13

Integrated Soil Fertility Management in Bean-Based Cropping Systems of Eastern, Central and Southern Africa

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1. Introduction

Common bean (*Phaseolus vulgaris* L.) is an important grain legume in Eastern, Central and Southern Africa (ECSA), where it is grown on over 3.7 million of hectares every year. In this region, bean consumption per capita exceeding 50 kg a year is perhaps the highest in the world, reaching over 66 kg in densely populated western Kenya (Wortmann et al., 1998). Bean provides the essential dietary protein, fiber and income to at least 100 million people in Africa (Kimani et al., 2001). Beans are grown primarily as a food crop and to generate income by smallholder, resource-poor farmers, in holdings that rarely exceed 1.5 hectares. They are grown in pure stands or in association with maize, bananas, or root or tuber crops, and in recent years, between rows of fruit crops, banana and coffee, especially in the early establishment phase of these traditional cash crops. About 22% of the production area is sole-cropped, 43% is in association with maize, 15% with bananas, 13% with root and tuber crops, and 7% with other crops (Wortmann et al., 1998). In southern Africa, beans are either grown in pure stands (42%) or in association with maize (47%), or to a lesser extent, with root crops (6%) or other crops (5%). Production is mainly rain-fed, except in Mauritius and the Nile Valley of Sudan where beans are grown as an irrigated crop. In lowland areas of Madagascar, Malawi, Mozambique, and DR Congo, beans are sown after another crop in order to use residual moisture and to take advantage of lower temperatures during the winter months.

Bean is produced essentially in the Eastern and Central African highlands, where the population density is the highest (Wortmann et al., 1998). It is produced by smallholder farmers with few resources to allocate to soil improvement. In the Great Lakes region for example, Dreschsel et al. (1996) report extremely low use of mineral fertilizer, only about 0.4 kg ha^{-1}. Moreover, because of the high population density, farmers are faced with rapid soil

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fertility decline as a result of continuous cropping and inappropriate cropping systems with very little or no external nutrient input to replenish soil fertility. Therefore, bean yield is generally low in most regions and is most likely to decline because of the ever increasing population density. In fact, under current farming systems in small holders' fields, soil nutrient balances are negative (Bationo et al. 2006), except in banana based systems (Wortmann and Kaizzi, 1998).Although bean grain yields are variable across countries and regions, they generally vary from 200 kgha^{-1} in less favorable environments to 700 kg ha^{-1} in more favorable environments when grown in pure stands, and about half of this when intercropped (Kimani et al., 2001).

In ECSA, low soil fertility is the most important yield-limiting factor in most of the bean-producing regions. The major soil fertility related problems are found to be low available phosphorus (P) and nitrogen (N), and soil acidity, which is associated aluminum (Al) and manganese (Mn) toxicity. According to the Atlas of common bean production in Africa (Wortmann et al., 1998), P is deficient in 65 to 80% of soils and N in 60% of soils in bean production areas of Eastern and Southern Africa, while about 45 to 50% of soils are acidic with a pH less than 5.2, containing high levels of either Al or Mn. The details on the importance of the edaphic stresses for common bean production are presented in table 1. Low soil fertility causes considerable losses in productivity as the estimated bean production losses due to edaphic stresses in the ECSA are about 1,128 million tons per year (Table 1).

Bean grows well in deep well drained, sandy loam, sandy clay loam or clay loam with clay content of between 15 and 35% with no nutrient deficiencies (Thung and Rao, 1999). The optimum soil pH range is 5.8 to 6.5 and Al saturation is below 10% (Lunze, 1994). It will not grow well in soils that are compacted, too alkaline or poorly drained.

Constraints	Eastern and Central Africa	Southern Africa	Eastern and Central Africa	Southern Africa	Sub Saharan Africa
	% Total bean area affected			Annual losses (t)	
N deficiency	50	60	263,600	125,200	389,900
P deficiency	65	80	243,200	120,400	355,900
Acidity	45- 50	45 - 50	152,700	65,800	220,000
Al/Mn toxicity	52	42	97,500	60,300	163,900
Total			757,000	371,700	1129,700

Table 1. Major soil related production constraints and bean yield losses in Africa (Wortmann et al. 1998)

In light of these constraints, the Pan African Bean Research Alliance (PABRA) has undertaken regional efforts to develop integrated soil fertility management (ISFM) technologies that improve sustainability, productivity and quality of the bean crop in various environments across ECSA. Over the past two decades, there have been research initiatives from both national programs and bean research networks Eastern and Central Africa Bean Research Network (ECABREN) and the Southern Africa Bean Research Network (SABRN), both of which belong to PABRA, to develop strategies and technologies to improve sustainably bean crop productivity and production in various production environments in ECSA. A range of technologies have been evaluated and developed to address the regional constraints, and efforts were made to promote the promising technologies widely.

Several technologies have been developed through collaborative research efforts within PABRA. The objective has been developing strategies and technologies that enhance resilience to environmental stresses and improve bean productivity and product quality. These include: (i) development of diagnostic tools for soil fertility assessment that are adapted to local conditions; (ii) replenishing soil nutrient pools, maximizing on-farm recycling of nutrients, and reducing nutrient losses to the environment; and (iii) improving the efficiency of external inputs. As common bean can derive part of its N from the atmosphere under low input agriculture (Giller *et al.*, 1998), improving biological nitrogen fixation using seeds inoculation with appropriate rhizobacteria and soil management was considered. Currently recommended ISFM options in bean based cropping systems include farmyard manure, compost, biomass transfer, green manure and cover crops, liming, phosphate rock (PR) and mineral fertilizers in different combinations with organic resources. The soil management options are complemented by utilization of resilient bean germplasm that perform well under low soil fertility conditions.

This paper reviews ISFM options developed by the ECABREN and SBRN and the approaches for effective and efficient delivery of these technologies to farmers.

2. Integrated soil fertility management (ISFM) options

2.1 Concept of ISFM

Integrated soil fertility management (ISFM) is an approach that stresses sustainable and cost-effective management of soil fertility (Sanginga and Woolmer, 2009; Vanlauwe et al., 2010). This soil fertility strategy relies on a holistic approach that embraces the full range of driving factors and consequences of soil degradation- biological, chemical, physical, social, economic, health, nutrition and political (Bationo et al., 2006). ISFM attempts to make the best use of inherent soil nutrient stocks, locally available soil amendment resources and mineral fertilizers to increase land productivity while maintaining or enhancing soil fertility. Vanlauwe et al. (2010) define ISFM as 'A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. A conceptual diagram is shown in Figure 1.

2.2 Local soil fertility diagnostic tools

Soil fertility can vary drastically from one end of field to the other (Vanlauwe, 2006). Therefore, response to applied soil management and external inputs can vary accordingly and no single recommendation can be made for a whole farm. As ISFM technologies are generally complex, labour intensive and costly, a more accurate intervention and recommendation system is crucial to improve the chance of adoption of these technologies by farmers. To assure farmers get the maximum return from the investment in inputs for

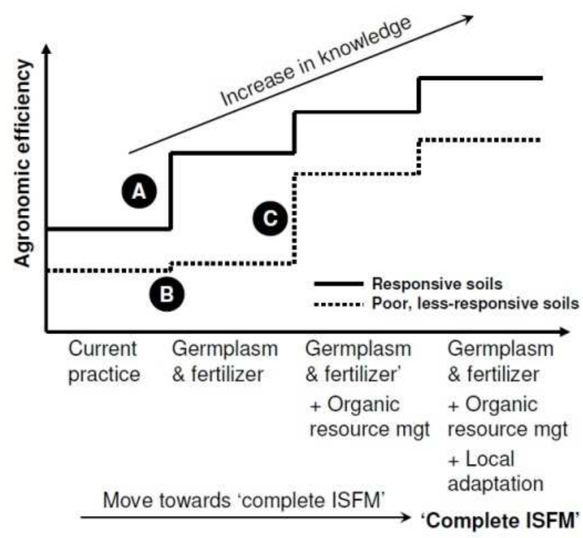


Fig. 1. Conceptual relationship between the agronomic efficiency of fertilizers and organic resource and the implementation of various components of ISFM, (Vanlauwe et al., 2010)

soil improvement, it is important that recommendations well target specific local conditions. Hence the indicator of soil quality is important for local communities to better manage their soil resources though better decision making (Barrios et al., 2001). These have to be simple enough for use by farmers and extension personnel. Dominant plant species on a farmland have the potential to integrate changes in soil quality, reflecting changes in the physical, chemical and biological characteristics of the soil (Pankhurst et al., 1997).

There have been research initiatives from both national programs and PABRA to integrate farmers' perceptions of soil fertility in simple soil fertility assessment. In South Kivu province of D.R. Congo, Ngongo and Lunze (2000) tested bean response to fertilizer application on soils with varying levels of weed infestation. Field trials were conducted for two seasons to test the effect of compost applied at 20 t ha^{-1} rate. Where *Gallisonga parviflora* is the dominant weed species, soil nutrient levels were high, bean (*Phaseolus vulgaris L.*) yield was high and did not increase further compost application. Where *Pennisetum polystachia* is the dominant species, soil fertility and bean productivity were low. Bean yield on these fields was increased considerably with the application of compost. The results (Table 2) confirm the farmer's perception that *Pennisetum polystachia* is an indicator of low soil fertility. *Conyza sumatrensis* and *Bidens pilosa* indicate intermediate level of soil fertility and response to compost was also intermediate.

Similar results were reported by Ugen and Wortmann (2006) in Uganda. Relative densities of *Digitaria scalarum* (blue couch), *Eleusine indica (L.) Gaertn.* (goosegrass), *Euphorbia hirta* (garden spurge), *Cyperus spp.*, *Oxalis latifolia H.B.K.* and *Sorghum halepense (L.) Pers. (johnsongrass)* varied more with nutrient supply than did other species. Soil properties had less effect on the distribution of *Ageratum conyzoides* L. (*tropic ageratum)*, *Bidens pilosa* (*hairy beggarticks)*, *Commelina benghalensis L. (tropical spiderwort)*, and *Galinsoga parviflora Cav. (smallflower galinsonga)*. High relative densities of *Digitaria scalarum* and *Euphorbia hirta* were generally associated with low soil nutrient levels. *Eleusine indica (L.) Gaertn.* (*Goosegrass)*, *Sorghum halepense (L.)* Pers. (*johnsongras*s), and *Oxalis latifolia* were associated with higher nutrient levels in soil.

Dominant weeds	Bean yield (kg ha^{-1})			
	1994B		1995A	
	+C	-C	+C	-C
Gallinsoga parviflora	995.3a	1000.0a	1713.3a	1700.0a
Pennisetum polystachia	427.7cd	170.7cd	696.7cd	41.7e
Conyza sumatrensis	720.1b	627.8b	827.7c	419.7d
Bidens pilosa	1012.0a	950.0a	933.3c	873.3c
Digitaria vestida var scalarum	892.2a	457.7c	1335.3b	1251.0b
Mean (kg ha^{-1})	809.5	641.2	1101.3	857.1
C.V. (%)	25.9	25.9	21.2	21.2

+C: with compost and –C: without compost

Table 2. Bean response to compost on fields with different weed species in South-Kivu, D.R. Congo (Ngongo and Lunze, 2000)

A more detailed assessment of soil chemical properties based on weed species density was done in Uganda by Ugen, et al. (1999). In this study, they made observations on 39 fields with annual crops over 4 locations in Eastern and Central Uganda. Densities of weed species relative to the total weed population were determined and surface soil samples were collected and analyzed for organic carbon (OC), soil pH, available P, K, Ca and Mg and total N, P and K levels. The results are presented in table 3.

Species	OC	pH	P	K	Ca	Mg	N total	P total	K total
Eleusine			+	+	+	+		+	+
Euphorbia			-		-	-		-	
Sorghum	+	+		+	+		+		
Oxalis	+	+	+	+					
Nutsedge	-					-			

Source: Ugen, M., Wien A. D., Wortmann C.. CIAT Annual Report 1999

Table 3. Positive (+) and negative (-) relationships of the relative densities of weeds species with soil properties which may be useful in diagnosis of soil fertility status

Oxalis latifolia was correlated with OC content, as this weed was unlikely to be present when percentage C was less than 2.3, and increased in density as soil C increased. Soil pH was well correlated with both *Sorghum halepense* and *Oxalis latifolia*. *Sorghum halepense* was found to be a good indicator for soil pH, being generally absent when soil pH was less than 5.8, while *Oxalis latifolia* increased in importance when soil pH increased. *Eleusine indica* was not likely to occur when soil P availability was less than 13 mg kg^{-1} and increased with increased P availability, while the total P was positively correlated with

Eleusine indica, but negatively correlated with *Euphorbia hirta* densities. *Sorghum halepense* occurred infrequently when exchangeable K was less than 0.6 cmol(+)kg^{-1}. *Eleusine indica* and oxalis increased as exchangeable K; *Eleusine indica* and *Bidens pilosa* tended to increase as total K increased. Relative densities of *Digitaria scalarum*, *Euphorbia hirta* and *Cyperus esculentus L.* (yellow nutsedge) were negatively related to exchangeable Mg and accounted for 62% of variation in exchangeable Mg. Soil fertility assessment using natural weeds is the most convenient tool available to smallholder farmers and extension workers because it requires minimal training. Therefore, weed flora was used to develop a decision guide to aid farmers in the identification of areas in their fields with severe nutrient deficiencies in Uganda and Eastern DR Congo. Thus, farmers and extension workers have at their reach a quick and inexpensive way to assess the soil fertility levels and make decisions concerning soil management.

3. Genetic approaches

Genetic variation for abiotic stress tolerance exists within common bean germplasms in 15 national and regional bean programs (Singh, 1991; Aggarwaal, 1994; Lynch and Beebe, 1995; Rachier et al., 1999; Rao 2001; Beebe et al., 2009), and significant number of new lines bearing these traits were developed at CIAT headquarters in Cali, at CIAT Africa regional breeding program hosted by the University of Nairobi, Kenya and the national bean programs. Singh (2001) stated that development of high yielding cultivars adapted to low soil fertility and low input sustainable systems is essential to maximize yield of common bean to enhance food security, reduce production costs and generate income. PABRA considers development of low soil fertility-tolerant bean varieties as an option to increase bean yield at no additional cost (Kankwatsa et al., 2008). Thus, bean improvement for low soil fertility adaptation has become an important component of ISFM strategy for optimum bean production in low input systems of smallholder African farmers.

Screening common bean cultivars for low soil fertility tolerance is done under field conditions following a harmonized protocol (CIAT, 1994). The methodology consists of screening the same sets of bean genotypes at several locations under a single stress and combining results across sites with different stresses (Wortmann et al., 1995). Screening is done at two stress levels: moderate stress and no stress. The moderate stress corresponds to the stress level at which a well-adapted control variety under stress performs at 40 to 50% of its normal unstressed performance. The criterion for selection is essentially bean yield, but farmers' preferences and market preference were also considered. Five most popular market classes in ECSA are red kidney, red mottled, small red, white navy and pintos (Kimani et al., 2001). Such intentional market class choice was intended to link production to well-established markets and favor adoption by farmers. The potential genotypes identified are evaluated with farmers following the participatory varietal selection (PVS), a strategy developed within PABRA for heterogeneous environments where farmers have a range of preferences (Sperling et al., 1993). The selected varieties are then promoted through other participatory methods in on-farm trials. The sites selected in different countries represent a range of soils characteristics and agro-ecologies. Soil chemical characteristics at the experimental sites in different countries are presented in Table 4.

Sites and stress	Country	Altitude (m)	pH H_2O	Organic C (%)	Bray-I P (mg kg^{-1})	Exch. Ca (cmol(+) kg^{-1})	Exch. Mg (cmol(+) kg^{-1})	Exch. K (cmol(+) kg^{-1})	Exch. Al (cmol(+) kg^{-1})	Al saturation (%)
Nyamunyunye (Al)	DRC	1730	4.7	2.3	0.5	2.6	1.1	0.07	2.6	41
Gikongoro (Al)	Rwanda	1900	4.8	0.5	2.2	1.4	0.3	0.01	2.6	60
Antsirabe (P &Al)	Madagascar		4.6	3.7	1.2	0.45	0.65	0.28	2.43	59
Kakamega (low P)	Kenya	1550	4.9	2.6	7.3	1.6		2.3	na	
Mulungu 2 (low N)	Uganda	1690	5.8	2.4	9.6	5.5	3.1	0.56	na	
Selian (low N)	Tanzania		6.5	1.8	18.2	9.2	1.6	6.2	na	
Kawanda (low N)	Uganda	1190	5.5	2.1	20.0	2		0.5	na	
Kawanda (low K)	Uganda	1190	5.3	3.3	10.0	2		0.2	na	
Ikulwe (Mn)	Uganda	1200	5.2	2.8	3.0	4		0.8	na	

Table 4. Characteristics of surface soils (0-20 cm) at test sites in several African countries

To date, a total of 1,400 beans lines have been evaluated through BILA (Bean Improvement for Low fertility soils in Africa) for their relative tolerance to the stresses under consideration, particularly low N, low P and soil acidity, which is associated Al and/or Mn toxicity. Considerable genetic variability in germplasm was detected and several varieties identified with specific single or multiple edaphic stress tolerance. The initial screening did not consider market factors, but allowed selection of tolerant cultivars from national and regional bean programs, already well adapted to local environments. The following cultivars were identified as tolerant lines to different stresses from the evaluation at different BILFA sites (Lunze, 2002).

- Low N: RWR 382, RAO 55, ACC 433, UBR(92)25 and BAT 85
- Low P: Carioca, BAT 25, RAO 55, XAN 76 and MMS 224, ACC 433 and Ikinimba
- Low K: EMP 84, ICA Pijao, RAO 52 and BAT 1220
- Al toxicity : ACC 7/4, Ubusosera
- Mn : MCM 5001, XAN 76 and Urugezi

These cultivars were integrated into national bean breeding programs, and several tolerant varieties have been adopted by farmers and are among the released varieties (Ikinimba, XAN 76, Ubusosera, ACC 7/4, RAO 55, UBR(92)25, MwaMafutala, Ntekerabasilimu) in some countries including Madagascar, DR Congo, Malawi and Uganda, MLB 4089A , RWR 1092 in Kenya

3.1 Low soil fertility adapted bean lines or varieties of various market classes

The most popular bean types grouped in major market classes were screened and lines tolerant to edaphic stresses were selected to allow potential users to choose for their own market. Bean lines or varieties belonging to various market classes and types, grouped by their tolerance to low N, low P and low pH conditions are presented in table 5. Bean genotypes were evaluated for low N adaptation at two sites, Mulungu in DR Congo and Selian in Tanzania. The genotypes varied significantly in their grain yield under N deficient conditions and in their response to applied N. Without applied N, the yield varied from 695 to 1,789 kg ha^{-1} while with added N at the rate of 30 kg ha^{-1}, the grain yield varied from 1,258 to 3,139 kg ha^{-1} at Mulungu. Without N, most lines gave significantly higher yield than the local sensitive check Kirundo, and previously selected tolerant variety, MwaMafutala.

Low N			Low P			Low pH		
Line code	Seed size (100 seed weight, g)	Seed color	Line code	Seed size (100 seed weight, g)	Seed color	Line code	Seed size (100 seed weight, g)	Seed color
A 286	17	Carioca	AFR 619	34	Red	37/66/6	23	Tan
AFR 675	24	Navy	AFR 675	24	Navy	A 286	17	Carioca
AFR 699	40	Red	AFR 708	44	Calima	A 344	27	Cream
AFR 714	23	Navy	AFR 714	23	Navy	AFR 708	44	Calima
AND 871	35	Calima	AND 871	35	Calima	AFR 714	23	Navy
CAL 143	50	Calima	ARA 4	21	Cream	ARA 4	21	Cream
CAL 150	50	Calima	CIM 9314-36	41	Calima	BRB 119	31	Calima
CIM 9314-33	42	Red	CIM 9314-37	34	Calima	DB 201/77/1	19	Navy
CIM 9314-36	41	Calima	CIM 9331-1	25	Red	CIM 9314-3	37	Calima
CIM 9315-1	24	Pink	CIM 9331-2	29	Pink	CIM 9331-1	31	Red
CIM 9315-3	27	Calima	CIM 9331-3	23	Red	CIM 9415	38	Calima
CIM 9318-4	27	Calima	DB 196	20	Navy	CNF 5520	44	Calima
CIM 9331-3	23	Red	DOR 663	17	Black	DFA 53	28	White
DB 196	20	Navy	FEB 192	19	Cream	FEB 197	22	Black
DOR 715	18	Red	FEB 196	20	Carioca	G 12489	44	Calima
FEB 192	19	Cream	G 2858	21	Tan	G 2910	21	Calima
FEB 196	20	Carioca	G 5889	15	Cream	G 3480	15	Black
G 5889	15	Cream	LSA 32	32	Carioca	G 5889	15	Cream
LSA 32	32	Carioca	MORE 92018	49	Tan	HM 21-7	45	Red
MORE 92018	40	Tan	PAN 150	24	Carioca	LRK 34	45	Pink
PAN 150	24	Carioca	RWR 1873	35	Calima	LSA 144	22	Red
PRELON	20	Navy	RWR 2075	44	Red	PAN 150	24	Carioca
RAB 482	17	Red	RWR 2091	37	Red	RAB 482	17	Red
REN 22	21	Navy	SDDT 49	20	Carioca	RWR 1742	22	Red
RWK 10	40	White speckled	SDDT 54-C5	31	Pink	RWR 1873	35	Calima
SDDT 55-C4	42	Calima	UBR(92)24/11	15	Navy	UBR(92)11	18	Carioca
UBR(92)25	18	Navy	VEF 88(40)L1PYT6	24	Red	VEF88(40)L1PYT6	24	Red
VEF88(4O)L1PYT6	24	Red	XAN 76	18	Calima	XAN 76	18	Cream
			ZAA 5/2	33	Cream	ZAA 5/2	33	Calima

Table 5. Promising bean lines in different market classes and types, grouped according to their tolerance to stressful soil conditions- low N, low and pH (Lunze et al., 2002)

The performance of the best lines selected for their tolerance to low P was evaluated at Kakamega and Antsirabe in Madagascar. Several lines were outstanding compared with the local released bean variety GLP 585. Considerable yield advantage of up to 80% was observed compared with the local check. The outstanding genotypes tolerant to low P are AFR 619, XAN 96, ARA 4, AFR 708 and RWR 1873.The screening of genotypes for low pH was done at Mulungu, DR Congo; Gikongoro, Rwanda; and Antsirabe, Madagascar (in acidic soils that demonstrate positive response to liming) revealed that the genotypes selected as Al resistant at three low pH sites were generally the same and performed consistently across sites. However, the slight variability noticed across sites could be attributed to the difference in adaptation to local environments (Wortmann et al., 1995). At Mulungu, with no lime, most test lines gave significantly higher yield than the sensitive check variety Kirundo, while only two lines VTTT 923-6-1, HM 21-7 and AFR 593-1 outperformed the tolerant check MwaSole (Table 6). The yield advantage of Al-resistant genotypes could be as high as 300% compared with the check.

Line	Bean grain yield		Loss due toxicity (%)	% Yield advantage over check
	Stress (kg ha-1)	Non-stress (kg ha-1)		
VTTT 923-6-1	1494	1588	5.9	310.6
HM 21-7	1317	1455	9.5	273.8
AFR 593-1	1040	1801	42.2	216.2
MwaSole	999	1264	20.9	207.7
ARA-8-5-1	957	1394	31.3	199.2
AND 932-A-1	932	1206	22.7	193.8
BZ 12984-C-1	866	874	0.9	180.0
Mwamafutala	625	1510	58.6	129.9
Kirundo (control)	481	988	51.3	100

Adapted from Lunze et al., 2007

Table 6. Bean lines and varieties resistant to Al toxicity in soil with a yield advantage over the check

At Antsirabe, Madagascar, several lines outperformed the local check Soafianarana and improved check Goiano Precoce. Most genotypes selected as resistant to Al toxicity at Antsirabe showed the same at Mulungu. The following lines gave consistently better yield under acid Al-toxic soil at the two low pH sites: AND 1056-1, AND 932-A-1, ARA 8-1B, BZ 12984-C-1 and VTTT 920-26. At Gikongoro, Rwanda many lines gave higher yield than the Al-resistant checks 7/4, Acc and RAB 478. However AND 93-A-1, BZ 12894-C-1 and AFR 593-1 were also identified as resistant to Al at the other two low pH sites, Mulungu and Antsirabe (Lunze et al., 2007).

The overall evaluation across sites and stresses allowed selection of bean lines that had consistently high yield under different stresses and across sites, with identified tolerance to one, two or even all three soil constraints considered. BZ 12894-C-1, AND 932-A-1, DRK 137-1, Nm 12806-2A are outstanding across sites and in response to all stresses - high aluminum toxicity, low N and low P availability. Several other lines have manifested tolerance to two stresses: ARA 8-B-1, AFR 709-1, AFR 703-1 and AND 1055-1 are tolerant to low P and low pH: RWK 10, ARA 8-5-1, and T 842-6F11-6A-1 tolerant to low N and low pH. These appear to have multiple tolerances to edaphic stresses and good adaptation at all environments. The results show existence of tolerance to low soil fertility in market class bean types. The promising varieties identified provide opportunities for higher bean productivity on acid soils and those with limited N and P supply (Lunze et al., 2007).

3.2 Dissemination and impact

Efforts have been made to promote all the promising and potential cultivars in all regions with problem soils as their yield advantage in similar environments has been confirmed. The benefit of low soil fertility adapted bean varieties has been demonstrated in Eastern DR Congo (Njingulula, 2003; Mastaki, 2006), Malawi, Kenya and Uganda (Kankwatsa et al., 2008). In Eastern DR Congo, with very low fertility soils, Ubusosera and RWR 382 have become the main varieties grown by farmers, replacing previously grown local or improved varieties. Kimani (2005) reported that different countries have selected and widely promoted bean genotypes that are adapted to their own environment (table 7). More than 10 years later, most farmers still kept BILFA varieties because of their adaptation to marginal soil conditions (Musungayi et al., 2008). Njingulula (2003) conducted a study to assess the impact of two low soil fertility adapted varieties in Eastern Congo and has indicated that farmers who have adopted those two varieties (Ubusosera named MwaSole, resistant to Al and RWR 382, locally named MwaMafutala adapted to low N) have noticeably improved their socio-economic conditions. In this study, (1) 32% of respondents noted that bean quantity for consumption and sale was increased, (2) 28.4% of respondents said that bean become more permanent throughout the year, (3) 30% of respondents mentioned that nutrition was improved as they could eat twice a day compared to only once previously, (4) and other farmers responded they purchased livestock and various household items such as bicycles, radio, etc and paid medical care and school fees.

Lines	Countries where adopted
RWR 1873	Uganda, Kenya, DRC
RWR 1946	Uganda, Kenya, DRC
RWR 2075	Uganda, Kenya, DRC
UBR(92)25	DRC, Malawi, Tanzania, Uganda
RWR 719	Ethiopia, Rwanda and Kenya
ACC 7/4, Ubusosera	Rwanda, DRC
DFA 54, DFA 53, DOR 633, DOR 715, AFR 708	Uganda, Kenya

Source: Kimani, 2005

Table 7. Bean lines/varieties adapted to low soil fertility in different countries

4. Use of organic resources

Organic matter based soil nutrient management is a traditional practice that continues on smallholder farms. Among the organic resources used are animal manure, compost, crop residues for soil incorporation, natural fallowing, improved fallows, relay or intercropping of legumes, and biomass transfer (Place *et al.,* 2003). Organic manure, compost and farmyard manure are the most common inputs used to improve soil fertility by small scale farmers (Musungayi et al. 1990; Kankwatsa et al., 2008). The need for both organic and mineral inputs to sustain soil health and crop production through ISFM has been highlighted due to their positive interactions (Vanlauwe et al. 2010).

4.1 Compost and farmyard manure

FYM use is the only possible practice for many resource poor farmers to improve crop and soil productivity. FYM and compost application are the most common practices used to improve soil fertility on smallholder farms although the quantities available are inadequate to meet crop nutrient demand. Organic manure available on farm estimates on dry matter basis varied from to 3.1 to 18.9 t ha^{-1} in Central Kenya (Opala, 2011) and 0.6 t ha^{-1} in Eastern DR Congo, sufficient to cover only 25% of their land under crops every season (Musungayi et al, 1990).Thus, scarcity of organic materials on farm limits their use at recommended rates. Because of scarcity of these resources, most farmers have developed localized application rather than broadcasting. This involves applying FYM or compost in the furrow or planting hole and covering it with soil before placing bean seeds, to avoid direct contact of manure with seeds. Considerable yield increase is achieved using compost alone, and the increase is dependent on initial fertility level in soil (Table 8).

Soil dominated by	Bean yield (kg ha^{-1})		
	Without compost	With compost	Yield increase
Pennisetum polystachia	41.7	697	655
Conyza sumatrensis	418	828	408
Bidens pilosa	876	933	60
Digitaria sestida	1251	1335	84
Mean	857	1101	244
CV (%)	24.2	21.2	

Adapted from Ngongo, 2001

Table 8. Effect of compost application to fields dominated with different weeds on bean yield

The potential of organic resources, such as FYM and compost to improve bean productivity, either as source of nutrients or by improving mineral fertilizer efficiency is well established in the region and various fertilization recommendations have been formulated. However, any substantial effect of organic amendments requires very large quantities that are not readily accessible to the majority of bean growers who are smallholder farmers (Thung and Rao, 1999).

4.2 Biomass transfer

Search for alternative sources of organics and more economical resources have always been a concern of the national bean programs. Many shrubs and trees, such as *Lantana camara, Tephrosia vogelii* and *Tithonia divesrifolia* which are common on smallholder's farms in ECSA have been studied in different countries.. Among all shrubs, *Tithonia* is the most common shrub with substantial biomass production in most countries of the region. It is grown for land stabilization along the road and for erosion control on cropland, and as plot or compound boundary, and as an ornamental plant. *Tithonia* use and popularization as soil improving resource has gained interest with the increasing need of intensifying bean-based production system with the recognition of the potential of this species to accumulate nutrients. Jama et al., (2000) estimated *Tithonia* biomass available after nine months for transfer to fields at 2 t ha^{-1} kg of dry matter in Western Kenya. *Tithonia* has very high shoot vigour with relatively high nutrient concentrations in its biomass. Concentration of N ranges from 3.0 to 4.1%, P from 0.24 to 0.56% and K from 2.7 to 4.0% (Jama et al. 2000). Besides this advantage in nutrient concentration, the biomass of *Tithonia* is also known to be rapidly decomposing (Buresh and Tian, 1998) due to proper balance in lignins, polyphenols and N (Palm et al., 1997). In fact, it has the ability to extract relatively high amounts of nutrients from the soil, a property which may make the practice not sustainable in the long run due to nutrient depletion. On soils with high natural nutrient stock however, such as soils of volcanic origin of the Great Lakes region, *Tithonia* use has shown considerable potential in improving crop production. In most cases, as in the productions systems of a growing number of small scale farmers without livestock, *Tithonia* remains the only and essential source of organic material available on the farms (Rabary, 2001).

Tithonia biomass transfer is a practice extensively studied in Rwanda, Kenya, Tanzania and DR Congo for its integration into bean-based production systems. In Rwanda and DR Congo, considerable bean yield increase is obtained, 227% in Rwanda (Ruganzu and Nabahungu, 2002) and 68% in DR Congo (Ngongo, 2002).

4.2.1 Rate application of *Tithonia* biomass

Determining the appropriate rate of biomass transfer is essential for integration of *Tithoni*a biomass use in farmers' cropping systems, either to beans grown as monocrop or as a mixed crop. The effect of the rate of application on bean yield of monocrop was evaluated in DR Congo and Rwanda (Ngongo, 2002; Ruganzu and Nabahungu, 2002; Nabahungu and Ruganzu, 2001). In Rwanda, the study was conducted on soils with pH varying from 3.8 to 4.9. The rate of application of *Tithonia* biomass varied from 0 to 12 t ha^{-1} on dry matter basis (Table 9). The optimum rate of application was determined to be 6 t ha^{-1} in Rwanda, and 4 to 6 t ha^{-1} depending on the initial soil fertility in DR Congo (Table 10). This slight difference is due to the difference in soil fertility at experimental sites, Rubona in Rwanda and Mulungu in DR Congo. In light of these results, the appropriate rate of application of *Tithonia* biomass on climbing bean may vary between 4 and 6 t ha^{-1}, which is slightly lower than the recommendation on maize of 7.5 t ha^{-1} in Tanzania (Ikerra et al. 2007). In the later study, they found that the optimum rate of application on maize could be set at 5 t ha^{-1} in the long rainy season while in short rainy season, the recommendation could be higher at 7.5 t ha^{-1}.

Tithonia rate of application (t ha-1)	Bean yield (kg ha-1)
0	917
2	1314
4	1714
6	2086
8	1486
10	942.9
12	1271

Table 9. Climbing bean yield response to applied *Tithonia* biomass in Rwanda (Ruganzu and Nabahungu, 2002)

Rate of application *Tithonia* (t ha-1)	Bean yield (kg ha-1)		
	Soil fertility level		
	Low	Medium	High
0	230 d	949 c	1777 b
2	533 c	1358 b	1841 ab
4	838 b	1788 a	1901 b
6	1565 a	1788 a	2034 a
CV %	39.2	39.2	39.2
Mean yield (kg ha-1)	791.5	1470.7	1887.7

Source: Ngongo, 2002

Table 10. Climbing bean yield response to applied *Tithonia* biomass in DRCongo

The rate of application in bean- maize mixed cropping, a more common cropping system in farmers' field, was evaluated by Ngongo (2002) in DR Congo (Table 11). In this system, the best yield of both crop either sole crop or intercropped was obtained at the rate of 8 t.ha^{-1}ofbiomass.

Tithonia Biomass (t/ha)	Bean yield (kg. ha-1)		Maize yield (kg. ha-1)	
	Bean sole crop	Bean- Maize intercrop	Maize sole crop	Maize- bean intercrop
0 t ha-1	703.6 *c*	748.0 *c*	1250 *c*	2250 *b*
4 t ha-1	887.0 c	900.1 *c*	1930 *bc*	2450 *b*
8 t ha-1	1410.0 *a*	1139.0 *b*	2220 *b*	3470 *a*
C.V. (%)	16.34	16.34	21.72	21.72
Mean (kg ha-1)	1000.2	929.03	1800	2720

Figures followed by the same letter are not significantly different at 0.05 probability. Source: Ngongo, 2002

Table 11. Bean and maize yield response to *Tithonia* biomass in sole cropping and intercropping systems in DR Congo.

4.2.2 Method of application of *Tithonia* biomass

The technique of *Tithonia* use was fine-tuned by Ngongo (2002), who studied the appropriate time for biomass application. The time of application prior to bean sowing varied from 0 to 7 days. The best bean yield was obtained when biomass application was made at least 4 days prior to sowing. It was concluded that there was no reason to apply *Tithonia* biomass 7 days before planting (Table 12). The mode of application involved applying the fresh biomass on soil surface and incorporating it into soil 24 hours later, leaving it to decompose for 4 to 7 days before sowing bean.

Biomass application 6 t ha^{-1}	Bean yield (kg ha^{-1})	
	2000A	2000B
Control	563 fg	375 g
At sowing	1,253 bc	985 cde
At 7 days before sowing	1,327 bc	1,174 bcd
At 4 days before sowing	1,703 a	1,273 bc
At 2 days before sowing	1,423 ab	1,105 bcde
Surface applied and worked in at sowing	776 ef	854 def
C.V. (%)	19.4	
Mean yield (kg ha^{-1})	1,174	

Figures followed by the same letters are not significantly different at 0.05 %

Table 12. Effect of different application of *Tithonia diversifolia* on bean yield

4.3 Green manure and cover crops

Research and extension efforts were made to identify legumes that present farmers with as many options as possible so that they can choose cropping systems that are best suited to their needs. Many plant species have been selected and their potential benefit demonstrated using both on-station and on-farm experiments. More detailed field investigations have been done in Uganda and DRC. The green manure and cover crops are primarily used to enhance land productivity by improving N economy in the production systems. Several legume species have been evaluated and found to be well adapted to the region and produce substantial amounts of biomass. Among the potential green manure species identified were *Crotalaria ochroleuca*, *Mucuna pruriens* (L.) DC, *Lablab purpureus* (L), and *Tephrosia vogelii* Hook, which were tested extensively in on-farm experiments for their potential to improve productivity and to obtain feedback based on farmers' perception (Wortmann et al., 1994; Esilaba et al., 2001). High N concentration in *Crotalaria* biomass grown under N-limiting conditions indicated that large quantities of N were biologically fixed. Mean maize grain yields following *Crotalaria* sole crop were 180% and 240% of maize grain yields following maize in two on-station trials and nine on-farm trials, respectively. In the study done by Fishler and Wortmann (2001), grain yields of maize and bean following one season of *Crotalaria* fallow were 41% and 43%, respectively, and the yields were more than following a two-season weedy fallow. Grain yields of maize following a one-season fallow with *Mucuna* and *Lablab* were 60% and 50% higher, respectively, compared to maize following maize. Maize and bean yield were more, although effects were small, during the second and third subsequent seasons, indicating additional benefits from the residual effects of the green manures.

In spite of the demonstrated advantages of green manure and cover crops, the adoption by farmers has always been very poor, hampered by several factors such as availability of seeds, difficulties in planting and establishing the crop, and labor intense practice such as mowing and incorporating the cover crop (Esilaba et al. 2005). Alternative methods of green manure integration on farm were studied, particularly simultaneous cultivation of green manure with main crop, bean or another crop. In fact, in densely populated regions, leaving land under green manure for the whole season is not always acceptable to farmers. Therefore, intercropping with main crop has been developed. In Eastern Uganda, *Mucuna* and *Lablab* were successfully produced by intersowing into maize at three weeks after sowing maize, although the yields of the associated maize crop were reduced by 24% to 28%, and farmers estimated the labor requirements for *Mucuna* and *Lablab* to be less than for *Crotalaria* (Fishler and Wortmann, 2001). In Uganda, the yields of the green manure species were reduced by 40–70% when intercropped with a food crop as compared to sole crop production and that yields of food crops were reduced by 61–87% when intercropped with *Crotalaria ochroleuca* G. Don. In contrast, maize grain yield response in the first season following sole-crop of green manure production ranged from 0 to 240% (Fishler and Wortmann, 2001). Production of the green manure by intercropping *Crotalaria* with either maize or beans was found to be feasible with little reduction in food crop yield with a mean Land Equivalent Ratio of 1.3.

Additional benefits of cover crops reported in Uganda are weed suppression, soil erosion control and control of mole rats (Fishler and Wortmann, 2001). Results from these trials also indicated that *Mucuna pruriens* (L.) and *Lablab purpureus* (L) were best for weed suppression and to control soil erosion. Also the requirements for tillage and weeding could be lower following green manure and cover crops. In addition, maize can often be planted directly in the holes left from uprooting *Mucuna* and *Lablab*, thus reducing labor requirements during the following season. *Tephrosia vogelii* Hook. f. was effective in controlling mole rats and there was significant adoption by neighboring farmers.

4.4 Climbing bean rotation effects

Climbing bean is by far the bean type with high biomass production and probably with high BNF, and therefore considerable green manure effect is expected. Its integration in the production system can improve productivity and sustainability of bean-based cropping systems. In fact, climbing bean develops extensive nodulation, up to three times more than bush bean (Van Schoonhoven and Pastor-Corrales, 1994). This is an indication of higher capacity for N fixation. It has been suggested that the contribution from N fixing legume in rotation could be responsible for most of the beneficial rotation effect observed in the subsequent maize crop (Sanginga, 2003; Bado, 2002; Balldock et al, 1981). Evidence of net positive soil N balance by climbing bean has been reported (Kumarasinghe et al. 1992). In this study, they reported that at the late pod-filling stage the climbing bean had accumulated 119 kg N ha^{-1}, 84% being derived from fixation, 16% from soil, and only 0.2% from the ^{15}N fertilizer. In a long-term experiment, Wortmann (2001) reported improved sorghum yield in the rotation with climbing bean and estimated that N derived from the atmosphere was 40% to 57% of plant N, depending on the calculation used. It is clear that evidence of benefit of climbing bean cultivation exists, either as rotational effects or improved N nutrition.

On-station and on-farm farmer participatory trials were conducted by Lunze and Ngongo (2011) to assess the beneficial effects of the climbing bean on the subsequent maize crop in rotation, compared to bush bean and continuous maize cropping systems. The estimate of N contribution from the climbing bean to the system estimated as N fertilizer replacement values (Bado, 2002), and these values varied from 15 kg N ha^{-1} to 42 kg N ha^{-1} in the first season of rotation. Note that this method is believed to overestimate the amount of N supplied by the legumes in the systems (Bullock, 1992). Without applied N fertilizer, the average maize grain yield increase over three cropping seasons in response to the preceding climbing bean effect were 489 kg ha^{-1} and 812 kg ha^{-1} compared to bush bean and maize as preceding crops, respectively, which is 17.5% and 33.8% increase. However better yield advantage of climbing bean over continuous maize was obtained in the long rains cropping season (Season A), 43.2% compared to 24.2% in short rains season (Season B) (Table 13).

Preceding crop	N Rate (kg/ha)	Maize grain Yield (kg/ha)		
		Season 2002A	Season 2002 B	Season 2003 A
Bush bean	0	2911	2735	2625
	33	4542	3738	3656
	66	5297	4206	4003
Climbing bean	0	3821	2847	3072
	33	4869	4115	4000
	66	5019	4375	4278
Maize	0	2724	2477	2102
	33	4141	3556	2872
	66	4836	3931	3897
Mean Yield		4540	3558	3336
LSD (0.05)		334.9	707.1	379.2
CV (%)		6.5	9.8	10.0

Table 13. Effects of preceding crop and fertilizer N on maize grain yield over 3 seasons at Mulungu, DR Congo (Lunze and Ngongo, 2011)

These studies in Uganda and DR Congo provide evidence for beneficial effects of climbing bean to improve N nutrition of the following maize crop. It is presumed that climbing bean promotion is an appropriate strategy for higher productivity and sustainability on smallholder farms, as substantial gain of N will be achieved by proper integration of climbing bean in the bean-based production systems in ECSA. Additional effects of growing climbing bean are expected, such as reducing erosion because it provides more extensive soil cover through its canopy compared to bush bean. These beneficial effects are considerable on relatively medium fertility soils where climbing bean effects were highest, because of the large quantity of biomass produced.

5. Biological nitrogen fixation in bean

The enhancement of the capacity of beans for biological fixation through symbiosis with *Rhizobium phaseoli* was recognized by biological nitrogen fixation(BNF) working group within PABRA as an important option to improve the productivity of bean crop on farms (Nyabienda, 1988). This was particularly true for regions where farmers have limited access to N fertilizers. However, improvement of bean BNF requires a multiplidisciplinary approach that will require the plant breeder to increase the host capacity to fix N_2 as bean is considered as a poor N_2 fixing legume (Giller, 2001), and selection of effective *Rhizobium* strains that can compete for nodulation with native populations of bacteria present in most soils.

5.1 N_2 fixation variability in bean germplasm

BNF is among the strategies extensively investigated as one of the avenues to improve bean productivity. Matheson (1997) measured N_2 fixation at Kawanda and Namulonge, Uganda using two common methods: ^{15}N abundance method and N-difference method using non-nodulating beans lines INIAP 404 and EXRICO. N2 fixed was lower at Namulonge than at Kawanda. It ranged from 10.6 to 35.1 kg Nha^{-1} and from 0.7 to 20.4 kg N/ha, respectively, at Kawanda and Namulonge. This study found that the genotypes identified as tolerant to low soil N had greater N fixing capacity. Table 14 summarizes the genotypic variation in N_2 fixation of common bean at Kawanda, Rwanda.

The same author calculated the net N balance and found a negative net N balance for all varieties, ranging from - 23.6 kg ha^{-1} to - 5.3 kg ha^{-1}, indicating that more N had been exported in grain at harvest than had been fixed and retained in soil. The yield was negatively related to net N balance: the higher the yield, the more negative the net N balances. However, unlike bush bean, climbing beans exhibit greater N_2 fixation capacities (Wortmann, 2001; Lunze and Ngongo, 2011). Lunze and Ngongo (2011) estimated N_2 fixation by climbing bean r from 16 to 42 kg ha^{-1} per season. N fixation is further enhanced by several cultural practices and agronomic management, i.e. inoculation, P fertilization and liming, that are discussed below.

5.2 Inoculation

BNF is extensively investigated as one of the avenues to improve bean productivity. Rhizobial inoculation is a common practice to promote BNF in bean, given that the *Rhizobium* strain is well adapted to local environments. Strain CIAT 899 is currently used for bean seed inoculation in all regions of ECSA. Inoculation with this strain in Burundi showed a yield advantage up to 59% in Gitega (Ruraduma, 2002). Evaluation by the same author of local *Rhizobium* strains so far has failed to identify a more efficient strain.

5.3 Liming and P fertilization effects

The efficiency of BNF is further improved by liming and P fertilization. This is not always affordable for smallholder farmers. Considering these factors, bean seed pelleting with lime and phosphate was evaluated in Burundi and Malawi. On-farm trials at Ikulwe, Iganga District of Uganda, the %N_2 fixation was estimated for a well-adapted high yielding variety

Variety	Biomass kg/ha R9	Yield (kg/ha)	Total N (kg/ha)	% N fixed	N2 Fixed (kg/ha) 15N method	N2 fixed (kg/ha) Difference Method
BAT 1297	218,4	1033	63,9	43	26,8	28,6
BAT 308	217,9	969	51,5	34,4	17,6	16,2
INIAP 404	136	601	31,1	-12,5	-3,7	-4,2
CNF 5513	220,6	1413	61,5	35,6	22,1	26,2
H2 MULATHINO	230	1061	61,5	39,7	23,1	26,5
IBHBN 69	241,9	1161	57	45,4	25,2	21,7
IBR (92B) 43	184	890	52,6	31,2	16,1	17,3
MCM 1015	201,7	1090	52,9	41,4	22	17,6
MCM 1016	223,8	1015	60	35,1	22,2	24,7
MLB645689A	202,4	1279	55,8	42,1	21,7	20,5
MMS 243	230,5	1000	69,4	36,2	23,3	34,1
MMS 250	207	1175	56,3	38,7	21,9	21
MMS 253	176,4	1080	50,2	51	25,9	14,9
MORE 90040	230	1318	62,1	55,1	33,9	26,8
MUS 97	217,7	1465	58,8	44,4	25,9	23,5
EXRICO	199,1	545	39,5	12,5	5,1	4,2
RWK 5	186,9	1326	51,5	39,7	19,9	16,2
RWR 109	209,8	1025	59,7	44,8	27,4	24,2
RWR 382	267,9	956	68,7	50,9	35,1	33,4
UBR (92) 09	198,3	1304	57,8	58,4	33,7	22,5
UBR (92) 10	233,2	941	66,2	33,1	21,3	30,9
UBR (92) 11	197,5	1155	53,9	49,5	26,1	18,6
UBR (92) 12	209,7	1209	58,7	29,4	10,6	23,4
UBR (92) 17	180,4	888	52,3	49,4	25,4	17
UBR (92) 20	258,2	889	69,9	42	28,8	34,6
UBR (92) 25	202	1132	61,9	47,6	29,4	26,6
UBR (92) 38	208,8	788	65,3	38,9	52,1	30
XAN 76	185,3	1416	54	50,6	26,1	18,7
CAL 96	201,4	962	59,9	39,2	23,4	24,6
MCM 5001	171,7	1004	52,8	49,6	26,1	17,5
Mean	208,3	1070	57,2	39,9	22,9	21,9
s.e.d.	27,37	129	8,77	10,93	6,129	8,77

INIAP 404 and EXRICO: non-nodulating reference lines; CAL and MCM 5001: check varieties

Table 14. Nitrogen fixation, biomass and yield of 30 varieties grown under low N conditions at Kawanda (1996)

MCM 5001, considering the effects of inoculation and P application on N_2 fixation. Neither inoculation nor 100 kg ha^{-1} of TSP (triple super phosphate) application increased bean yield, but 100 kg ha^{-1} TSP with inoculation yielded significantly higher yields than these treatments individually. Inoculation had therefore greater effects on bean yield at higher P levels. The estimate of % N_2 fixation without addition of P fertilizer and inoculation ranged from 5% to 32%, while the addition of 50 kg ha^{-1}of TSP increased N_2 fixation by 50%. However, they did not observe any significant differences (P<0.05) in %N_2 fixation between treatments and farms.

In Malawi, Chilimba and Kapapa (2002) evaluated bean seed pelleting with dolomitic lime. On-farm trials conducted in Dedza where soils are strongly acidic showed significant responses of four bean varieties to inoculation and seed pelleting with lime on BNF and grain yield. Seed pelleting and inoculation showed beneficial effects in increasing plant N content, nodule numbers and even grain yield. In acidic soils, both inoculation plus seed pelleting significantly improved BNF and grain yield whereas in a normal non-acidic soil, inoculation only or pelleting only significantly improved BNF and grain yield. The on-farm evaluation was conducted in Bembeke Extension Planning Area where soil pH is 4.5 and the soil is fine, kaolinitic, thermic, Kandiudafic Eutrudox while at Chitedze research station the soil pH is 5.9 and the soil is classified as fine, kaolinitic, thermic, Udic Kandhaplustalfs.The results on the evaluation on soils with varying soil pH are presented in Table 15.

	Marieta			Ester			Chitedze		
Treatments	% N	Nodule No.	Grain yield (kg ha-1)	% N	Nodule No.	Grain yield (kg ha-1)	% N	Nodule	Grain yield (kg ha-1)
Control	3.12	15.5	1056	2.05	21.6	389	2.30	10,8	1438
Inoculation	3.64	82.7	1599	3.48	85.5	1119	3.56	78,8	1937
Pelleting	2.18	18.3	1043	2.68	28.0	911	2.01	12,3	2410
Inoc & Pell	4.52	115.1	1981	4.37	117.6	1612	4.40	94,4	2184
Mean	3.35	57.9	1419,75	3.12	63.2	1007,7	3.07	49.0	1992.25
SE	0.483	4.839	231.2	0.428	5.07	230.4	0.4677	2,66	156.1
CV%	21.3	28.97	28.3	12.8	27.83	39.7	58.9	18,8	26.13

Adapted from Chilimba and Kapapa, 2002

Table 15. Effect of inoculation and seed pelleting on % N, nodule number and the yield of beans at three locations (Marieta, Ester and and Chitedze) in Malawi

The results of the above studies confirm that both lime and P fertilizer application rate can be considerably reduced by coating bean seeds to achieve relatively higher yield. This technology is considered a good ISFM strategy.

6. Mineral fertilizers

Most smallholder farmers in the ECSA regions are well aware of the value of mineral fertilizers, but the rate of application remains low, below the recommended rates, except for commercial farmers. The essential reason for this is the high cost of mineral fertilizers, and low profitability. In most regions however, bean comes after cereals, which are commonly fertilized so that bean benefits from residual fertilizer effects. Nonetheless, fertilizer recommendations have been developed in several countries for bean, particularly in Kenya, Tanzania, Burundi and South Africa.

On Ferrarsols (Oxisols) of Burundi, mineral fertilizer applied alone on bean was found to be non-economical, and under certain conditions bean yield was depressed. The recommended rate (kg ha^{-1}) for Burundi was 15 – 30 for N, 50 – 60 for P_2O_5 and 30 for K_2O, with 2 to 5 t organic manure (Ruraduma, 2002). The ISFM strategy suggests options that combine organic resources and mineral fertilizers to achieve higher yield, economically. Fertilizer application to bean crop is developed for those grown as a sole crop or intercropped with maize. In addition to determining the rate of application, the proper time of application is important to maximize N_2 fixation, as early application of N can inhibit nodulation of bean. In Uganda, Wortmann, (1998) recommended applying a small amount of N at the planting time and the major part of fertilizer N at the second weeding time, to favor bean productivity and N2 fixation. That is an application of 5 kg N ha^{-1} and 20 kg P ha^{-1} at sowing time and applying 35 kg N ha^{-1} at second weeding time for both maize and bean that are intercropped. In on-farm trials with the objective of developing appropriate fertilization practice on snap bean, Ugen et al. (2009) evaluated rates and timing of the mineral fertilizers CAN, NPK 17-17-17 and DAP (diammonium phosphate), which are the common fertilizers in the marketplace. In this study, application of DAP at planting and topdressing with NPK-17:17:17 at 21 days after emergence appeared to be appropriate for bean production. More complete mineral fertilizer recommendations used in South Africa are presented in Tables 16, 17 and 18 (Liebenberg, 2002).

6.1 Nitrogen

According to Liebenberg (2002), inoculation of dry bean seed is regarded as ineffective in South Africa. Consequently, dry beans should be considered as incapable of satisfying all of their N requirements through N_2-fixation. The application of all the N fertiliser at planting time is recommended, particularly where non-decomposed material has been ploughed in before planting.

Yield potential (t ha^{-1})	1,5	2,0	2,5
N fertilisation (kg ha^{-1})	15,0	30,0	45,0

Source: Liebenberg, A.J., 2002.

Table 16. Guidelines for nitrogen application

6.2 Phosphorus

Commercial production in South Africa showed modest yield responses to P fertiliser application in dry beans and P is not normally a yield-restrictive factor. Under subsistence production, where small quantities of fertilizer are applied, P can be a yield-limiting factor. Where the P content of the soil is lower than 20 µg g^{-1} (Bray 1), it is recommended that TSP be broadcasted and ploughed into the soil to a depth of 15 to 20 cm before planting. P fertiliser must still be band-placed at the time of planting. In low pH soils, P can be utilised efficiently by band-placing 3.5 cm to the side of the row and 5 cm below the seed.

Soil analysis Bray 1 (mg kg^{-1})	P application for potential (t ha^{-1})		
	1,5	2,0	2,5
	P fertilization (kg/ha)		
13	16	22	28
20	12	16	20
27	10	13	16
34	9	12	15
> 55	5	5	5

Source: Liebenberg, A.J., 2002.

Table 17. Guidelines for phosphorus fertilisation

6.3 Potassium (K)

When dry beans are grown on soils with high clay content, K is not normally a limiting factor. Deficiencies are most likely to occur on sandy soils with an analysis of less than 50 mg kg^{-1} K. The optimum leaf K content is 2% potassium.

Soil analysis NH_4OAc, pH 7 K (mg kg^{-1})	K application for potential (t ha^{-1})		
	1,5	2,0	2,5
	P fertilization (kg ha^{-1})		
40	22	27	32
59	19	24	29
78	17	21	26
98	15	19	24
> 98	0	0	0

Source: Liebenberg, A.J., 2002. Dry bean production

Table 18. Guidelines for potassium fertilisation

6.4 Effect of cropping systems

Wortmann et al. (1996) studied the relationship between maize monoculture to fertilizer N and P and the intercrop response from 62 fertilizer response trials conducted in Kenya. Their results indicate that intercrop was more productive than the monoculture with no fertilizers applied, but overall responses of the systems to applied nutrients did not differ. Maize both in monoculture and intercropped responded more frequently to applied N than did the intercrop bean. Frequency of response to applied P was similar for both crops and both production systems.

6.5 Combination with organic manure

It is well established that combining mineral fertilizer with organic resources improves fertilizer use efficiency. In Western Kenya's Vihiga District, the recommendation is 50 N kg

ha^{-1} and 50 P kg ha^{-1} with 5 t ha^{-1} of farmyard manure (Rachier et al., 2001). The N and P rates are reduced by 50% in the following season. If money or credit is not available, in addition to 5 t ha^{-1} FYM, only 25 kg ha^{-1} N and P are recommended. The following season, the N rate is reduced by 25% and no P is applied. If FYM is available on farm, 5 t ha^{-1} FYM together with 25 kg ha^{-1} N and P are recommended. This rate is reduced by 50% in the second season. If the green manure is grown, then N, P and FYM rates are reduced by 50% in the first season, and in the second season only 25 kg P ha^{-1} is needed. In the study conducted by Ngongo (2002) in DRC, the aim was to reduce the quantities of both mineral fertilizer and *Tithonia* biomass recommended. The author evaluated bean response to application of 4 t ha^{-1} *Tithonia* biomass with varying rates of mineral fertilizer (Table 19).

Treatments	Bean grain yield (kg ha^{-1})	
	1998B	1999 A
Control	551 d	1066 cd
4 t/ha *Tithonia*	1132 cd	1744 a
4 t/ha *Tithonia* + 20 kg NPKha^{-1}	1341 bc	2201 ab
4 t/ha *Tithonia* + 40 kg NPKha^{-1}	1313 bc	2296 a
4 t/ha *Tithonia* + 60 kg NPKha^{-1}	1402 bc	2390 a
60 kg/ha NPKha^{-1}	1405 bc	
C.V. (%)	23,41	23.41
Mean (kg. ha^{-1})	1190,67	2004

Table 19. Effects of *Tithonia* biomass in combination with mineral fertilizers on bean yield in DR Congo.

The results confirmed that less fertilizer could be recommended when *Tithonia* is applied. The application of 4 t ha^{-1} *Tithonia* with 20 kg ha^{-1} of NPK fertilizer was as efficient as the recommended mineral fertilizer rate of 60 kg ha^{-1}. Thus a 3-fold reduction of inorganic fertilizer is possible when *Tithonia is* applied.

7. Mijingu phosphate rock

Bean growing environments are well described in all ECSA countries and P deficiency is widely reported as the most important bean production constraint (Wortmann et al., 1998). The low P availability to plants is explained by the nature of the soils that are highly weathered with low total P and/or high P fixing capacity (Rao et al., 1999). Rock phosphate (RP) which is a resource relatively common throughout ECSA countries is recognized as a fertilizer with high potential to improve bean crop productivity having low cost, compared to conventional mineral P fertilizers. The deposits of the RP are reported in many countries and exploited to some extent in Tanzania (Mijingu), Malawi (Tundulu), Zambia (Isoka), South Africa, DR Congo (Kanzi) and Burundi (Matongo). Minjingu Phosphate Rock (MPR), a sedimentary biogenic deposit which contains about 13% total P and 3% neutral ammonium citrate soluble P is reported to be highly reactive (Jama and Van Straaten, 2006).

On acidic soils of Tonga in Rwanda, Nabahungu et al. (2002) studied the effects MPR associated with limestone and green manures (GM) (*Tithonia* and *Tephrosia* biomass) on P uptake and on maize yield. This study showed that MRP significantly contributed to P increase in the soil and resulted in increased P uptake and maize yield. Green manures in combination with MPR increased P uptake significantly. The results indicated that using a combination of limestone, MPR and GM is the best strategy in improving maize productivity on acid soils (Table 20). The effect of RP alone or GM alone is low, whereas the combination of MPR with organic resources improved its effect.

Treatment	Maize Yield (kg/ha)
Control	148
MPR	3267
Tithonia	3349
Tephrosia	1452
Tithonia + MPR	3993
Tephrosia + MPR	4554
Tithonia + Lime + MRP	5594
Tephrosia + Lime + MRP	5907
CV %	11.1

Table 20. Maize yield response to Mijingu rock phosphate and fertilizers (adapted from Nabahungu, 2007)

A combination of RP and GM produces a demonstrated yield advantage over control or each of these treatments alone. The recommendation for acidic soils of Rwanda is to combine organic resources with RP and lime (ground limestone or burnt lime) allow maize yields to increase up to approximately 6 t ha^{-1}. The same recommendation is applied for bean. In Northern Tanzania, the recommended rate of application is 250 kg ha^{-1} MRP combined with FYM at 5 to 10 t ha^{-1} or a GM grown in the previous season (*Mucuna pruriens or Vernonia subligera*).

Other practices for MRP utilization have been developed in Kenya and Tanzania. The RP-fortified compost technology is well accepted by farmers in Western Kenya (Odera and Okalebo, 2009). Another option which combines PR, liming, *Rhizobium* inoculation and bean seeds, developed by a Phosphate rock evaluation project (PREP), known as PREP-PAC. This product comprises PR (2 kg), urea (0.2 kg), legume seed, rhizobial seed inoculants, seed adhesive and lime pellet, packed to fertilize 25 m^2 of land. In Western Kenya the use of PREP-PAC and climbing bean package increased maize and bean yield by 0.72 and 0.25 t ha^{-1} respectively, resulting in a 161% return in investment (Nekesa et al., 1999). PREP-PAC use on bean for the two seasons in seven districts in Easter Uganda showed significant increases of 881 kg ha^{-1} in bean yield, increasing from 1,316 to 2,197 kg ha^{-1} (Esilaba et al., 2005). This product is commercialized, and makes the PR more accessible to smallholder farmers, thus offers opportunity for easier handling and use for increased bean productivity. Another PR from Uganda, Busumbu RP (BRP) was studied by Nabahungu et al. (2007) who reported that composting increased P availability and P recovery from BRP to the extent similar to that of TSP, as well as the availability of Ca and Mg.

8. Liming

Lime application is a common soil improvement practice generally recommended on acidic soils. The rate of application is based on exchangeable soil Al concentration. For tropical soils, lime recommendation is 1.5 times the exchangeable Al in t ha^{-1}, the rate which is sufficient to neutralize toxic Al. One of the first studies to determine the optimum rate of lime for bean was done in Malawi by Aggarwal et al. (1994). In this study, bean response to applied calcitic lime at the rate of 0, 25, 50, 75 and 100% of the exchangeable Al was evaluated in 1992-93 cropping season using 15 varieties and in 1993 -94 season using 8 varieties. Additional treatment was lime applied at 100% of exchangeable Al plus P since the soil was P- deficient. The results indicated that although the performance of the varieties was poor due to low fertility, liming caused a linear increase in nodule number, nodule weight, and grain weight up to 75% level of Al neutralization (Table 21). The yield declined at higher rate of lime application due to nutrient imbalance, which might have been induced by lime. Lime recommendation is therefore soundly based on neutralizing the exchangeable soil Al concentration, rather than increasing soil pH

Lime level to neutralize (%) exch. Al	Seed Yield ($kgha^{-1}$)	Nodule/plant	Nodule weight ($mgplant^{-1}$)	Root weight ($gplant^{-1}$)	Shoot weight ($gplant^{-1}$)
0	147	0.85	7.59	0.41	1.59
25	161	1.52	13.98	0.42	1.63
50	153	2.43	19.11	0.40	1.41
75	266	5.01	37.29	0.43	1.78
100	235	3.95	32.46	0.43	1.64
100 + P	253	4.84	44.93	0.44	1.71
SE	194	0.92	6.88	0.04	0.16

Table 21. Effect of lime application on seed yield, nodule number, root weight and shoot weight of common bean varieties grown during 2 seasons at Bembeke, Malawi

Finely powdered ground limestone, cheaper than lime (neutralizing value of 90 to 100) evaluated in Rwanda, was comparable to agricultural lime found in the marketplace. Thus lime recommendation was devised for ground limestone. Table 22 presents the results of bean response to lime (agricultural lime) and limestone in two seasons (Nabahungu and Ruganzu, 2001).

Treatments	Bean yield (kg.ha-1)	
	2000 A	2000 B
Control	733	456
Lime 1 t ha^{-1}	1283	295
Limestone 0.5 t ha^{-1}	1300	209
limestone 1 t ha^{-1}	1817	247
Limestone 1.5 t ha^{-1}	1467	333
LSD (0.05)	831	241

Adapted from Nabahungu and Ruganzu, 2001

Table 22. Bean response to agricultural lime and ground limestone at Rubona, Rwanda

Bean yield was very low without lime and doubled with lime application, but was still considered low. For better yield, lime application should be associated with organic resource application, which according to Palm et al. (1997) improves productivity on acid soils by its interactions with the mineral soil in complexing toxic cations and reducing the P sorption capacity of the soil. Examples from DR Congo, Rwanda and Burundi indicate that combining lime with organic manure results in considerable bean yield increase. Rutunga et al. (1998) studied crop rotation system of maize and beans, established at Rubona (Rwanda) from 1984 to 1992. They evaluated the effects of different types and rates of fertilizers in improving the productivity of acidic Oxisols. Continuous cropping of maize followed by beans for a period of 8 years gave no yield in control plots. A single application of 2 t ha^{-1} of lime increased significantly ($p = 0.01$) the soil pH, Ca^{2+} content, cationic exchange capacity, and decreased the level of the exchangeable Al. However, this quantity of lime, when applied every two years for a period of eight years, led to overliming. The application of more than 8 t ha^{-1} of FYM annually, combined with 300 kg ha^{-1} of NPK (17:17:17) fertilizer (every six months) significantly improved soil organic C and crop production at Rubona, Rwanda. The high rate 35 t ha^{-1} of FYM or the combination of "lime, FYM and NPK fertilizers" gave the best crop performance.

9. Decision support tools

Several technologies have been developed and widely tested with successful results, resulting in development of soil fertility management decision guide, particularly in Uganda (Farley, 1998;Esilaba et al. 2001), Kenya (Rachier et al., 2001) and Eastern Congo (Ngongo, 2001). Soil fertility management research results have been translated into recommendations that take into account the soil physical conditions as well as farmers' socio-economic status. Decision support systems (DSS) to the use of inorganic and organic sources have been developed for different environments and socio-economic conditions in bean based production systems in the region at different locations. These guides are efficient tools for realizing better bean crop yield in areas where they are developed. However, the extrapolation to other sites and location with different soil conditions, climate and population density and socio-economic conditions is not guaranteed with acceptable results as they are site specific (Esilaba et al., 2001). A model decision tool for Uganda is presented in Table 23 while for Eastern DR Congo the tool was developed using soil fertility assessment based on farmers' perception (Table 24). Other DSS are similar, but the local conditions and available resources vary.

10. Promotion and use of ISFM options

PABRA has developed and disseminated different technologies to address farmers' production constraints and to increase bean productivity in sustainable ways (Kimani et al., 2001). These comprise simple technologies such as new bean varieties and more complex, knowledge intensive ones such as integrated pest and disease management (IPDM) or ISFM. The technologies and their dissemination methods were based on low cost options that were in many cases developed through collaboration with multiple partners, and engaged and empowered end users in participation and adoption (Kankwatsa et al., 2008). The spread and adoption of new bean varieties have been very impressive; reaching several million farming families, while the spread and adoption of ISFM technologies have been slow. Scaling up and disseminating information on recommended technologies was through Farmer Research Groups using a modified farmer field school approach. Because farmers were driving the experimentation and dissemination processes, all aspects of local culture were taken into consideration (Kankwatsa et al., 2008) and they often made recommendation for improvement to suit their production circumstances, both in the social and the technological aspects: this led to the development of the ownership by the farming communities and a high rate of adoption among participating farmers.

Conditions	Maize, sole crop	Bean, sole crop	Maize-bean intercrop
Adequate money or credit available	Apply 50 kg ha^{-1} TSP and 25 kg ha^{-1} urea at sowing; apply 50 kg ha^{-1} urea at second weeding	Apply 100 kg ha^{-1} TSP and 20 kg ha^{-1} urea at sowing	Apply 100 kg ha^{-1} and 20 kg ha^{-1} urea at sowing; apply 50 kg ha^{-1} urea at 2nd weeding
Money or credit is inadequate	Apply 50 kg ha^{-1} urea at first weeding	Apply 50 kg ha^{-1} TSP and 20 kg ha^{-1} urea at sowing	Apply 50 kg ha^{-1} TSP and 20 kg ha^{-1} urea at sowing; apply 50 kg ha^{-1} urea at 2nd weeding
Green manure was produced the previous season	Do not apply inorganic fertilizer	Do not apply inorganic fertilizer	Do not apply inorganic fertilizer
Lantana, etc is available	Reduce application of urea at 2^{nd} weeding by 30% for each ton of fresh leafy material applied	Do not reduce fertilizer rate	Reduce application of urea at 2^{nd} weeding by 30% for each ton of fresh leafy material applied
Sowing is delayed until after 15 march or 15 September	Reduce fertilizer rate by 50%	Do not reduce fertilizer rate	Reduce fertilizer rate by 50%
Sowing is delayed until after 30 march or 30 September	Do not use fertilizer at sowing; top-dress urea at 50% rate if conditions are promising	Do not reduce fertilizer rate	Apply 50% of TSP at sowing; top dress urea at 50% rate if conditions are promising
Farm yard manure in available	Reduce fertilizer by 25% for each ton/ha of dry FYM applied	Reduce fertilizer by 40% for each ton of dry FYM applied	Reduce fertilizer by 20% for each ton/ha dry FYM applied
FYM was applied last season	Reduce fertilizer by 15% for each ton/ha of dry FYM applied	Reduce fertilizer by 30% for each ton of dry FYM applied	Reduce fertilizer by 10% for each ton/ha dry FYM applied
Land was rotated from banana or fallow within last one season	Apply N at 2^{nd} weeding, but only if maize is yellowing	Do not apply fertilizer	Apply N at 2^{nd} weeding, but only if maize is yellowing

Top-dress with urea if the crop is well established, the season appears promising, and especially if the lower leaves are yellowish-green in color.

Table 23. Tentative guide to fertilizer use for maize and bean in Uganda

Farmer Conditions		**Soil type according to farmer criteria***	**Bean type**	**Cropping system**	**Soil fertility management Recommendations**
Finances	**Organic resources**				
No money, no Credit	Compost not available	Plot dominated by *Gallinsoga parviflora*	Bush	Bush beans sole crop	No fertilizers
				Bush beans-maize intercropped	Apply 20 t ha^{-1} Kitchen ash
			Climbing	Climbing beans sole crop	Apply 4 t ha^{-1} *Tithonia* fresh biomass + 20 t ha^{-1} ash
				Climbing beans- maize intercropped	Apply 6 t ha^{-1} *Tithonia* fresh biomass + 20 t ha^{-1} ash
		Plot dominated by *Pennisetum polystachia* or *Bidens pilosa* (poor soils)	Bush	Bush beans sole crop	6 t ha^{-1} *Tithonia* + 20 t ha^{-1} ash
				Bush beans-maize intercropped	8 t ha^{-1} *Tithonia* + 20 t ha^{-1} ash
			Climbing	Climbing beans sole crop	10 t ha^{-1} *Tithonia* + 20 t ha^{-1} ash
				Climbing beans- maize intercropped	10 t ha^{-1} *Tithonia* + 30 t ha^{-1} ash
	Compost available	Plot dominated by *Gallinsoga parviflora*	Bush	Bush beans sole crop	No of fertilizers
				Bush beans-maize intercropped	20 t ha^{-1} ash
			Climbing	Climbing beans sole crop	6 t ha^{-1} *Tithonia* or 20 t ha^{-1} compost
				Climbing beans- maize intercropped	8 t ha^{-1} *Tithonia* or 20 t ha^{-1} Compost + 20 t ha^{-1} ash
		Plot dominated by *Pennisetum polystachia* (poor soils)	Bush	Bush beans sole crop	4 t ha^{-1} *Tithonia* or 10 t ha^{-1} compost
				Bush beans-maize intercropped	(6 t ha^{-1} *Tithonia* or 20 t ha^{-1} compost)
			Climbing	Climbing beans sole crop	6 t/ha *Tithonia* or 20 t ha^{-1} compost
				Climbing beans- maize intercropped	(8 t ha^{-1} *Tithonia* or 30 t ha^{-1} compost) + 30 t ha^{-1} ash
Money or credit Available	Compost not available	Plot dominated by *Gallinsoga parviflora*	Bush	Bush beans sole crop	30 kg/ha (P,K)
				Bush beans-maize intercropped	4 t ha^{-1} *Tithonia* + 50 kg ha^{-1} (P,K)
			Climbing	Climbing beans sole crop	6 t ha^{-1} *Tithonia* + 50 kg ha^{-1} (P, K)
				Climbing beans- maize intercropped	6 t ha^{-1} *Tithonia* + 50 kg/ha (N.P,K)
		Plot dominated by *Pennisetum polystachia* or *Bidens pilosa* (poor soils)	Bush	Bush beans sole crop	6 t/ha *Tithonia* + 50 kg/ha (N,P,K)
				Bush beans-maize intercropped	6 t/ha *Tithonia* + 75 kg/ha (N,P,K)
			Climbing	Climbing beans sole crop	8 t ha^{-1} *Tithonia* + 50 kg ha^{-1} (N,P,K)
				Climbing beans- maize intercropped	8 t ha^{-1} *Tithonia* + 75 kg ha^{-1} (N,P,K)

Farmer Conditions		**Soil type according to farmer criteria***	**Bean type**	**Cropping system**	**Soil fertility management Recommendations**
Finances	**Organic resources**				
	Compost available	Plot dominated by *Gallinsoga parviflora*	Bush	Bush beans sole crop	4-6 t ha^{-1} *Tithonia* or 20 t ha^{-1} compost
				Bush beans-maize intercropped	(8 t ha^{-1} *Tithonia* or 30 t ha^{-1} compost) + 50 kg/ha (N,P,K)
			Climbing	Climbing beans sole crop	(8 t ha^{-1} *Tithonia* or 20 t/ha compost) + 50 kg ha^{-1} (P,K)
				Climbing beans- maize intercropped	(8 T t ha^{-1} *Tithonia* or 20 t ha^{-1} compost) + 75 kg ha^{-1} (N,P, K)
		Plot dominated by *Pennisetum polystachia* or *Bidens pilosa* (poor soils)	Bush	Bush beans sole crop	(4 t ha^{-1} *Tithonia* or 10 t ha^{-1} compost) + 50 kg ha^{-1}(P,K)
				Bush beans-maize intercropped	(6 t ha^{-1} *Tithonia* or 20 t ha^{-1} compost) + 50 kg ha^{-1} (N,P,K)
			Climbing	Climbing beans sole crop	(8-10 t ha^{-1} *Tithonia* or 20 t ha^{-1} compost) + 50 kg ha^{-1}(N,P,K)
				Climbing beans- maize intercropped	(10 t ha^{-1} *Tithonia* or 30 t ha^{-1} compost) + 75 kg ha^{-1} (N,P,K)

Table 24. Decision guide for ISFM in a Bean-based cropping system in Eastern DR Congo

Awareness and adoption of ISFM technologies by farmers is found to be essential factor to their eventual widespread adoption in ECSA. Kankwatsa et al. (2008) found that farmer's awareness varied significantly with their participation to the technology promotional activities of farmers. They reported that participating farmers were more rational in their choice of technologies to solve specific constraints and more participating farmers adopted the IPDM and ISFM technologies than the non-participating farmers. To favor farmers' capacity to experiment and eventually to adapt technological options to their biophysical and socioeconomic conditions, they were exposed to a whole range of new soil fertility management options through farmers' field schools and dialogue with researchers in the process of farmers' participatory research. They have continued to experiment and ended to suggest modifications to the technologies. In Bushumba, Estern DRC, Njingulula and Ngongo (2007) reported the results of participatory evaluation of the rate of *Tithonia* application. They found that although the rate recommended by research was not much modified, farmers found the better manner to express the rate of application using a common volume measure. Farmers' recommendation of *Tithonia* biomass application was the rate of 3 to 4 basins per 4 m x 4 m portion of land, which is equivalent to 5 to 7.5 t ha^{-1}, in perfect agreement with the recommendation by researchers. Going through this process increased their confidence in their own ability to find solutions to different problems, and improved the rate of adoption of suitable technology. The impact studies were conducted by Kankwatsa et al (2008) in PABRA member countries to evaluate the fate of promoted ISFM technologies.

11. Conclusions

African smallholder farming conditions are worsened by declining soil fertility as a consequence of population pressure on a limited landbase. PABRA, as an African research for development program has made outstanding efforts in establishing partnership with numerous stakeholders, farmers, rural communities, non-governmental and governmental organizations, private sector, traders and research organizations (national, regional and international). In spite of complexity of ISFM technologies developed, bean productivity has been improved under low soil fertility conditions by developing strategies and technologies that enhance resilience to environmental stresses and by enhancing farmers' access to adapt and use cost effective integrated environmental stress management options (PABRA, 2008). The strategy of PABRA on ISFM has two broad avenues for achieving the objective. These include soil fertility management and deployment of resilient bean germplasm.

Genotypes with improved performance on low fertility soils is valued by farmers and readily adopted, and have made it possible to improve bean production in regions where they are adopted at no additional cost. Identification and use of cultivars tolerant to mineral deficiencies and toxicities are essential for reducing production costs and dependence of farmers on soil amendment inputs. The resilient bean cultivars have been shown superior to existing popular varieties developed without consideration of tolerance to soil infertility tolerance. Many bean genotypes have been selected with tolerance to single or multiple edaphic stresses (Wortmann et al., 1995; Rao, 2001). Therefore, as stated by Lynch et Beebe (l995), efficient cultivars would have several benefits, including increased food production, increased farm income, increased bean availability and consumption, and thereby improved nutrition for low income producers and consumers. Indeed, improved variety is considered as a fast adoption technology (Kankwantsa et al., 2008). The nurseries of these genotypes are maintained with the PABRA regional networks with characteristics of market preferences, besides tolerance to low soil fertility.

Bean productivity is further enhanced by various soil management options developed in participatory manner. The use of farmer participatory approach to technology dissemination enabled farmers to be familiar with, understand, experiment and adapt ISFM technologies. Through capacity building through farmers' groups and farmer research groups, farmers have been empowered to obtain various technologies and services from appropriate partners. Various locally available resources are used, as limestone and phosphate rock, alone or in combination with mineral fertilizers, and the effect of organic resources in improving nutrient use efficiency is well demonstrated. Considerable and beneficial bean yield increase is achieved. However, the low production of organic resources on farms calls for biomass transfer. *Tithonia* biomass is readily available and adopted by farmers and contributes considerably to bean productivity enhancement as an essential source of nutrients and organic amendment. Maximal use of locally available nutrients through low-external input technologies, techniques, combined with optimal use of external nutrients appears to be the most appropriate strategy in the existing economic environment (de Jager, et al., 2004).

Based on research data on soil fertility management in major bean growing areas, a comprehensive decision support system (DSS) was developed for use by farmers and extension workers in different agro-ecological zones and under diverse socio-economic scenarios. In contrast to standard guidelines, the DSS provides farmers with ISFM options under different scenarios, thereby allowing farmers the ability to choose the option(s) that best suit their needs and socio-economic conditions. Soil fertility conditions are assessed using criteria and indicators that are easy to measure, such as dominant weed species. The desired outcome is that the tool will be used by researchers, extension workers, and farmers for assessing and implementing options of using scarce resources for maintaining soil fertility and improving crop yields in bean-based cropping systems.

PABRA places special emphasis on increased access to cost effective and environmentally friendly integrated bean production, especially by female bean growers. Currently, two approaches are used to facilitate and increase farmer's access to ISFM technologies: a deliberate promotion and delivery of improved varieties and ISFM technologies as a single package; and policy advocacy and harnessing of enabling policies (including input support system) to deliver ISFM technologies to bean farmers. The Alliance (PABRA) feels confident that these approaches will greatly enhance the adoption of ISFM technologies by bean growers and overall bean production in eastern, central and southern Africa.

12. References

Aggarwal, V. D., Mughogho, S. K., Chirwa, R. & Mbvundula, A. D. (1994). Results of testing for tolerance to a low pH complex in Malawi. *Proceedings of a Working group meeting. Bean improvement for a low fertility soils in Africa*. CIAT Africa Workshop Series No. 26, Kampala, Uganda, January 23 – 26, 1994

Bado, B.V. (2002). Rôle des légumineuses sur la fertilité des sols ferrugineux tropicaux des zones guinéenne et soudanienne du Burkina Faso. *Thèse de Philosophiae Doctor (Ph. D.)*, Département des Sols et de Génie Agroalimentaire, Faculté des Sciences del'Agriculture et de l'Alimentation Université Laval, Québec, Décembre 2002

Barrios, E., Bekunda, M., Delve, R., Esilaba, A. & Mowo, J. (2001). Identifying and classifying local indicators of soil quality: Methodology for decision making in natural resource management. Eastern Africa version. *CIAT, SWNM, TSBF, AHI*. 2001

Bationo, A., Hartemink, O., Lungu, M., Naimi, P., Okoth, E., Smaling& Thiombiano L.(2006). African soils: Their productivity and profitability of fertilizer use. *Background paper prepared for the African Fertilizer Summit,* Abuja June 9 – 13, 2006

Beebe, S., Rao, I. M., Blair, M. W. & Butare L. (2009). Breeding for abiotic stress tolerance in common bean: present and future challenges. In: *Proc 14th Australian Plant Breeding & 11th SABRAO Conference*, 10 to 14 August, 2009, Brisbane, Australia.

Bullock DG (1992) Crop rotation. Crit Rev Plant Sci 11(4):309–326

Chilimba, A.D.C. & Kapapa, C. (2002). On-Farm Evaluation of Rhizobium inoculation and seed pelleting and Inoculation of Field Beans (*Phaseolus vulgaris*) in acid soils to enhance nodulation and grain yield.*Soil fertility management and bean improvement for low fertility soils in Africa "BILFA" Working Group Meeting,* Awassa, Ethiopia, November 12 – 16, 2002

Dreschel, P., Gyiele, L., Kunze, D., & Coffie, O. (2001). Population density, soil nutrient depletion and economic growth in Sub-Saharan Africa. *Ecological Economics*, Volume 23, pp. 152 – 258

Esilaba, A.O., Byalebeka, J.B., Delve, R.J., Okalebo, J.R., Ssenyange, D., Mbalule, M., & Ssali H. (2005). On farm testing of integrated nutrient management strategies in eastern Uganda. *Agricultural Systems*, Volume 86, pp. 144–165

Esilaba, A.O., Byalebeka, J.B., Nakiganda, A., Mubiru, S., Delve, R.J., Ssali, H. & Mbalule M. (2001). Integrated Nutrient Management strategies in Eastern Uganda. CIAT, Kampala. *CIAT Africa Occasional Publication Series*, No. 35, pp. 71

Fishler, M. & Wortmann, C.S. (2008). Green manures for maize-bean systems in Eastern Uganda: Agronomic performance and farmers' perceptions. *Agroforestry Systems*, Volume 47, Number 1 – 3, pp. 123 – 138

Giller, K. E. (2001). Nitrogen fixation in tropical cropping systems. 2 ed. CABI, Wallingford, Oxon UK.

Giller K.E., Amijee F., Brodrick S.J.& Edje O.T. 1998. Environmental constraints to nodulation and nitrogen fixation of Phaseolus vulgaris L. in Tanzania. II. Response to N and P fertilizers and inoculation with Rhizobium. African Crop Science Journal 6(2):171-178

Ikerra, S. T., Semu, E. & Mrema, J. P. (2007). Combining tithonia diversifolia and Mijingu phosphate rock for improvement of P availability and maize grain yield on a Chromic Acrisol in Morogoro, Tanzania, In: *Advances in integrated soil fertility management in sub_Saharan Africa: Challenges and Opportunities*, Bationo, A., Waswa, B., Kihara, J. & Kimetu J. pp. 333 – 344, Springer, Dordrecht, The Netherlands

Jama, B. & Van Straaten, P. (2006). Potential of East African phosphate rock deposits in integrated nutrient management strategies. *Anais da Academia Brasileira de Ciencias*, Volume 78, Number 4, pp. 781-790

Kumarasinghe KS, Danso SKA,& Zapata F (1992) Field evaluation of N-2 fixation and N-partitioning in climbing bean (Phaseolus vulgaris L.) using N-15. *Biol Fertil Soils* 13:142–146

Kankwatsa P., Ampofo K., Kasambala C. & Mukankusi C. (2008). Analysis of the socio-economic validity of new bean based integrated soil fertility management and integrated pest and disease management technologies: Uganda, Malawi, Swaziland and Eastern DRC. CIAT, Kampala

Kimani, P. M., Buruchara, R., Ampofo, K., Pyndji, M., Chirwa, R. M., & Kirkby, R. (2001). Breeding Beans for Smallholder Farmers in Eastern, Central, and Southern Africa: Constraints, Achievements, and Potential. *PABRA Millennium Workshop*, Arusha, Tanzania, 28 May – 1 June 2001

Liebenberg, A.J. (2002). Dry bean production. Directorate Agricultural Information Services, Department of Agriculture in cooperation with ARC-Grain Crops Institute, South Africa

Lunze, L. (1994). Screening for tolerance to aluminum toxicity in bean. In. *Bean Improvement for Low Fertility in Soils Africa: Proceedings of a Working Group Meeting*. Kampala, Uganda, May, 23-26, 1994

Lunze, L. & Ngongo, M. (2011). Potential Nitrogen Contribution of Climbing Bean to Subsequent Maize Crop in Rotation in South Kivu Province of Democratic Republic of Congo. In: *Innovations as Key to the Green Revolution in Africa*, A. Bationo et al. (eds.), 677 – 681, Springer Science, Dordrecht, The Netherlands . In press

Lunze, L., Kimani, P.M., Ndakidemi, P., Rabary, B., Rachier, G.O., Ugen, M.M. & Nabahungu, L. (2002). Selection of bean lines tolerant to low soil fertility conditions in Africa. *Bean Improvement Cooperative, BIC* Volume 45, pp. 182–183

Lunze L., Kimani P.M., Ngatoluwa R., Rabary B., Rachier G.O., Ugen M.M., Ruganza V. & Awad elkarim E.E. 2007. Bean improvement for low soil fertility in adaptation in Eastern and Central Africa. In: *Advances in integrated soil fertility management in sub_Saharan Africa: Challenges and Opportunities,*Bationo, A., Waswa, B., Kihara, J. & Kimetu J. pp. 325 – 332. Springer, Dordrecht, The Netherlands

Lynch, J.P., & Beebe, S.E. (1995). Adaptation of beans (Phaseolus vulgaris L.) to low phosphorous availability. *HortScience*, Volume 30, pp. 1165-1171

Mastaki, N. J. L. 2006 Le rôle des goulots d'étranglement de la commercialisation dans l`adoption des innovations agricoles chez les producteurs vivriers du Sud-Kivu (Est de la R.D.Congo). *Dissertation originale présentée en vue de l'obtention du grade de docteur en sciences agronomiques et ingénierie biologique. Filière : Economie et Développement Rural*. Faculté Universitaire des Sciences Agronomiques de GEMBLOUX

Mauyo, L.M., Okalebo, J.R., Kirkby, R.A., Buruchara, R., Ugen, M. & Maritim, H.K. (2007). Spacial pricing efficiency and regional market integration of cross-border bean (Phaseolus vulgaris L.) marketing in Rest Africa: The case of Western Kenya and Eastern Uganda. In: *Advances in Intergrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities*, A. Bationo et al. (eds), pp. 1027 – 1033, Springer

Musungayi, T., Njingulula, M., Mbikayi, N., & Lunze, L. 2006. Expansion des variétés biofortifiées de haricot et de patate douce à chair orange dans les provinces du Sud Kivu et Nord Kivu en R. D. Congo. Rapport d'Enquête. INERA (Unpublished)

Musungayi, T. Sperling, L. Graf, W. & Lunze, L. 1990. Enquêtes diagnostiques de la zone de Walungu, zone d'action de la Femme Solidaire pour le développement du Bushi, Rapport d'enquêtes (Inédit).

Nabahungu L. et Ruganzu, V. 2001. Effet du Travertin et de Tithonia diversifolia sur la Productivité du Haricot Volubile en Sols Acides du Rwanda. *PABRA Millenium Symposium*. Arusha, Tanzania, 28 May – 1 June, 2001

Nabahungu, N.L, Semoka, J.M.R &. Zaongo, C. (2007). Limestone, Minjingu Phosphate Rock and Green Manure Application on Improvement of Acid Soils in Rwanda. *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities.*Springer, pp 703-712

Nekesa P., Maritim H.K., Okalebo J.R. & Woomer P.L. 1999. Economic analysis of maize-bean production using a soil fertility replenishment product (PREP-PAC) in Western Kenya. *African Crop Science. J.* Vol 7. No. 4, pp 585-590

Ngongo, M. & Lunze, L. (2000). Espèces d'herbe dominante comme indice de la productivité de sol et de la réponse du haricot commun à l'application du compost. *African Crop Science J.* Volume 8, Number 3 pp. 251–261

Ngongo, M. (2001). Management of soil fertility in South Kivu with green manure of tithonia. In: PABRA Millenium Symposium..Arusha, Tanzania, 28 May – 1 June, 2001

Njingulula, M. (2003). Etude de l'impact socio-économique des variétés améliorées du haricot dans le système de culture paysan au Congo, République Démocratique. Proceedings of a Regional Workshop to Develop a Work Plan for Impact Assessment Studies and Monitoring and Evaluation.Kampala, Uganda. PABRA, CIAT. pp 83–87.

Njingulula, P. M. & Ngongo, M. (2007). Initiating rural farmers to participatory research: case of soil fertilization in Bushumba, East of DR Congo. In. *Advances in integrated soil fertility management in Sub_Saharan Africa: Challenges and Opportunities*. Bationo, A., B. Waswa, Kihara, J. & Kimetu J. (Eds) pp. 1051-1059, Springer

Nyabienda, P. & Hakizimana, A. (1988). Atelier sur la fixation biologique de l'azote du haricot en Afrique, CIAT African Workshop Series, No. 8, Rubona, Rwanda, 27 – 29 Octobre 1988

Opala PA. 2001. Management of organic inputs in East Africa: A review of current knowledge and future challenges. Archives of Applied Science Research, 2011, 3 (1): 65-76. Available from: www.scholarsresearchlibrary.com

PABRA. 2008. Supporting nutrition and health, food security, environmental stresses and market challenges that will contribute to improve the livelihood and create income of resource poor small holder families in Sub-Saharan Africa. PABRA, CIAT, Kampala, Uganda

Palm, C.A., Myers R. J. K. & Nandwa, S. M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: *Replenishing Soil Fertility in Africa*, Buresh RJ, Sanchez PA & Calhoun F (eds), pp 193–217. SSSA Special Publication 51. SSSA, ASA, Wadington

Pankhurst, C., Doube, B.M. & Gupta, V.V.S.R. (Eds.) (1997). Biological Indicators of SoilHealth. CAB International, Wallingford.

Rabary, B. 2001. Participatory research for improved agroecosystemmanagement: a mean for rural community development. PABRA Millenium Symposium. Arusha, Tanzania, 28 May – 1 June 2001

Rachier G.O., Wortmann C.S., Tenywa J.S. and Osiru D.S.O. 1999. Phosphorus acquisition and utilization in common beans: mechanisms and genotype differences. African Crop Science Journal Vol. 4: 187-193

Rachier, G.O., Salaya, B.D. & Wortmann, C.S. (2001). Verification of recommended rates of inorganic fertilizers and farmyard manures in maize intercrop under contrasting soil types. In: *PABRA Millenium Symposium*. Arusha, Tanzania, 28 May – 1 June 2001

Rao, I. M. (2001). Role of physiology in improving crop adaptation to abiotic stresses in the tropics: The case of common bean and tropical forages. In: *Handbook of Plant and Crop Physiology*, Pessarakli M, (ed). Marcel Dekker, Inc, New York, USA, p. 583–613.

Rao, I. M., Friesen, D. K. & Osaki, M. (1999). Plant adaptation to phosphorus-limited tropical soils. In: M. Pessarakli (ed.) Handbook of Plant and Crop Stress. Marcel Dekker, Inc., New York, USA, pp. 61-96

Ruraduma, C. (2002). Improving biological nitrogen fixation of beans. *Soil fertility management and bean improvement for low fertility soils in Africa "BILFA" Working Group Meeting*. November 12 – 16, Awassa, Ethiopia.

Rutunga, V, Steiner, K.G., Karanja, N.K., Gachene, C.K.K. & Nzabonihankuye, G. (1998). Continuous fertilization on non-humiferous acid Oxisols in Rwanda "Plateau Central": Soil chemical changes and plant production. *Biotechnol. Agron. Soc. Environ*. Volume 2, Number 2, pp. 135–142

Rutunga, V. (1997). Sols acides de la région d'altitude de la Crête Zaïre-Nil (Rwanda): Potentialités agricoles et forestières. Lengo Publishers, Nairobi, 68pp.

Sanginga, N. (2003). Role of biological nitrogen fixation in legume based cropping systems; a case study of West Africa farming systems. *Plant and Soil,* Volume 252, Number 1, pp. 25-39 (15)

Sanginga, N., & Woolmer, P. L, eds. (2009). Integrated Soil Fertility Management in Africa:*Principles, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture.* Nairobi. 263 p.

Singh, S.P. (2001). Broadening the genetic base of common bean cultivars: a review. *Crop Science* Volume 41, pp. 1659–1675

Sperling, L., Scheidegger, U., Buruchara, R., Nyabienda, P. & Munyanesa. (1993). Intensifying production among smallholder farmers: The impact of improved climbing bean in Rwanda. *CIAT African Occasional Publication Series* No. 12. CIAT/RESAPAC, Butare, Rwanda, p13

Thung, M. & Rao, I. M. (1999). Integrated management of abiotic stresses. In: *Common Bean Improvemen in the Twenty-First Century*.S. P. Singh (ed.),. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 331-370.

Tumuhaire, J.B., Rwakaikara, S.M.C., Muwnga, S. & Natigo, S. (2007). Screening legume green manure for climatic adaptability and farmer acceptance in the semi-arid agro-ecological zone of Uganda. In. *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities*, A. Bationo et al., pp. 255 – 259, Springer,Dordrecht, The Netherlands

Ugen, M. & Wortmann, C. S. (2001). Weed Flora and Soil Properties in Subhumid Tropical Uganda, *Weed Technology*, Vol. 15, Number. 3, pp. 535-543

Ugen, M. A., Ndegwa, A. M. Nderitu, J. H., Musoni, A. & Ngulu, F. (2009). Enhancing competitiveness of snap beans for domestic and export markets. ASARECA CGS Revised Full Proposal Document. Entebbe, Uganda

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K., Smaling, E., Woomer, P. L. & Sanginga, N. (2010) Integratedsoil fertility management: Operational definition and consequencesfor implementation and dissemination. *Outl onAgric* 39, 17–24

Vanlauwe B., Chianu J., Giller K.E., Merckx R , Mokwunye U., Pypers P., Shepherd K., Smaling E, Woomer P.L. & Sanginga N. 2010. Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *19th World Congress of Soil Science, Soil Solutions for a Changing World*. 1 – 6 August 2010, Brisbane, Australia.

Vanlauwe B, Tittonell P, &Mukalama J (2006) Within-farm soil fertility gradients affect response of maize tofertilizer application in western Kenya. *Nutrient Cycling in Agroecosystems* 76,171-182.

van Schoonhoven, A. & Pastor-Corrales, M.A. (1994) . Système standard pour l'évaluation du germoplasme du haricot. Publication CIAT, Cali, Colombia, No. 207

Wortmann, C.S.(2001). Nutrient dynamics in a climbing bean and sorghum crop rotation in the Central Africa Highlands, *Nutrient Cycling in Agroecosystems*, Volume 61, Number 3, pp. 267-272

Wortmann, C. S. & Kaizzi, C. K. (1998). Nutrient balances and expected effects of alternative practices in the farming systems of Uganda. *Agriculture, Ecosystems and Environment* Volume 71, pp. 117-131

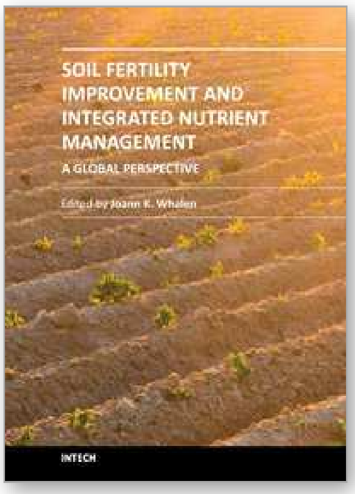
Wortmann, C. S. & Ssali, H. (2001) . Integrated nutrient management for resource-poor farming systems: A case study of adaptive research and technology dissemination in Uganda. *American Journal of Alternative Agriculture*, Volume 16, pp. 161-167

Wortmann, C.S., Isabirye, M. & Musa, S. (1994). Crotalariaochroleucaas a Green Manure Crop in Uganda. *African Crop Science J.*, Volume 2, Number 1, pp. 55-61

Wortmann, C.S., Kirkby, R.A., Aledu, C.A. & Allen, J.D. (1998). Atlas of common bean (Phaseolus vulgaris L.) Production in Africa, CIAT Cali, Colombia

Wortmann, C.S., Lunze, L., Ochwoh, V.A. & Lynch, J.P. (1995). Bean Improvement for Low Fertility Soils in Africa. *African Crop Science J*, Volume 3, Number 4, pp. 469-477

Wortmann, C.S., Schnier, H.F. & Muriuki A.W. (1996). Estimation of the fertilize response of maize and bean intercropping using sole crop response equations. *African Crop Science Journal*, Vol. 4. No.1, pp. 51-55, 1996



Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective

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Soil Fertility Improvement and Integrated Nutrient Management: A Global Perspective presents 15 invited chapters written by leading soil fertility experts. The book is organized around three themes. The first theme is Soil Mapping and Soil Fertility Testing, describing spatial heterogeneity in soil nutrients within natural and managed ecosystems, as well as up-to-date soil testing methods and information on how soil fertility indicators respond to agricultural practices. The second theme, Organic and Inorganic Amendments for Soil Fertility Improvement, describes fertilizing materials that provide important amounts of essential nutrients for plants.The third theme, Integrated Nutrient Management Planning: Case Studies From Central Europe, South America, and Africa, highlights the principles of integrated nutrient management. Additionally, it gives case studies explaining how this approach has been implemented successfully across large geographic regions, and at local scales, to improve the productivity of staple crops and forages.

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