of the farming systems in the areas where N2Africa works. The main legume crops promoted by N2Africa (climbing and bush beans, soybean, groundnut and cowpea) are also the legumes most commonly grown by farmers across the countries (Table 6). Kenya, Rwanda and DRC have the highest percentage of households growing climbing and bush beans. Groundnut is grown in all project areas, with the highest percentage of farmers growing the crop in Malawi (84%). Soybean is also cultivated by farmers in all eight countries, but generally by fewer farmers. Only in Nigeria, soybean production is widespread. Cowpea is also mainly produced in Nigeria. Pigeon pea is a common legume in Mozambique and it is grown by some of the interviewed farmers in Malawi. Bambara nut is grown in many areas, but often by a small numbers of farmers (Franke and De Wolf, 2011).

Table 6: Cultivation of legume crops (% of households) in N2Africa countries in 2010

	DRC	Kenya	Rwanda	Malawi	Mozambique	Zimbabwe	Nigeria	Ghana
Bambara nut	1	1		3	1	7	0.4	7
Bush bean	81	82	63	24	31	12		6
Climbing bean	43	12	46	7		0.3		
Cowpea	1	50		17	44	21	74	26
Faba bean					3			
Garden pea			5					
Green gram		6						
Groundnut	11	35	22	84	24	50	49	40
Pigeonpea				4	32			
Soybean	13	19	21	25	22	9	40	21

Source: Franke and De Wolf (2011)

Only in the detailed farm characterizations, accurate measurements of the area under legumes were done. The baseline study contains information based on farmers' estimates. A comparison between these two data sources shows that the difference can easily be a factor two, and in many cases even more (Table 7). In DRC, Ghana and Mozambique, the area cultivated with legumes (based on farmers' estimates) is generally larger than 0.5 ha. In Kenya, Rwanda and Malawi this is often less, especially when data from the farm characterizations is considered.

Table 7: Average area under legumes (ha) by households growing legumes, as reported in baseline study* and detailed farm characterizations (DFC) in 2010

	Cowpea		Soybean		Groundnut		Bush bean		Climbing bean	
	Baseline	DFC	Baseline	DFC	Baseline	DFC	Baseline	DFC	Baseline	DFC
DRC	0		0.64		0.77		0.63		1.20	
Ghana	0.57		0.70		0.84		0.65		0	
Kenya	0.10		0.10		0.20		0.27		0.19	
Nigeria	nd	0.31	nd	0.06	nd	0.58	nd		0	
Rwanda	0		0.08		0.11	0.01	0.22	0.02	0.17	0.04
Malawi	0.28	0.11	0.57	0.12	0.48	0.40	0.28	0.19	0	
Mozambique	0.59		0.64		0.41		1.29		0	
Zimbabwe	nd		nd		nd	0.20	nd		0	

* Area cultivated with legumes in baseline is based on farmers' estimations, not on actual measurements.
Source: Franke and De Wolf (2011) and detailed farm characterizations Rwanda, Malawi and Zimbabwe

Multiplying the area cultivated with legumes per farm (based on the baseline study, unless there is data available from a farm characterization) with the amount of N_2-fixed per ha gives BNF per farm (Table 8). Since the average area cultivated with one of the legumes is generally less than 1 ha (except for bush bean in Mozambique and common bean in DRC), BNF per farm is only about half of the value for N-fixed per ha. Soybean in Mozambique, DRC and Ghana, and cowpea in Ghana have the highest amounts of N-fixed per farm. N-fixation in Kenya, Malawi and Rwanda is reduced to virtually nothing due to the small farm area cultivated with legumes. Promoting an expansion of the area planted with legumes is therefore very important to enhance BNF per farm.

Table 8: BNF per farm* (kg N farm^{-1}) in N2Africa countries

	Agronomy trials			Detailed farm characterisation			D&D trials
	N_2-fixed in grain	N_2-fixed in stover	Total N-fixed	N_2-fixed in grain	N_2-fixed in stover	Total N-fixed	N_2-fixed in grain
Cowpea							
Ghana	14	55	70				13
Malawi	1	5	6				
Nigeria	4	7	11				
Soybean							
DRC	30	17	47				
Ghana	29	34	62				19
Kenya	3	2	5				
Mozambique	45	24	68				
Nigeria	1	1	2				
Rwanda	2	1	3				
Groundnut							
Ghana	11	14	25				16
Malawi	4	2	5	20		-	
Nigeria	9	18	27				
Zimbabwe				17	14	31	
Bush bean							
DRC	19		19				
Kenya	4	2	6				
Rwanda	1	0	1				
Climbing bean							
Kenya	2	4	6				
Rwanda	2	1	3	1	2	3	

* Farm area based on baseline study (farmers' estimates) for DRC, Ghana, Kenya and Mozambique, and on DFC for Malawi, Nigeria, Rwanda and Zimbabwe.

2.3 Preliminary impact assessment N2Africa on BNF

At field level, N2Africa aims at increasing N_2-fixation through inoculation and proper nutrient management, especially through P and/or K fertilizer applications. The control yields (no inoculation, no fertilizer) in the agronomy trials form the baseline of N-fixation. A first assessment of the impact of N2Africa on biological nitrogen fixation can be established by comparing these control yields with treatments with:

- Inoculation
- P-fertilizer (TSP or SSP)
- P+K fertilizer (TSP + KCl)
- A combination of inoculation and P (+K) fertilizer

The amount of N_2-fixed is calculated in the same way as described before (yields multiplied by the N-content of grain and stover and then multiplied by the percentage of N_2-fixed with or without inoculation). The results of this first impact assessment, based on results of the agronomy trials, are presented in Table 9. This table includes total aboveground biomass. In Appendix 2 the impact on grain and stover N is presented separately.

Table 9: N_2-fixed in aboveground biomass (grain + stover) (kg N ha^{-1}) for control, inoculation (I), P-fertilizer[1] and P+K fertilizer[2] in N2Africa agronomy trials

	Control	+I	+P	+P +K	+I +P	+I +P +K
Cowpea						
Ghana	122		126	110		
Nigeria	37		53			
Soybean						
DRC	73	102	68	49	106	77
Ghana	89	112	104	123	148	160
Kenya	51	67	63	64	92	87
Mozambique	107	169	108		171	
Nigeria	39	43	46		56	
Rwanda	33	51	33	32	51	54
Zimbabwe	15	33	14		56	
Groundnut						
Ghana	30		29	29		
Nigeria	47		80			
Bush bean						
DRC	30	34	32	30	39	42
Kenya	22	24	22	19	26	22
Rwanda	43	61	47	49	49	55
Climbing bean						
DRC				18		20
Kenya	31	41	42	38	47	46
Rwanda	63	70	78	67	70	75

[1] P-fertilizer = Triple Super Phosphate (TSP) or Single Super Phosphate (SSP)
[2] K-fertilizer = Potassium chloride (KCl)

In cowpea, only the response to fertilizers was tested. N_2-fixed increased in Nigeria after application of P-fertilizer, but in Ghana neither P nor P+K fertilizer increased N_2-fixation. In soybean, inoculation alone increased N-fixed in all countries. The effect of P only, or a combination of P+K, was less pronounced. When inoculation and P were both applied, N_2-fixed increased considerably. In Zimbabwe for instance, the increase was almost fourfold, because the soils in which the trials were performed were very poor and control yields were small. In Mozambique, inoculation was responsible for the largest increase in N_2-fixed, and application of fertilizer did not improve N_2-fixation. This is explained by the fertile soils of the research station where the trials were performed. Addition of K only showed some effect in Ghana. Average N_2-fixation in groundnut was not improved with P or K fertilizer in Ghana, but P almost doubled N_2-fixed in Nigeria. Bush bean only showed a response in N_2-fixed in the treatments with inoculation and P, or inoculation and P+K fertilizer in DRC and Rwanda. Inoculation alone did not increase N_2-fixation. In Kenya, none of the treatments increased N-fixation. Climbing beans in Kenya showed the strongest response to the combination of inoculation and P-fertilizer. Adding K-fertilizer did not further improve N_2-fixation. N_2-fixed in Rwanda benefited most from P-fertilizer.

Apart from the agronomy trials, also the D&D trials performed in Ghana, Nigeria and DRC showed that N-fixation in soybean grain responded strongly to inoculation (Table 10). The response to P-fertilizer was less pronounced, but the combination of inoculation and P-fertilizer resulted in the highest amount of N-fixed. N-fixation in cowpea in Ghana generally increased with application of P-fertilizer compared to the control, although the response is not very strong. In groundnut, on average, P-fertilizer did not increase N-fixed. Only in combination with K-fertilizer there was a moderate response.

Table 10: N_2-fixed in grain (kg N ha^{-1}) for control, inoculation (I), P-fertilizer[1] and P+K fertilizer[2] in N2Africa D&D trials

	Control	+I	+P	+I +P	+P +K
Cowpea					
Ghana	22		28		
Soybean					
DRC	29	52	31	65	
Ghana	27	40	31	48	
Nigeria	32	52	43	72	
Groundnut					
Ghana	15[3]/20[4]		18		25

[1] P-fertilizer = Triple Super Phosphate (TSP)
[2] K-fertilizer = Potassium chloride (KCl)
[3] Relative to +P treatment
[4] Relative to +P+K treatment

The results in Table 10 represent the average N_2-fixed in at least 40 D&D trials in each of the countries. The variability between the fields is large, however. In Ghana, for instance, N_2-fixation in cowpea barely increased as a result of P application when N-fixed (or grain yields) on the control plots were very low (Figure 1). For the control plots with N-fixed of about 20 to 50 kg N ha^{-1}, most trials showed an increase in N_2-fixation after P application. In one trial, grain N even increased from 50 kg N ha^{-1} in the control to more than 100 kg in the treatment with P.

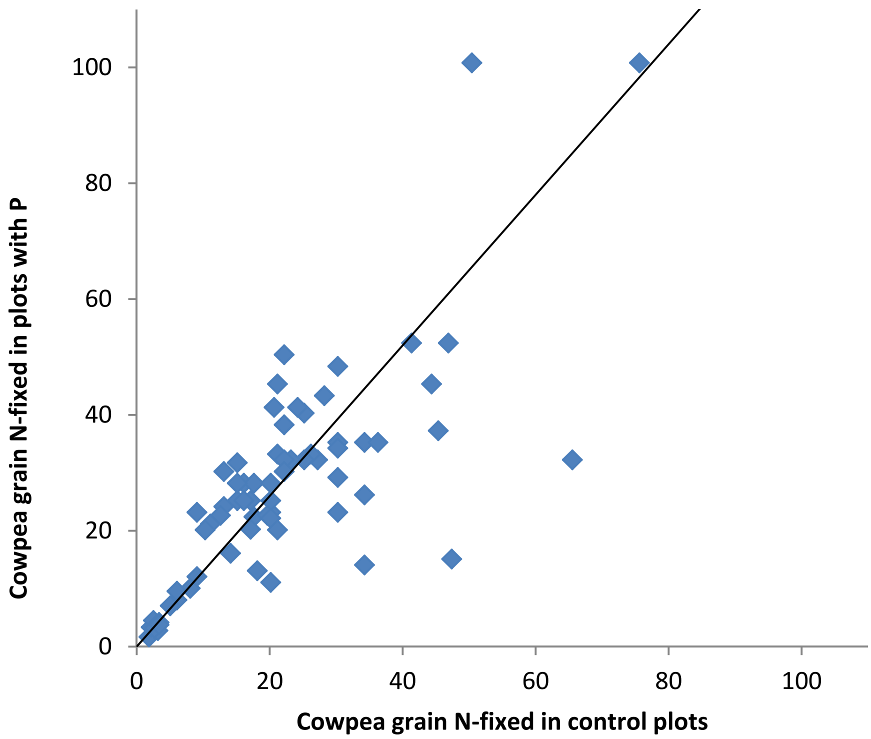

Figure 1: Cowpea grain N_2-fixed in control plots compared to plots with P (D&D trials from Ghana in 2011)

The same variability was found in soybean D&D trials in Ghana. Almost all trials showed a response to inoculation, but the effects of P-fertilizer were mixed: in nearly half of the trials P only did not increase N-fixed (Figure 2). The combination of inoculation and P-fertilizer resulted in the strongest increase in N-fixed, although again the trials with very low yields on the control plot did not benefit from any of the treatments.

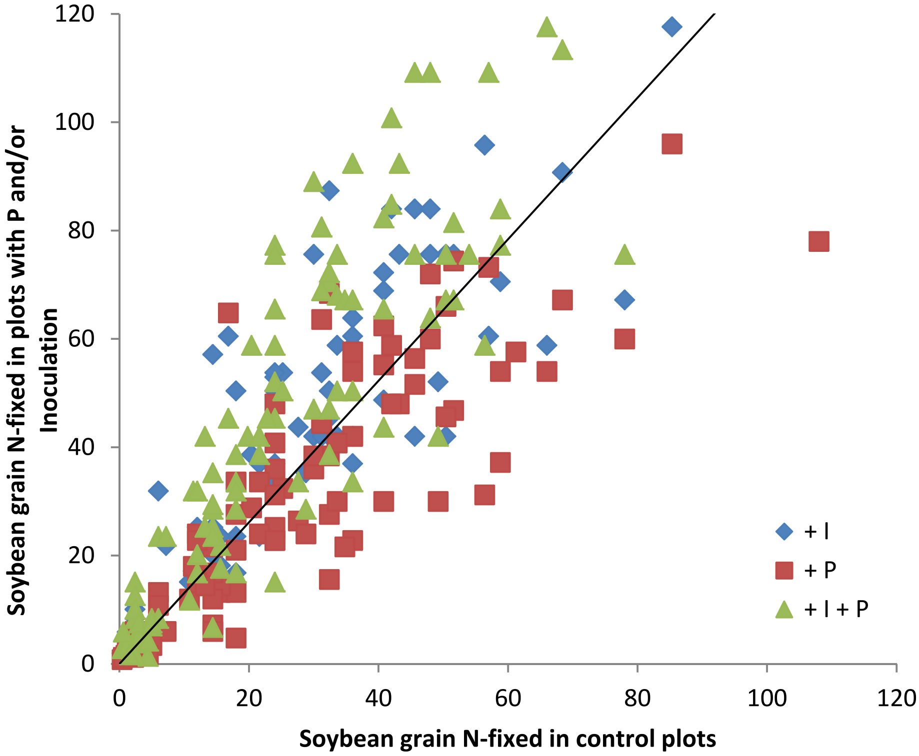

Figure 2: Soybean grain N_2-fixed in control plots compared to plots with P and/or inoculation (D&D trials from Ghana in 2011)

In groundnut in Ghana, P-fertilizer increased grain N_2-fixed in many of the fields, but there were also fields in which N-fixed was lower than in the control. This explains why the average N_2-fixed presented in Table 10 did not show an increase as a result of P-fertilizer. The combination of P+K increased N-fixed, but again mainly for plots in with a certain minimum control yield.

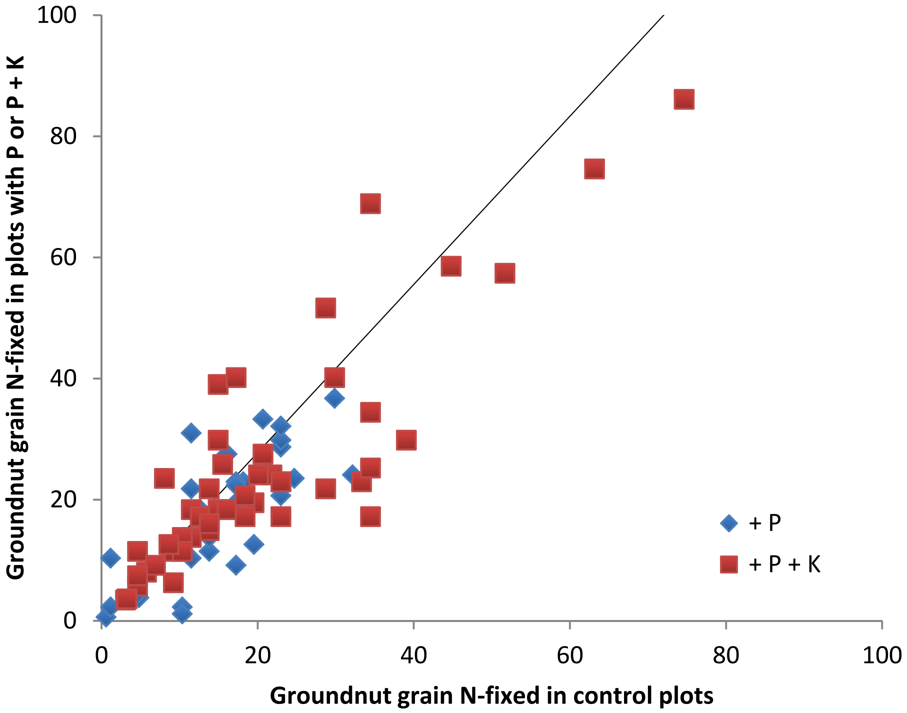

Figure 3: Groundnut grain N-fixed in control plots compared to plots with P and P+K (D&D trials)

3. Concluding remarks

The range in values for %N from N_2-fixation and amount of N_2 fixed found in literature is wide. Individual factors like variety, inoculation or P-fertilizer can substantially increase these values, and interaction effects between these factors may result in even larger increases. Also baseline BNF values assessed in this report showed that N_2-fixed ha^{-1} greatly differs between countries, regions and crops. This is partly the result of differences in yields in different agro-ecological zones, and partly because of differences in N_2-fixing potential between the legumes.

A first impact assessment of inoculation, P and K fertilizer shows that grain N_2-fixed in soybean is improved strongly by inoculation, and increases even further through a combination with P and K fertilizer. Cowpea and groundnut generally benefit from application of P-fertilizer (inoculation was not tested), whereas for bush bean and climbing bean the responses to inoculation or fertilizer are mixed. These increases in N_2-fixed largely also apply to stover N, which offers potential to increase soil N when residues are either left in the field or returned as manure. The largest potential for an increase in N-fixed, however, is the increase in area under legumes; either in the area per farm, or in the number of households growing legumes.

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Appendix 1: N-content of grain and stover in legumes

Average N-content in grain and stover (%) for selected grain legumes in Africa

	N-content grain (% of total grain weight)	N-content stover (% of total stover weight)
Cowpea[1]	3.5	3.1
Soybean[2]	6.0	2.5
Groundnut[3]	3.9	2.2
Bush bean[4]	4.4	3.8
Climbing bean[4]	4.1	4.1

References: 1. (Adjei-Nsiah et al., 2008, Bado et al., 2006, Belane et al., 2011, Ebanyat et al., 2010, Manenji, 2011); 2. (Ebanyat et al., 2010, Manenji, 2011, Ojiem et al., 2007) 3. (Bado et al., 2006, Ebanyat et al., 2010, Ncube et al., 2007, Ojiem et al., 2007, Rebafka et al., 1993, Manenji, 2011); 4. (Ojiem et al., 2007, NARL, 2012, Manenji, 2011)

Appendix 2: N-fixed in grain and stover (kg N ha^{-1})

N-fixed in grain and stover (kg N ha^{-1}) for control, inoculation (I), P-fertilizer[1] and P+K fertilizer[2] in N2Africa agronomy trials

	Grain						Stover					
	control	**+I**	**+P**	**+P +K**	**+I +P**	**+I +P +K**	**control**	**+I**	**+P**	**+P +K**	**+I +P**	**+I +P +K**
Cowpea												
Ghana	25		37	33			97		89	77		
Nigeria	13		21				24		32			
Soybean												
DRC	47	66	44	49	69	77	26	36	24		37	
Ghana	41	57	54	54	75	79	48	55	50	69	73	81
Kenya	32	41	41	41	59	54	19	26	22	23	33	33
Mozambique	70	110	70		111		37	59	38		60	
Nigeria	23	26	26		34		16	17	20		22	
Rwanda	23	36	22	23	37	40	10	15	11	9	14	14
Zimbabwe	9	24	9		40		6	9	5		16	
Groundnut												
Ghana	13		14	13			17		15	16		
Nigeria	16		28				31		52			
Bush bean												
DRC	30	34	32	30	39	42						
Kenya	14	14	13	10	15	11	8	10	9	9	11	11
Rwanda	28	39	29	30	28	35	15	22	18	19	21	20

	Grain						Stover					
	control	**+I**	**+P**	**+P +K**	**+I +P**	**+I +P +K**	**control**	**+I**	**+P**	**+P +K**	**+I +P**	**+I +P +K**
Climbing bean												
DRC				18		20						
Kenya	12	16	16	16	18	17	19	25	26	22	29	29
Rwanda	44	46	55	46	48	52	19	24	23	21	22	23

[1] P-fertilizer = Triple Super Phosphate (TSP) or Single Super Phosphate (SSP)
[2] K-fertilizer = Potassium chloride (KCl)

List of project reports

1. N2Africa Steering Committee Terms of Reference
2. Policy on advanced training grants
3. Rhizobia Strain Isolation and Characterisation Protocol
4. Detailed country-by-country access plan for P and other agro-minerals
5. Workshop Report: Training of Master Trainers on Legume and Inoculant Technologies (Kisumu Hotel, Kisumu, Kenya-24-28 May 2010)
6. Plans for interaction with the Tropical Legumes II project (TLII) and for seed increase on a country-by-country basis
7. Implementation Plan for collaboration between N2Africa and the Soil Health and Market Access Programs of the Alliance for a Green Revolution in Africa (AGRA) plan
8. General approaches and country specific dissemination plans
9. Selected soybeans, common beans, cowpeas and groundnuts varieties with proven high BNF potential and sufficient seed availability in target impact zones of N2Africa Project
10. Project launch and workshop report
11. Advancing technical skills in rhizobiology: training report
12. Characterisation of the impact zones and mandate areas in the N2Africa project
13. Production and use of Rhizobial inoculants in Africa
18. Adaptive research in N2Africa impact zones: Principles, guidelines and implemented research campaigns
19. Quality assurance (QA) protocols based on African capacities and international existing standards developed
20. Collection and maintenance of elite rhizobial strains
21. MSc and PhD status report
22. Production of seed for local distribution by farming communities engaged in the project
23. A report documenting the involvement of women in at least 50% of all farmer-related activities
24. Participatory development of indicators for monitoring and evaluating progress with project activities and their impact
25. Suitable multi-purpose forage and tree legumes for intensive smallholder meat and dairy industries in East and Central Africa N2Africa mandate areas
26. A revised manual for rhizobium methods and standard protocols available on the project website
27. Update on Inoculant production by cooperating laboratories
28. Legume Seed Acquired for Dissemination in the Project Impact Zones
29. Advanced technical skills in rhizobiology: East and Central African, West African and South African Hub
30. Memoranda of Understanding are formalized with key partners along the legume value chains in the impact zones
31. Existing rhizobiology laboratories upgraded
32. N2Africa Baseline report

33. N2Africa Annual country reports 2011
34. Facilitating large-scale dissemination of Biological Nitrogen Fixation
35. Dissemination tools produced
36. Linking legume farmers to markets
37. The role of AGRA and other partners in the project defined and co-funding/financing options for scale-up of inoculum (banks, AGRA, industry) identified
38. Progress Towards Achieving the Vision of Success of N2Africa
39. Quantifying the impact of the N2Africa project on Biological Nitrogen Fixation

Partners involved in the N2Africa project

Caritas Rwanda

Diobass

Eglise Presbyterienne Rwanda

Nairobi University

Resource Projects-Kenya

Université Catholique de Bukavu

University of Zimbabwe