Master Farmer Training in Biological Nitrogen Fixation and Grain Legume Enterprise

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for Training of Trainers and Master Farmers
within the N2Africa East African Outreach Project

TSBF CIAT

Putting nitrogen fixation to work for smallholder farmers in Africa

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This training package consists of an introduction and nine learning modules

Introduction to the N2Africa Project

This project will:

- **link the protein and nitrogen needs of poor African farmers directly to massive atmospheric reserves provide them with new income-generating crop production enterprises**
- **advance renewable soil fertility management**
- **promote adoption of profitable accompanying farm technologies and value-adding enterprises.**
- **deliver legumes and BNF technologies to farmers throughout sub-Saharan Africa**

Putting nitrogen fixation to work for smallholder farmers in Africa

N2Africa Project Goals

- **N2-fixation inputs increased from 35 kg N per hectare to over 90 kg per hectare**
- **total amounts of N per farm increased from 8 to 30 kg N per year on 225,000 farms (37,500 in west Kenya by 2013)**
- **15,250 tons of N per year from biological N fixation worth 28 million USD**
- **increase grain legume yields by an estimated 123,000 tons, worth 50 million USD**

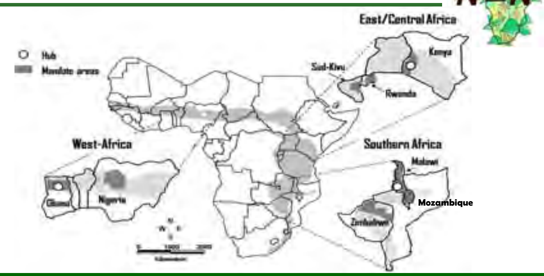
Putting nitrogen fixation to work for smallholder farmers in Africa

N2Africa expected project outcomes

- **Diversify N2-fixing legume species that are integrated into smallholder farming systems in sub-Saharan Africa;**
- **Expand cultivation of grain and forage legumes, greater productivity in legume-based farming systems, and enhanced family incomes;**
- **Select efficient rhizobial inoculant strains and improved grain legume varieties with enhanced BNF capacities adapted to various environmental stresses;**
- **Establish a state-of-the-art laboratory and culture collection of elite strains of rhizobia for target legumes; and**
- **Establish of rhizobial inoculant production in countries of West, East and Southern Africa, through partnership with the private sector.**

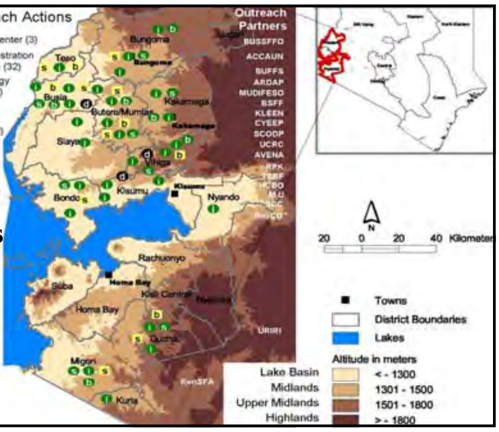
Putting nitrogen fixation to work for smallholder farmers in Africa

N2Africa is a regional project



The N2fixAfrica Project operates in three impact zones and mandate areas, and eight target countries through its three sub-regional hubs

Activities in the West Kenya Action Site



Demonstration packages (above), input delivery (right) and partnership (below)

Master Farmer Training in BNF

- **Develop practical understanding in the management of nitrogen, legumes, rhizobia and biological nitrogen fixation**
- **Gain skills in rhizobial inoculant handling and application**
- **Improve abilities to design, install and interpret response to inoculant tests in farmers' fields**
- **Strengthen skills in working with farmers and their organizations to promote grain legume enterprise**

Achieving the projected benefits from the N2Africa Project

Project impact	Target	Approach
Number of countries	8	Engage national partners in Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda & Zimbabwe
Number of households	225,000	Develop dissemination strategy involving farmer associations, extension systems and NGOs,
Average legume yield	+ 945 kg per ha	Introduce improved grain legume varieties and improved management practices
Increase BNF	+ 46 kg N per ha	Introduce rhizobium inoculants, better manage native rhizobia and the legume-rhizobium symbiosis
Household benefits	+ $465 per year	Improve post-harvest handling and marketing of legumes, promote value-added processing, provide new opportunities to women farmers

Master Farmers in Action! Seed inoculation (upper left and clockwise), assembling technology testing packages, assessing soybean performance, operating village input shops, distributing input packages, first commissioned group of Master Farmer trainers.

Key sources of information

Applied BNF Technology. **1990. University of Hawaii NifTAL Project. P.W. Singleton and others.**

Biological Nitrogen Fixation and Grain Legume Enterprise: Guidelines for N2Africa Master Farmers. **2010. CIAT-TSBF. Nairobi. P.L. Woomer.**

Integrated Soil Fertility Management in Africa. **2009. TSBF-CIAT. N. Sanginga & P.L. Woomer.**

Legume Inoculants and their Use. **1984. Food and Agriculture Organization. Rome.**

Nitrogen Fixation in Tropical Cropping Systems. **2001. CABI Publishing. UK. K.E. Giller.**

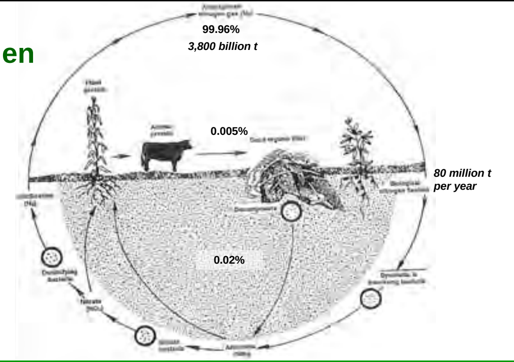
Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa **(N2Africa Project Document). 2009. Wageningen University, The Netherlands. K.E. Giller and others.**

N2Africa Master Farmer Training

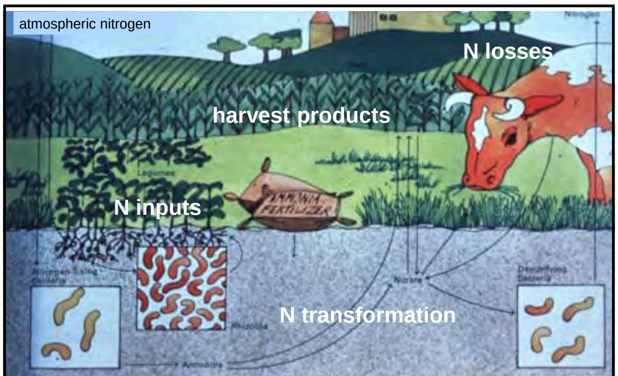
Module 1. Nitrogen in small-scale agriculture

- The nitrogen cycle
- Nitrogen in plant, animal and human nutrition
- Soil fertility decline and nitrogen depletion
- Biological nitrogen fixation (BNF)
- The legume-rhizobium symbiosis

The Nitrogen Cycle



Most nitrogen resides in the atmosphere in inert form. Biological nitrogen fixation captures that nitrogen for biological transformation including return to the atmosphere. A key strategy is to recycle nitrogen internally within the farm.



Successful nitrogen management optimizes inputs, maintains internal cycling and directs nitrogen losses toward harvest products.

The approximate concentrations of nutrient elements required for healthy plant growth).

Element	concentration in dry matter (mg per kg)
Oxygen	480000
Carbon	420000
Hydrogen	60000
Nitrogen	**14000**
Potassium	10000
Calcium	5000
Magnesium	2000
Phosphorus	2000
Sulfur	1000
Chlorine	100
Iron	100
Manganese	50
Boron	20
Zinc	20
Copper	6
Molybdenum	0.1
Cobalt	trace
Silicon	trace
Sodium	trace

Nitrogen (N) in plants

Vital constituent of protein and protoplasm

Necessary for biomass increase and reproduction in plants.

Present in all enzymes necessary for plant functions.

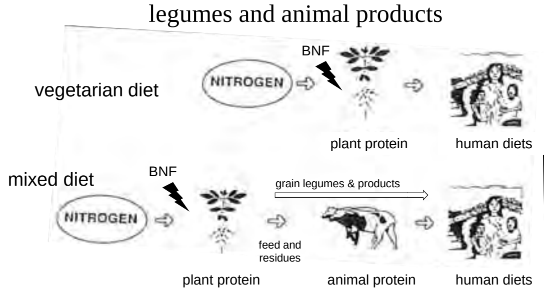
Deficiency symptom is chlorosis of the lower leaves, with extreme deficiency leaves become pale yellow, even white, and die.

Grain legumes typically yield lower than cereals and root crops but their protein content is much greater

	Crop	Yield kg/ha	Protein content %	Total protein kg/crop
Legumes	Soybean	2400	38	912
	Cowpea	1800	25	450
	Groundnut	1600	26	416
	Bean	1400	25	350
Root crops	Sweet potato	12000	1.3	156
	Cassava	16000	1.2	192
Cereals	Maize	2800	9.5	266
	Sorghum	2000	10	200

Protein: an important component of human nutrition

Concentrated protein is available to people through grain legumes and animal products



Food composition of selected grain legumes

food legume	edible part	protein	fat	carbo-hydrate	Ca	P	Thiamin
		----- propotion dw -----			--- mg/100 g ----		
groundnut	seed	0.25	**0.48**	0.25	52	438	0.84
soybean	seed	**0.39**	0.20	0.36	245	606	0.73
	sprout	**0.42**	0.10	0.43	251	580	0.74
common bean	seed	0.25	0.02	**0.69**	137	368	0.42
	green pod	0.22	0.02	**0.70**	350	300	1.20
	leaf	0.27	0.03	0.5	**2076**	**568**	**1.36**
cowpea	seed	0.26	0.02	**0.69**	124	432	0.67
	green pod	**0.33**	0.05	**0.55**	478	522	1.24
	leaf	**0.36**	0.03	0.50	**664**	**964**	**3.18**

Expressed on a dry weight (dw) basis. From Sanginga & Woomer, 2009

Chemical fertilizer is the fuel that powered the Green Revolution's forward thrust (Norman Borlaug)

Soil fertility depletion in smallholder farms is the fundamental bio-physical root cause of declining per capita food production in Africa, and soil fertility replenishment should be considered as an investment in natural resource capital (Sanchez et al. 1997)

The nitrogen reserve of agricultural soils must be replenished regularly in order to maintain crop production. Replacement of soil nitrogen is accomplished by the addition of **inorganic fertilizers and by biological nitrogen fixation** (Giller et al. 2009)

The nutrient supply strategy **"N from the air and others from the bag"** offers flexible adjustment to local conditions and opportunity for optimizing the use of locally available organic resources and agro-minerals (Sanginga and Woomer 2009)

Nitrogen budget in Kisii, Kenya (Van der Pol, 1992)

		kg N per ha per year
Nitrogen inputs	**Mineral fertilizer**	**17**
	Organic manures	**24**
	Atmospheric deposition	**6**
	Biological nitrogen fixation	**8**
	Sedimentation	**0**
Nitrogen outputs	**Harvest products**	**-55**
	Crop residue removal	**-6**
	Leaching	**-41**
	Gaseous loss	**-28**
	Runoff and erosion	**-37**
Nitrogen balance		**-112**

Nitrogen depletion is a regional threat

Zone	N depletion rate kg per ha per year	Total depletion million tons per year
East Africa	36	1.4
Coastal West Africa	27	1.7
Southern Africa	20	0.5
Sahel	11	0.6
Central Africa	10	0.2
Sub-Saharan Africa	22	4.4

From Smaling et al. 1997

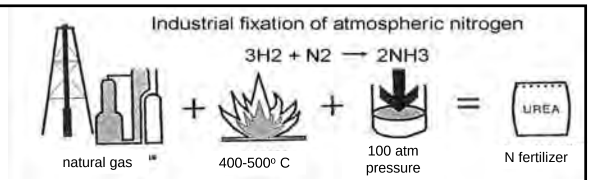
Management of soil nitrogen

Major causes of N deficiency include insufficient N in the soil solution, leaching, waterlogging and plant competition for limited N reserves.

Corrected with fertilizer containing ammonium, nitrate or urea

Remedial measures include improved drainage of waterlogged fields, weeding to eliminate competition and liming to adjust the pH.

Symbiotic N-fixing legumes offer direct advantages of N supply from the atmosphere and residual sources of organic N in crop residues, roots and nodules.



- **Mineral nitrogen fertilizers are produced industrially by chemically fixing N2 gas in the air to produce ammonia.**
- **This process is energy expensive as it requires both high temperature and pressure, accounting for the high price of N fertilizer.**
- **Global consumption of N as mineral fertilizer is now 110 million t/yr but only 2.4% of that is used in Africa.**
- **N fertilizer production continues to increase and is seen as a necessary component of modern agriculture.**

Biological Nitrogen Fixation (BNF)

BNF transforms atmospheric N into biologically useful forms

BNF occurs in bacteria, both free living and symbiotic

Legumes are the most important symbiotic plants and form root nodules

Legumes are associated with rhizobium bacteria

Legumes and rhizobia have co-evolved and become specialized

Different legumes and rhizobia fix different amounts of N

Symbiotic BNF requires that N supply in the soil be limiting

BNF offers an inexpensive alternative to mineral fertilizers

Benefits from BNF can extend to subsequent crops

Large amounts of energy are also required to support nitrogen fixation in root nodules. BNF requires biological energy in the form of plant photosynthates. BNF requires about 10 kg of carbohydrates per kg of atmospheric N fixed.

Root nodules differ in shape, size, color, texture and location. The shape and location of nodules is determined by the host plant. Root nodules may be spherical (soybean, left), finger-like (alfalfa, below), lobed, fan-shaped or coralloid.

Module 1: Nitrogen. Key concepts

- Nitrogen is an essential element for all living organisms. It is a key component of proteins.
- Nitrogen moves through nature in a cyclic manner
- Nitrogen depletion results from crop removal, erosion and gaseous loss and must be offset by N inputs
- Bacteria are able to convert atmospheric N to ammonia in a process called biological nitrogen fixation (BNF)
- In the rhizobia-legume symbiosis, rhizobia provide the plant with fixed N, which the plant uses for its growth.
- Inorganic N fertilizer is produced by chemical nitrogen fixation, requiring non-renewable energy inputs.
- Biological Nitrogen Fixation in the rhizobium-legume symbiosis is an inexpensive, valuable resource option for smallholder farmers.

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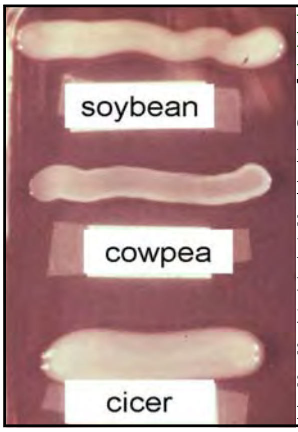
Module 3. Rhizobium bacteria as a biological resource

- Rhizobia are special bacteria
- The lifecycle of rhizobia
- Rhizobium in the soil
- Rhizobium on plant roots
- Cross-inoculation groups
- Managing rhizobia on the farm

Rhizobia are Special Soil Bacteria

- Among soil bacteria there is a unique group called rhizobia.
- Rhizobia are especially beneficial to the cultivation of legumes.
- Rhizobia are remarkable bacteria because they can have two habitats.
- The first home is the soil where they exist alongside many other soil microorganism.
- Rhizobia's other home is within the root nodule structure of host legumes.



Rhizobia in the laboratory

The commercial production of rhizobia inoculants requires that the rhizobia be recovered taken from the soil and the nodule into the laboratory. There the rhizobia are cultured for inoculant production using specialized media under sterile conditions and form milky-white colonies (left).

Rhizobia in the laboratory

When we examine rhizobium under the microscope, we find that they are short rods 0.5 to 0.9 micrometers wide and 1.2 to 3.0 micrometers long (lower left). They require oxygen to live and move using special thread-like structures called flagella (upper left). They do not form spores but increase through cell division (red circle).

The life cycle of rhizobia

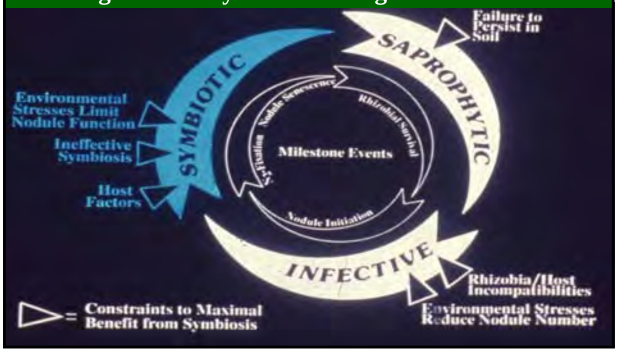
The **saprophytic phase** of the cycle, rhizobia may persist in the absence of the legume hosts either in the bulk soil, the decaying root nodules from previous symbiosis, or in the rhizospheres of non-host plants

The **infective phase** in the cycle of rhizobia represent a series of events involving both symbiotic partners. The infection process is sensitive to stresses of the environment, particularly soil acidity and salinity.

The **symbiotic phase** of the cycle refers to the development and function of root nodules. This phase is also subject to environmental factors that affect the host plant.

High numbers of **native rhizobia** present a competitive barrier to the successful establishment of introduced rhizobia.

The life cycle of rhizobia consists of three phases, each with their own milestone events and constraints to achieving effective symbiotic nitrogen fixation



Rhizobium as saprophytes

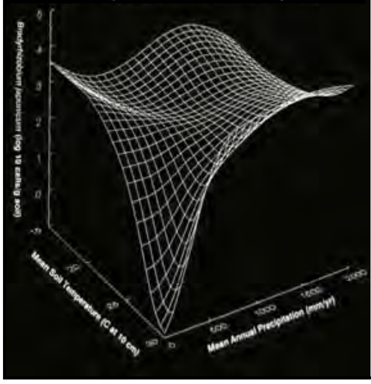

soybean rhizobia living on soil particles

Rhizobia live in the soil without their legume partner. When rhizobia are living in the soil, they are **saprophytes,** organisms which live on the soil. We refer to the rhizobia that are already living in the soil as **native** rhizobia. The rhizobia put into the soil through farmer's inoculants are **introduced.** The population of native rhizobia can be very diverse with many distinct strains.

Rhizobia in the soil can be counted with population sizes ranging from zero to thousands per gram of soil depending upon micro-climate and soil conditions. The cowpea rhizobia counts below were recovered in several soils from East and Southern Africa.

Climate	Elevation		
	lowlands	midlands	highlands
	------------ rhizobia/g soil) ----------		
Semi-arid	10	23	4368
Sum-humid	40	177	3370
Humid	na	1627	2700

Survival of soybean rhizobium in tropical soils



When large numbers of soybean rhizobia are introduced to the soil, their final populations depend upon soil moisture and temperature. Note that average temperatures less than 25ºC and rainfall less than 800 mm per year combine to greatly reduce rhizobium survival.

Rhizobium and plant roots

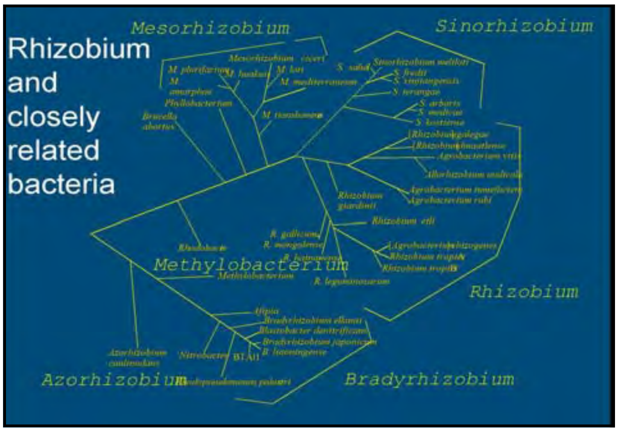
It appears that in many agricultural soils the presence of vegetation whether legumes or non-legumes, encourages larger numbers of rhizobia compared to soil with poor vegetation cover. Rhizobia are found in large numbers in the soil close to the root of legumes and non-legumes. This region close to the root is called the rhizosphere. Rhizobia develop well in the rhizosphere of many plants because root exudates provide nutrient substrate and growth stimulants.

Rhizobium specificity and cross-inoculation groups

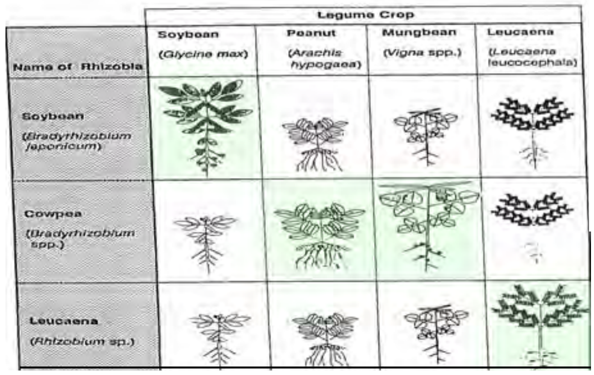
- **Different legumes show preference for certain rhizobia and vice versa**
- **Rhizobia may be grouped based upon nodulation but this does not assure effectiveness**
- **Some legumes are promiscuous while others are host-specific**
- **Rhizobium taxonomy is extremely complex while cross-inoculation grouping is more understandable and practical**
- **Even within cross-inoculation groups effectiveness groupings exist**
- **Some strains of rhizobia perform extremely well with legume species and varieties**

Selected cross-inoculation groups of rhizobia

Rhizobial group	Subgroup and hosts
Bean rhizobia	Bush bean, climbing bean, runner bean
Clover rhizobia	Clovers
Pea rhizobia	Peas, faba bean, vetches, lentils
Alfalfa rhizobia	Alfalfa, melilotus, fenugreek (masala)
Chickpea rhizobia	Chickpea (garbonzo bean)
Leucaena rhizobia	Leuceana, calliandra, gliricidea, prosopis
Soybean rhizobia	Soybeans
Cowpea rhizobia	*Cowpea subgroup:* cowpea, green gram, pigeon pea, crotolaria, bambara nut, siratro
	Lima subgroup: lima bean (butter bean), tepary bean, canavala
	Groundnut subgroup: groundnut, guar
	Centro subgroup: Centrosema

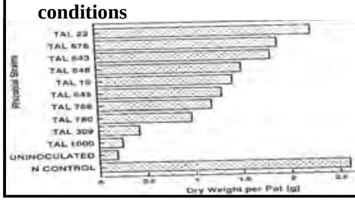


Cross inoculation groups (host specificity)

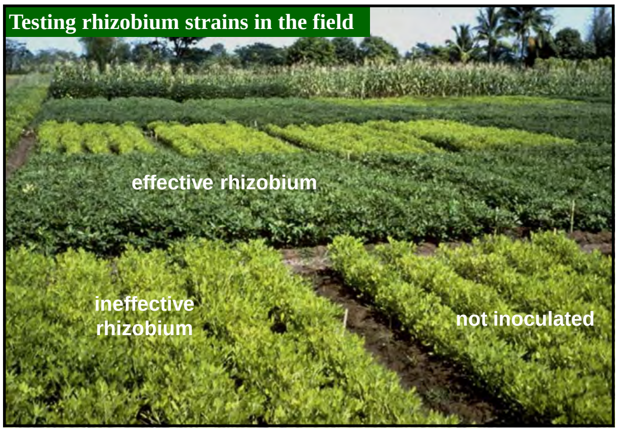


Strain specificity and elite rhizobia

- **Some strains are more efficient at BNF on specific legume hosts and varieties**
- **Strains also differ in competitive abilities to form nodules**
- **Combining these traits allows the identification of elite strains of rhizobia**
- **An example of different strain performance on gram grown under sterile conditions is presented (below)**
- **Traits identified in the laboratory and greenhouse must be validated under field conditions under a range of environmental conditions**



Testing rhizobium strains in the field



Key concepts

- Rhizobia are special soil bacteria that are important for BNF with legumes.
- Rhizobia are conveniently classified by the legumes they nodulate .
- Rhizobial inoculants must be properly matched with the legume.
- Elite strains of rhizobia must be selected for use in inoculants.
- The soil and its environment affect both native and introduced rhizobia in the soil.
- Native rhizobia are very important in legume nodulation but may reduce benefits from

Discussion question 1

A farmer has been cropping soybean for three short rains in the same field using rhizobial inoculant. This year she planted soybean without inoculating her seed and is happy with the soybean crop because it is well nodulated and plant growth is healthy and green. ***How is it that the soybeans were nodulated without inoculation?*** The farmer intends to not inoculate her soybean in the future. ***What do you advise and why?***

Discussion questions (2)

A farmer preparing to plant soybeans and has changed over from growing groundnut last season. He has inoculated soybean seeds with the inoculant left over from groundnut. ***Should he plant his inoculated soybeans? What are the possible solutions do you offer?***

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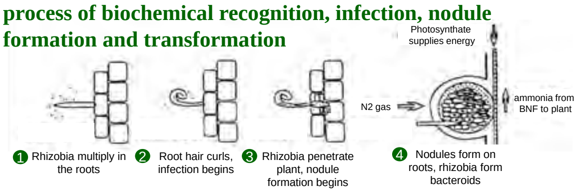
Module 4. The legume-rhizobium symbiosis

- Nodulation of legumes by rhizobia
- Specificity and cross-inoculation groups
- Nitrogen fixed by legume crops
- Managing and increasing BNF

Nodulation of legumes by rhizobia involves a complex process of biochemical recognition, infection, nodule formation and transformation

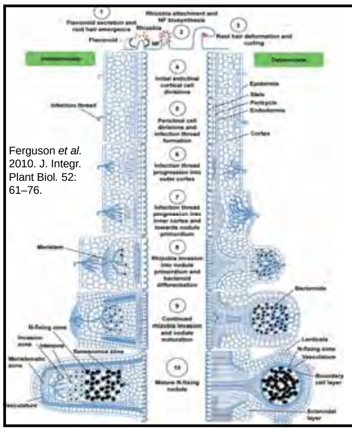


Step 1. Rhizobia multiply in the host rhizosphere, the two exchange biochemical recognition signals and rhizobia attach to root hairs.

Step 2. Root hairs curl and form an infection tunnel that provides rhizobia entry into the host (other entry mechanisms exist)

Step 3. Rhizobia penetrate through several layers of cells, infects root cells, nodule primordia develops and swells

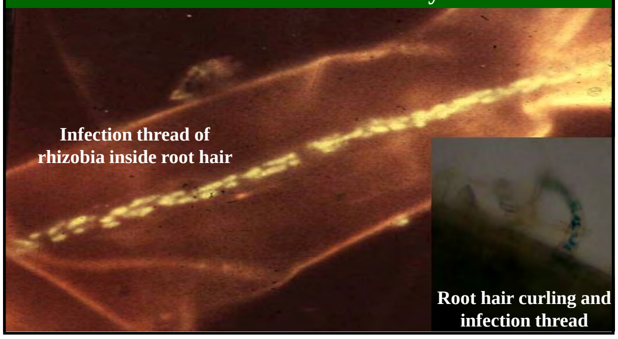
Step 4. Rhizobia transform to N-fixing bacteroids, plant provides photosynthates, BNF occurs and fixed N exported to plant



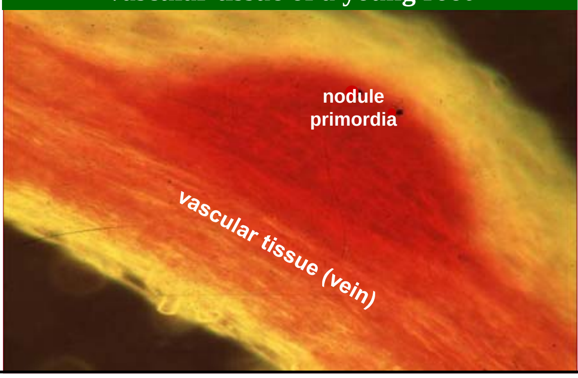
Ferguson *et al.* 2010. J. Integr. Plant Biol. 52: 61–76.

Developmental stages of indeterminate and determinate legume nodules. Illustrated are the developmental stages of pea (indeterminate; left) and soybean (determinate; right) nodules. Emerging root hairs produce nod factors (NF). The root hair deforms and forms a pocket, in which the rhizobia become entrapped. Infection threads initiate in the pocket. Cell division begins in the inner cortex for indeterminate nodules or the sub-epidermal cell layer for determinate nodules. Additional cells divide leading to the formation of the nodule primordium. The infection threads release rhizobia that differentiate into nitrogen-fixing bacteroids. At the top of the primordium of indeterminate nodules, a meristem develops that continually forms new cells hat become infected, leading to successive rhizobia invasion. In contrast, determinate nodules do not develop a persistent meristem and hence their invaded cells are all at a similar developmental phase.

An infection thread of rhizobia enter the plant root hair (Photo by B.B. Bohlool). Other infection mechanisms exist such as "crack entry"



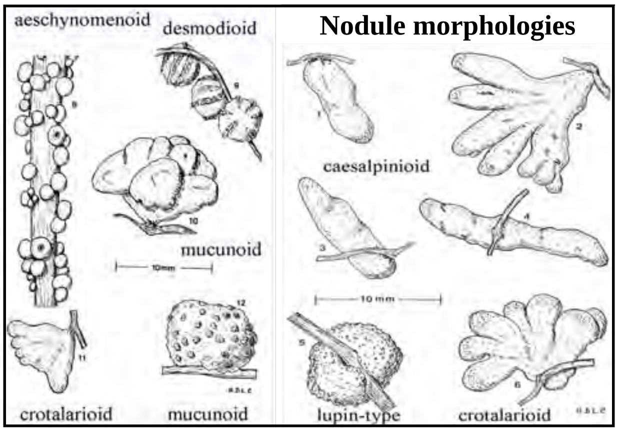
A nodule primordia forming alongside plant vascular tissue of a young root

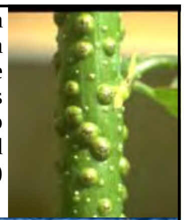


A fully nodulated soybean root system

Nodule development requires 21 to 28 days. Effective nodules have red interiors, are larger and clustered around the upper roots but continue to develop and form through the late flowering stage.

Nodule morphologies



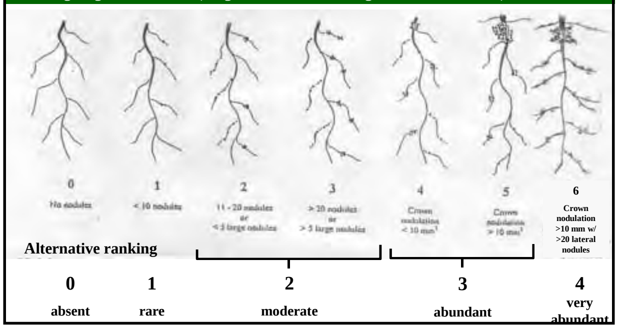


Stem nodules form on some shrubs adapted to saturated soils (right)

Groundnut nodules and young pods (above). Bean nodules (right).

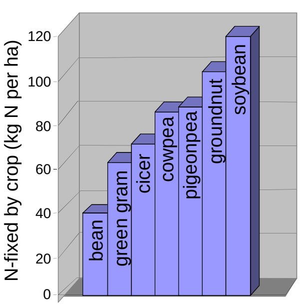
Scoring legume root nodulation

Nodulated root systems may be assigned a rank and then results compared to assess nodulation and the effect of inoculation. This is more rapid than collecting, counting and weighing root nodules (diagram and 0-6 ranking from J. Howelson).



The red interior of nodules results from leghaemoglobin, a protein that regulates oxygen. BNF is regulated by the enzyme nitrogenase. Ineffective nodules have pale interiors and are often smaller.

Root nodules are differentiated including bacteroidal zones, cortex and pronounced connection to plant vascular system, allowing for rapid exchange of substrate. Many have exterior lenticels for entry of N2 gas. Root galls are diseases with non-differentiated (callus) growth.



Nitrogen fixation by tropical grain legumes

after K.E. Giller 2001

Nitrogen fixation by pasture, green manure and tree legumes

legume	N fixation kg N per ha
Tephrosia	111
Mucuna	115
Lablab	116
Gliricidia	142
Desmodium	143
Crotolaria	144
Calliandra	147
Leucaena	177
Siratro	192

Successful BNF by legumes in the field depends on key interactions:

$$L \times R \times E \times M$$

or ***L**egume genotype* × ***R**hizobium strain* × ***E**nvironment* × ***M**anagement* where environment includes climate (temperature, rainfall) and soils (acidity, limiting nutrients etc). Management includes aspects of agronomic management (use of fertilizers, plant density, weeding). Establishment of effective BNF depends on optimizing all of these components together.

Environmental constraints to BNF: Physical factors

High temperature: kills rhizobia in soil, reduces root nodulation *(response: grow temperature tolerant legume varieties)*

Drought: kills rhizobia in soil, reduces BNF *(response: grow deep rooting by legume host)*

Salinity: Legume hosts are more sensitive to salinity than rhizobia, salinity reduces nodulation *(response: salt tolerant legume varieties and species)*

Waterlogging: Rhizobia perform well in flooded soils but legumes grow poorly due to oxygen deficiency and toxic minerals (response: legumes with shallow roots perform better e.g. beans)

Environmental constraints to N-fixation: Chemical factors

Low pH: Rhizobia tolerant of low pH to 4.5. Low pH results in Al toxicity in oxide soils.

Al toxicity: Rhizobia sensitive to Al *(select tolerant rhizobia)*. Nodulation very sensitive to Al toxicity *(cowpea and groundnut are more tolerant)*

P deficiency: Rhizobia tolerant of low P but nodulation and BNF are sensitive. *(mycorrhiza improves legume P use efficiency)*

Ca deficiency: Rhizobia tolerant of low Ca but nodulation through root hairs is reduced. Groundnut requires Ca to develop pods *(liming of acid soils)*.

Micronutrients: Mo, Co, B and others are necessary for BNF. See table below. Micronutrient deficiencies occur at extreme pH levels.

Micronutrient	Effect of deficiency on BNF
Boron (B)	Reduced nodule number and size
Cobalt (Co)	Delayed nodulation
Copper (Cu)	Reduced BNF
Iron (Fe)	Reduced nodule initiation and development
Molybdenum (Mo)	Ineffective nodules
Zinc (Zn)	Reduced nodule number and size

Mineral nitrogen and grain legumes

Legumes can also use mineral nitrogen from the soil and fertilizer but available N reduces BNF

Legumes have a very high requirement for nitrogen and without BNF they need large amounts of nitrogen fertilizer to maximize yields

Legumes prefer to use mineral nitrogen rather than BNF because it is ***more efficient for the plant***

The cost of producing legumes with BNF is much less than with fertilizer nitrogen and is ***more profitable for the farmer***

Nitrogen in some common tropical food crops

crop	yield	grain N	total N
	---------- kg per ha ----------		
maize	2000	31	36
rice	3000	36	42
soybean	2000	121	143
cowpea	1200	48	56

Starter nitrogen

Legumes grow better if there is some mineral nitrogen available before the nodules form and BNF begins

A small amount of starter mineral nitrogen (10 to 30 kg per ha) at planting can increase BNF when the plant is older

With starter N, the seedling will be larger when the first nodules are formed and there is more energy for nodule development

Starter nitrogen will increase yields only in soils that are extremely deficient in nitrogen and where crop yield potential is high

Starter nitrogen should only be recommended to farmers if there is convincing evidence that there will be an economic benefit

Response of Soybean to Starter Nitrogen (after Singleton et al. 1990)

N Applied kg N per ha	with inoculant	no inoculant
	---- kg grain per ha ----	
0	2160	1340
10	2250	1640
30	2370	1580
60	2200	1620

Key Concepts

- The BNF symbiosis results from the complex processes of infection of roots by rhizobia, nodule development, nodule function and nodule senescence.
- The amount of nitrogen that is fixed by a legume depends on several factors. The level of available soil nitrogen is probably the most important factor. The activity of BNF is at a maximum when soil nitrogen is minimal.
- Legumes differ greatly in the amount of nitrogen they leave in the field for subsequent crops. The concepts of harvest index, nitrogen harvest index, and percent nitrogen from BNF are useful for estimating nitrogen inputs from legumes and benefits of legume BNF to the crop system.
- In addition to being grown directly for their seed, legumes are beneficial as rotational crops, green manure, cover crops, forage, and fuelwood.

N2Africa Master Farmer Training

Module 5. Rhizobium inoculants

- The need to inoculate
- Producing legume inoculants
- Types of inoculants
- Selecting quality inoculants
- Inoculant storage and handling
- Cost comparison of inoculants & fertilizer
- Sound use of legume inoculants

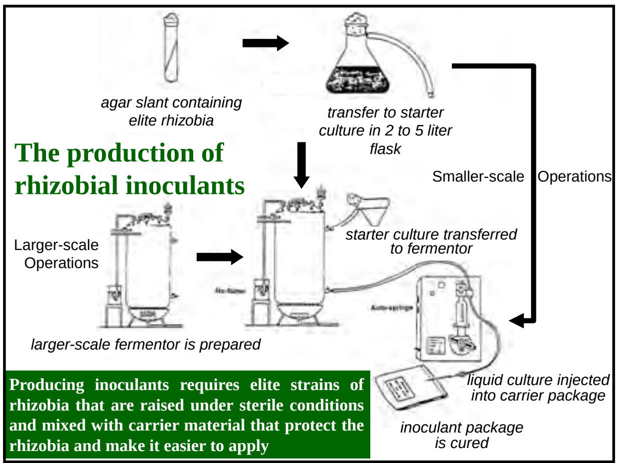
The need to inoculate (1)

- In many soils, the nodule bacteria are not adequate in either number or quality. Under these conditions, it is necessary to inoculate the seed or the soil with highly effective rhizobia.
- Root nodule bacteria are cultured in the laboratory and combine with a suitable carrier material, such as peat, compost or filter mud, to make an inoculant.
- The process of adding this inoculant to the seed is called inoculation.

The need to inoculate (2)

- Inoculation is often required when new legumes are introduced to an area.
- Host-specific rhizobia are frequently developed for new varieties of legumes.
- Many soils are heavily infested with ineffective rhizobia capable of inducing nodulation without benefiting the legume host.
- Very large inoculant rates of competitive and effective strains may counteract these aggressive native rhizobia.

The production of rhizobial inoculants



Producing inoculants requires elite strains of rhizobia that are raised under sterile conditions and mixed with carrier material that protect the rhizobia and make it easier to apply

Types of inoculants (1)

- Legume inoculants are of two general types: those designed for application to seeds or directly to the soil.
- Seed inoculants are the most common because they are easy to apply and are generally effective under most conditions.
- Application of liquid formulation inoculants directly to the soil may be necessary to obtain effective nodulation when planting legume seeds in hot, dry or highly acidic soils or under adverse weather conditions, or when the seeds are treated with chemicals toxic to rhizobia.

Types of inoculants (2)

- High-quality peat-based inoculants are generally considered the most dependable. Shelf life varies with carrier, handling and storage temperature.
- It is important that inoculant quality be monitored by an independent laboratory and conservative expiration dates be established to protect the interests of users.

Selecting quality inoculants (1)

- Inoculant should contain only rhizobia capable of producing effective nodules Effective inoculants may consist of one or several elite strains.
- Inoculant should provide large numbers of viable rhizobia allowing for application of at least 10,000 bacteria per seed.
- Carrier medium must protect the rhizobia in the package and on the seed. It should be easy to apply and adhere well to the seed.

Selecting quality inoculants (2)

- Inoculant must be free of other bacteria which might be detrimental to rhizobia or to the young legume seedling. Some inoculants contain other beneficial root bacteria..
- Inoculant must be packaged to protect the rhizobia until it is used. The package should allow exchange of gases and retention of moisture.
- The package should provide clear instructions and list the legumes that it effectively nodulates and carry an expiry date beyond which the product cannot be considered dependable.

Inoculant labeling and storage requirements

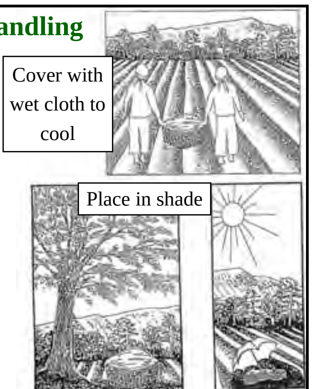
The information required on the legume inoculant package should include:

- Name of the crops for which the inoculant is intended
- Scientific name of the *Rhizobium* species
- Number of live rhizobia per gram
- Expiration date beyond which the product cannot be used
- Lot number for quality control feedback
- Instructions for use
- Net weight of inoculant
- Trade name, manufacturer and address
- Necessary storage conditions

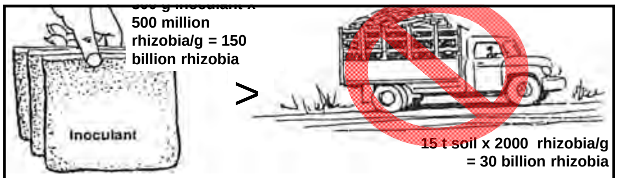
BIOFIX complies closely with industry standards of product labeling

Inoculant storage and handling

Legume inoculants are perishable and quickly lose their effectiveness when exposed to a temperature of 40° C or more. Inoculants retain their effectiveness for six months or longer when stored at a temperature around 20° C. This period can be extended if refrigerated near 4° C but freezing inoculants damages the product.



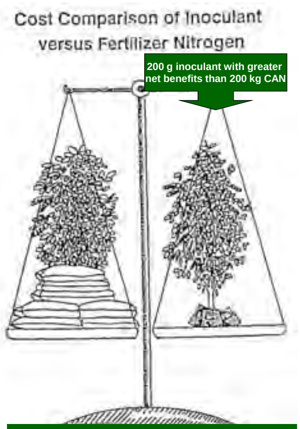
Simple precautions prior to inoculant application and planting protects rhizobia



Transferring rhizobia in soil is inefficient compared to the use of inoculants

- Inoculants contain superior strains of rhizobia, soil does not
- Inoculants contain only rhizobia, soils may also be infested with pests and disease organisms
- Inoculants are light and easily transported, soils are bulky and transport expensive

Note that three 100 gram packages of inoculant contain much more living rhizobia as 15 tons of field soil!



Tipping the scales in favor of BNF

Total BNF = 100 kg N per ha

Cost of inoculants = KSh 200

Cost of sticker = KSh 50

Labor = 1 hour = KSh 75

Total cost = KSh 325

Cost of equivalent fertilizer

100 kg N ≈ 4 bags of CAN

1 bag of CAN = KSh 1800

Cost of fertilizer = KSh 7200

Labor = 6 hours = KSh 450

Total cost = KSh 7650

Benefits from inoculation = 7650/325 = 24-fold benefits!

Sound use of legume inoculants

- **Use the correct inoculant for each legume. Check the label for the legume species you are planting.**
- **Protect inoculant from sun and heat to keep it alive. The ideal storage temperature is between 4º and 26º C.**
- **Store inoculant in tightly closed bags.**
- **Use a sticker when inoculating seeds.**
- **Use the recommended amount of inoculant. Use no less than 5 g per kg of seeds.**
- **Inoculate seeds just before planting.**
- **Apply soil inoculant when the soil is moist or just before irrigation.**
- **Cover the furrows after planting inoculated seeds.**

Some common mistakes in inoculant handling and use

- Exposing inoculants to temperatures above 30 C
- Using inoculants after their expiration date or after they have been exposed to high temperatures.
- Letting inoculants dry out.
- Mixing fertilizer with inoculated seeds.
- Broadcasting inoculants onto dry soil.
- Appling additional inoculant to the surface when the soil is dry.
- Planting commercially prepared, pre-inoculated seeds.

Summary points

- There are many soil conditions which make it necessary to inoculate legume crops to get maximum yields.
- The choice of methods for seed and soil inoculation depends on materials available and climate and soil conditions.
- The proper inoculant must be used with each legume.
- Inoculant contains living organisms which must be protected from heat and sun.
- If inoculant is not stored properly, the number of rhizobia in the inoculant will decline.
- Poor inoculant quality is an important reason that farmers do not get yield increases from inoculation.
- Inoculant production is a process which requires specialized equipment, knowledge and skills.
- Different types of inoculants are produced for various needs.

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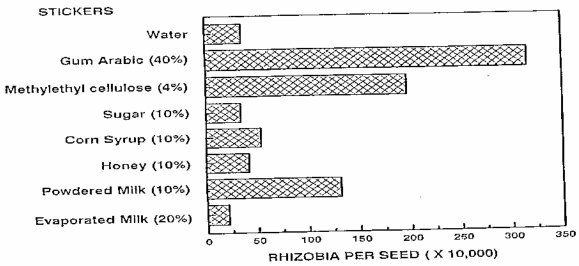
Module 6. Inoculation of legumes with rhizobia

- Slurry inoculation
- Two-step seed inoculation
- Seed coating technologies
- Pellets and other techniques
- Inoculation strategy
- Master farmer advice on inoculation

Sticker materials (adhesives) are recommended to bind the rhizobia to the seed. Different stickers greatly affect the numbers of viable rhizobia on seeds at planting (see diagram). Gum arabic is obtained from the African tree *Acacia senegal* and consistently proves to be the best sticker material



Inoculating legume seeds using the slurry method

Preparing the slurry. For soybean seed, a slurry consisting of 1 part of inoculant and 3 parts sticker is recommended. For larger seeds, the ratio of sticker decreases (e.g. 1:2 for bean) For demonstration and practice of this procedure, only a small amount of seed will be coated. Inoculant and adhesives are mixed together before adding to legume seeds.

Slurry inoculation

- Place 10 kg of soybean seed into a 20 liter bucket
- Add 400 ml of inoculant-adhesive slurry
- Stir the seeds with a wooden spoon until coated
- Spread the seeds onto a canvas to dry
- Conduct inoculation and drying in the shade
- Plant inoculated seeds as soon as possible

Inoculating legume seeds using the slurry method

After *Legume Inoculants and their Use*, 1984. FAO, Rome.

Inoculating seeds using the two-step method

- Place 5 kg of soybean seeds into a plastic bag.
- Add 100 ml of gum arabic sticker
- Inflate the bag and twist it shut
- Shake the bag vigorously for about one minute
- Open the bag and add 50 g of inoculant
- Shake again, but more gently for one minute.
- Immediately after coating, spread the seeds on paper and allow them to dry in a shady place

Too vigorous or prolonged shaking may dislodge the inoculant from the seeds. If seeds are treated with pesticide, be care not to inhale.

The two-step method of seed inoculation

Materials: legume seed, rhizobial inoculant, sticker solution, measuring spoon and plastic bag

① Place seed and adhesive into plastic bag

② Inflate bag and shake for one minute

③ Inspect seeds to assure even coating

④ Place inoculant into plastic bag

⑤ Inflate bag and shake again for one minute

⑥ Place seeds onto clean surface to dry

Close up of soybean seeds inoculated by the two-step method

Different amounts of sticker is required for various legume seed depending upon their size (surface area). More adhesive is required for smaller seed. More adhesive is also required for the slurry method.

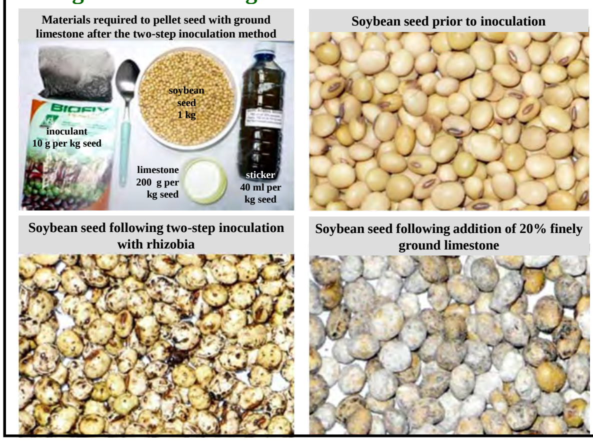
legume seed	seed weight g/seed	--- slurry method --- sticker ml/kg seed	inoculant g/kg seed	-- two-step method -- sticker ml/kg seed	inoculant g/kg seed
soybean	0.14	30	10	20	10
bush bean	0.42	22	10	19	10
climbing bean	0.45	20	10	18	10
groundnut	0.50	18	10	16	10
cowpea	0.14	30	10	20	10

Pelleting limestone after the two step method

Seeds may be pelleted with finely ground limestone or rock phosphate using either the slurry or two-step method. In both cases, the amount of inoculant remains the same (10 g per kg seed) but the amount of adhesive increases by 33% The following describes seed pelleting with limestone using the two-step method.

- Inoculate 5 kg soybeans using the two-step method but use twice (200 ml) the adhesive
- Add one kg of limestone and again shake gently
- Inspect that seeds are uniformly coated
- Spread pelleted seeds on paper or canvas
- Dry under shade
- Plant dried, pelleted seed as soon as possible

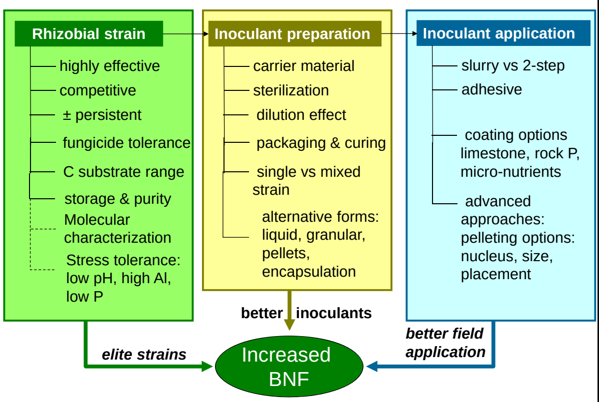
Legume seed coating with inoculant and limestone



Pelleting seed with minerals requires that more adhesive be applied. More minerals may be applied to smaller seeds. Acidic minerals, such as super phosphate or sulfur must not be applied as pellets as these injure rhizobia.

legume seed	seed weight g/seed	---------- two-step pelleting ---------- sticker ml/kg seed	inoculant g/kg seed	coating g/kg seed
soybean	0.14	40	10	200
bush bean	0.42	33	10	160
climbing bean	0.45	30	10	150
groundnut	0.50	25	10	100
cowpea	0.14	40	10	200

The process of inoculant optimization



Discussion Questions: Providing Master Farmer Advice (1 if 3)

Q1. A farmer has stored her inoculant in a small shed for over two weeks. You enter the shed and find that the temperature was above 40°C. ***What recommendation can you give to the farmer?***

Q2. A farmer has told you that in order to save labor and money she is going to apply inoculant to the seed without applying sticker by dusting. ***Provide her the alternatives and discuss the advantages in relation to her concerns about the need to save labor and money.***

Providing Master Farmer Advice (2 of 3)

Q3. A farmer asks you to look at his legume crop. He has inoculated the bean crop but after four weeks there are no nodules. The crop looks healthy. ***What questions should you ask this farmer to determine why the bean crop is affected by inadequate inoculation?***

Q4. A farmer tells you she doesn't think inoculation is necessary because she inoculated cowpeas last year and the yield was not improved. This year, she is planting soybeans this year in the same field. ***Provide her with reasons why she did not increase cowpea yield with inoculation last year and why she should inoculate soybeans this season.***

Providing Master Farmer Advice (3 of 3)

Q5. A farmer was unable to plant his legume seed as planned because of delayed rains. He inoculated his seed and has now stored the seed for more than two weeks. ***Provide the farmer with some useful advice on how to plant this seed.***

Q6. Identify a cereal-legume cropping system with potential in your area and develop a set of inoculation and crop residue recommendations for farmers. Take into account the entire farming system, climate, soil conditions, crop management and choice of crop species and varieties. ***Recommend inoculation rates and methods, considering the availability of local materials, resources, and past experience of the farmers.***

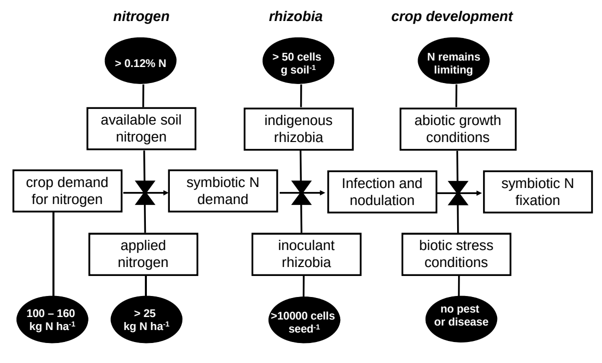
N2Africa Master Farmer Training

Module 7. The response to legume inoculation

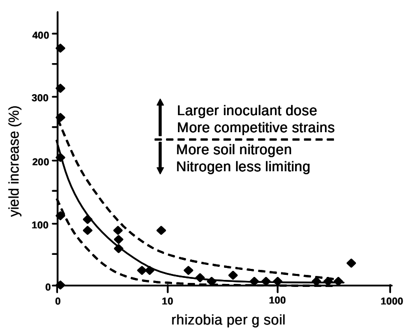
- Assessing root nodulation
- Assessing response to inoculation
- The role of available nitrogen
- The role of native rhizobia
- Economic gains through BNF

Inoculation response in young soybean (above) and older groundnut (below)

Root nodulation and BNF are controlled by available soil nitrogen, the number of effective rhizobia and overall crop development



The population size of indigenous rhizobia affects observed inoculation response



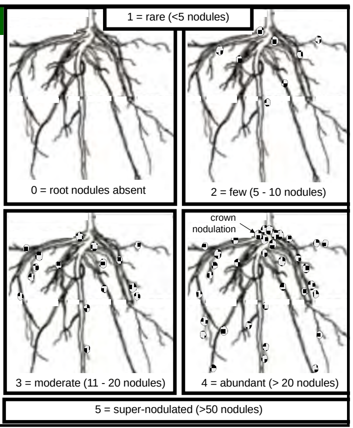
Between 50 and 300 native rhizobia per gram of soil may act as a barrier to inoculation response.

Inoculation strategies involving larger doses and more competitive rhizobia can partially overcome native rhizobia.

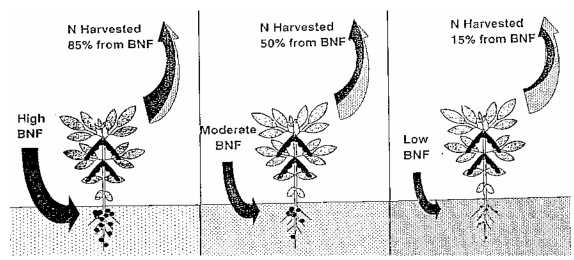
Inoculation response is greatly reduced in soils with high available nitrogen.

Assessing Root Nodulation

The amount of BNF is related to the biomass effectiveness of root nodules but these measurements are time consuming and difficult to measure in the field. An alternative approach is to rank root nodulation based upon the number and distribution of nodules on the root system. One such system classifies root nodulation as **absent, rare, few, moderate, abundant** and **very abundant** (or super-nodulated). With some experience, Master Farmers can quickly assess root nodulation.



Root nodulation and BNF are strongly affected by the availability of nitrogen in the soil



low soil N
abundant nodules

moderate soil N
diffuse nodules

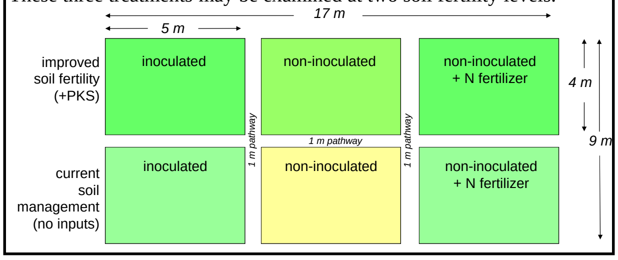
high soil N
few nodules

Field test of inoculation response

When the situation is not known, a field test to determine the need for inoculation is recommended. Three basic treatments are needed:

- Inoculated plants with the best inoculant available.
- Non-inoculated plants receiving no fertilizer treatment.
- Non-inoculated plants furnished with fertilizer nitrogen

These three treatments may be examined at two soil fertility levels.



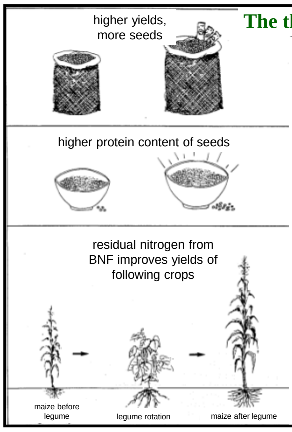
Explanations for field situations in farmers' BNF technology tests: Non-inoculated fields

Situation	Explanation
No nodules on non-inoculated control. Plants yellow.	**No native rhizobia capable of infecting that legume.**
Many small nodules scattered over root system. Plants yellow.	**Native rhizobia are ineffective in fixing nitrogen.**
No nodules on non-inoculated control. Plants green.	**Soil high in mineral nitrogen. No native rhizobia capable of nodulating that legume.**
Small nodules on non-inoculated control. Plants deep green.	**Soil high in mineral nitrogen. Native rhizobia may be affective or ineffective.**
Non-inoculated control plants have numerous large nodules. Plants deep green in color.	**Native rhizobia infective and effective. Inoculation is not necessary.**

Explanations for field situations in farmers' BNF technology tests: Inoculated fields

Situation	Explanation
Inoculated plants have no nodules. Plants yellow.	**Improper inoculant used or rhizobia in inoculant is dead**
Inoculated plants have small nodules and deep green color.	**Soil high in mineral nitrogen. Nodules not operating.**
Inoculated plants have large nodules, red on the inside. Plants deep green.	**Native rhizobia ineffective. Inoculant highly effective.**
Inoculated + nitrogen –plants larger and greener than those receiving only inoculant.	**Rhizobia not adequate. Need more effective strains or larger dose.**
Inoculated plants receiving phosphorus and potassium are more vigorous than non-fertilized plants from inoculated plots.	**Soil low in phosphorus and potassium. Needs fertilizer for maximum nitrogen fixation.**

The three benefits of managing BNF



Higher grain legume yields are achieved without the need for costly nitrogen fertilizers (soybean +120%, bean +200%)

Legume grains contain more protein (soybean +0.5%, bean +0.2%) resulting in improved household nutrition and higher prices

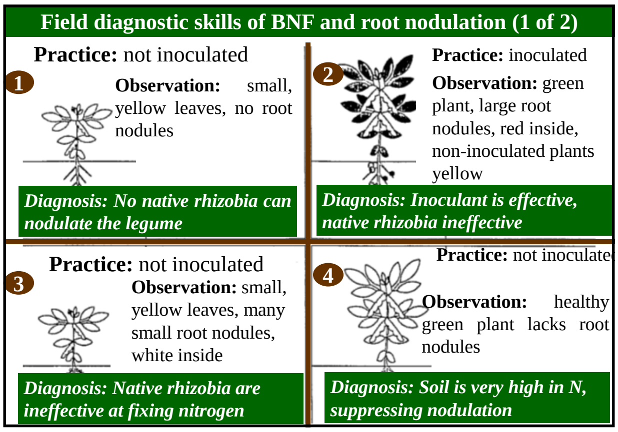
Residual nitrogen substitutes for N fertilizer (soybean +23 kg N/ha, bean +12 kg N/ha) resulting in savings and higher yields of rotational crops (soybean-maize +590 kg maize/ha worth KSh 8600).

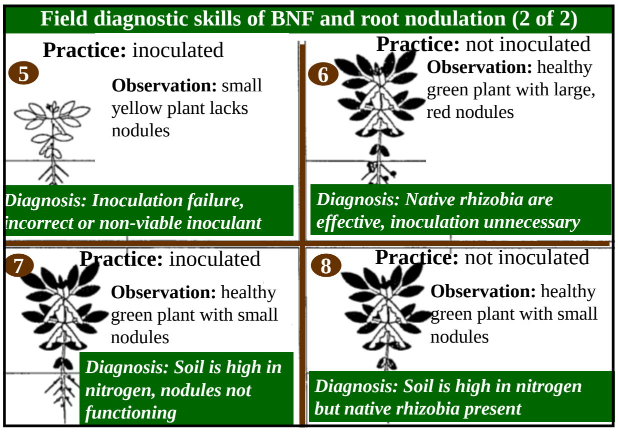
Projected economic gains through BNF by soybean and bean including residual benefits

Summary by Crop	Soybean	Bush bean
Current crop yield (kg/ha)	1,082	527
Additional legume yield (kg/ha)	1,298	1,065
Net value of increased production (KSh/ha)	51,920	28,400
Increase residual N (kg/ha)	23	12
Fertilizer equivalent value (KSh/ha)	3,036	1,584
Maize yield increase (kg/ha)	552	288
Increased maize value (KSh/ha)	8,587	4,480
Total value of increased BNF (KSh/ha)	63,543	34,464

Inoculation can increase the protein content of seed even if there is no increase in seed yield. This occurs when grain develop with a continuous supply of symbiotic nitrogen. The protein content of soybean seed may increase by 3.2%, improving its nutritional value and price (see table below).

legume grain	without inoculant	inoculant applied	increased N
	------- % N in seed ---------		--- % ---
soybean	5.7	6.2	8
bush bean	2.8	3.0	7
cowpea	3.9	4.2	7





Key concepts

- There are three component benefits from BNF, higher yields of grain legumes, improved protein content of seed and fertilizer savings through residual N.
- Rhizobium inoculants perform when their legume crops have insufficient soil N to meet the crop's requirements. Nitrogen, and not another requirement for growth, must be limiting growth.
- BNF performs best under improved crop management.
- Native rhizobia that are highly infective reduce the benefits of inoculation. It these native rhizobia are effective, then inoculation is unnecessary. If they are ineffective then higher doses of inoculant are necessary.

N2Africa Master Farmer Training

Module 8. Grain legume enterprise in small-scale farming

- Increasing nitrogen fixation by legumes
- Grain legume production strategies: intercropping, rotation, relay cropping
- Legumes and Conservation Agriculture
- Post harvest handling of grain legumes
- Legume marketing and sales
- Value-added processing of grain legumes

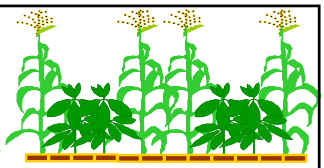
How to increase the inputs from Biological Nitrogen Fixation

- Increase the area of land cropped with legumes (targeting of technologies)
- Increase legume productivity through better management and fertilizer
- Select better legume varieties
- Select better rhizobium strains and inoculate
- Link to markets and create new enterprises to increase demand for legumes

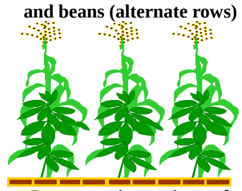
Grain legume production strategies: intercropping

- Simple innovations in maize-legume intercropping permit farmers to grow a wider range of food legumes as under-storey intercrops with cereals.
- The most common intercropping practice is to alternate maize and bush beans or cowpeas, either between or within rows. These legumes mature quickly and can tolerate shading, but yields are low.
- Alternatively, cereals may be planted at their recommended population, but every-other row is shifted to provide a wider alternate inter-row to the legume or strip-cropped by lowering maize populations but maintaining similar yields.

Traditional intercropping of maize and beans (alternate rows)



Staggered intercropping of maize and beans (MBILI)



Intercropping maize and climbing legumes

Intercropping cassava and grain legumes

Grain legume production strategies: intercropping

- Different approaches permit more productive intercropping with groundnut, green gram, soybean and other higher-value food legumes that are not otherwise intercropped with maize because of excessive shading
- Intercropping also permits cultivation of legumes that suppress *Striga* such as *Lablab* and *Desmodium*
- Another useful example of intercropping is upland rice and soybean where soybean reduced bird damage to rice.
- When maize and pigeon pea are intercropped, maize is harvested first and pigeon pea grows for several more months, producing a complete canopy cover and yields of up to 1.5 t ha^{-1}.

Grain legume production strategies: intercropping

Conventional maize-bean, (upper left), upland rice-soybean (upper right), MBILI with groundnut (lower right), out of control lablab with maize (lower left)

Grain legume production strategies: rotation

- Legumes may be grown in rotation with other crops one in three or four seasons (e.g. L-M-M-M-L-M-MM) in monomodal climates or every other season in bimodal rainfall conditions (M-L-M-L)
- Cereal-legume rotation replenishes soil nutrients and improves the availability of organic resources, particularly when legume varieties have traits appreciated by farmers.
- Strong commercial demand for legumes further justifies targeted investment into crop rotation.

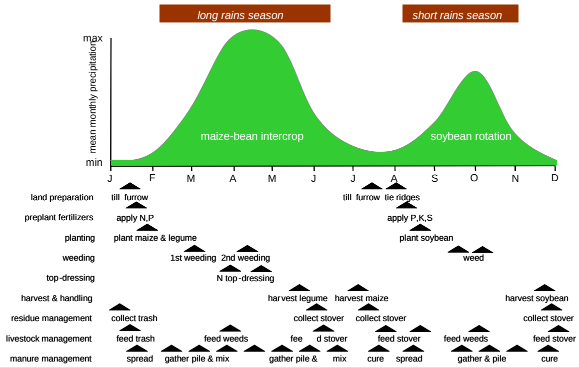
Grain legume production strategies: rotation

- Promiscuous soybean and the dual-purpose cowpea lines available to farmers in West Africa produce about 2.5 t of grain, 2.5 to 4 t of forage, fix between 44 and 103 kg N and have a positive N balance of 43 kg N ha–1. Growing maize after soybean improves grain yield 2.5-fold.
- Legume rotations may be intercropped at both stages, such as maize-cowpea followed by groundnut-pigeonpea
- Widespread adoption of cereal-legume rotation is supported through farmer collective action, development of underlying value-added cottage industries, product development and branding, information exchange and development of rural savings and banking systems

Grain legume production strategies: rotation

Climbing beans in Rwanda (upper left), soybean in Nigeria (upper right), pigeonpea-groundnut in Malawi, (lower right), Striga Smother in Kenya (lower left)

Field operations of a maize-legume rotation integrated with livestock operations in a climate with bimodal rainfall



Grain legume production strategies: relay cropping

Relay cropping involves planting a crop into the same land where another is already established

Relay cropping is a viable strategy in intercropping where one crop is shorter duration than the other and is replaced after harvest with another crop

Maize-bean intercropping may be relayed after beans are harvested by planting a green manure or root crop, as maize dries the relay crop's canopy closes (above)

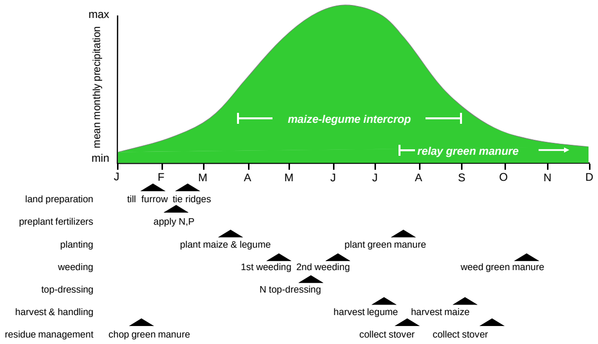
Grain legume production strategies: relay cropping

A second crop of beans may also be planted but this risks pest and disease. Note how the dried lower leaves of maize were removed (lower right)

In non-humid areas, relay crops must be drought resistant so they continue to develop into the dry season

Pigeon pea is a useful relay crop that may persist throughout the dry season

Field operations of a maize-legume intercrop with green manure relay



Grain legume production strategies: Phosphorus and liming

no amendments **+ lime and P**

(0.5 t/ha) (12.5 kg/ha)

Soyabean grown on sandy or highly weathered soils often require inputs of lime and phosphorus before nitrogen becomes limiting and BNF may proceed

Legumes in Conservation Agriculture

Conservation Agriculture is a recent and evolving concept to land management that seeks to optimize crop yields and farm profits in a manner that balances economic and environmental benefits

Advocates of Conservation Agriculture maintain that intensive soil tillage is unnecessary and ill-planned because it leads to soil degradation and loss of crop productivity.

Conservation Agriculture is built around 1) avoiding soil tillage, 2) maintaining soil cover and retaining crop residues, 3) practicing crop rotations and 4) precision placement of inputs

Symbiotic legumes are important in crop sequences because of their nitrogen contribution to the soil

Proponents argue that adoption of Conservation Agriculture brings direct financial rewards to farmers and broader community and environmental benefits

Legumes in Conservation Agriculture

Legume	Role (s)	Drought resistance	Weed suppression	Shade tolerance	Potential BNF	Food/feed value	Comments
Soybean *Glycine max*	rotation	moderate	moderate	low	high	high/ high	Rhizobia specific & promiscuous types
Lablab *L. purpureus*	rotation/ relay	high	high	moderate	high	high/ high	Use trailing, rust resistant types
Groundnut *Arachis hypogaea*	rotation/ intercrop	high	low	moderate	moderate	high/ high	Bunch & runner types, use rosette resistant types
Common bean *Phaseolus vulgaris*	rotation/ intercrop	low	low	high	low	high/ moderate	Bush & climbing types, many pests
Cowpea *Vigna unguiculata*	rotation/ intercrop	low to moderate	low	moderate	moderate	high/ moderate	Bush, trailing & climbing types
Pigeon pea *Cajanus cajan*	rotation/ relay	high	low	low	high	high/ high	Shrub & dwarf types
Mucuna *Mucuna spp.*	cover crop	moderate	high	low	high	none	Extremely vigorous & competitive
Tephrosia *Tephrosia spp.*	improved fallow	high	low	low	high	none	Produces rotenone insecticide

About five years (or growing seasons) of no-till conservation practices are required before soil properties improve through continuous no-till and full stubble and residue retention and 20 years are required to obtain full benefits

Intensive tillage	Phase of Conservation Agriculture (years or seasons)		
Soil properties	Adoption (0 to 5 years)	Consolidation (5 to 20 years)	Maintenance (>20 years)
Physical disaggregation	Some micro-aggregate formation	Macro-aggregate formation	Diverse, stable soil aggregates
No surface cover	Seasonal stubble and residues	Year-round litter layer forms	Organic surface horizon established
Reduced SOM	SOM loss is arrested	Steady increase in SOM	Stabilized SOM and organic recycling
Reduced soil biological activity	Microbial biomass increases	Macrofaunal services restored	Soil biodiversity and biological processes restored

Constraints to Conservation Agriculture by smallholders

- Adoption requires long-term planning and commitment to resource protection
- High demand exist for crop residues within the household
- Difficult to maintain continuous soil cover
- Termites consume surface mulch within weeks and then turn on crops
- Other animals in surface litter are not necessarily beneficial
- Some community by-laws protect the rights of stubble grazing
- New skills and tools are required in fertility and weed management
- Specialized equipment must be purchased and maintained.
- Waterlogging of no-till soils is a problem in humid areas.
- Greater hand weeding workload placed upon women

The disadvantages appear to outweigh the advantages. Need exists an African-style Conservation Agriculture.

Post harvest handling of grain legumes

Post-harvest handling assures that grain legumes provide quality food and meet buyers' standards

Excess moisture predisposes to dangerous fungi (mycotoxins)

Tradeoff between field drying and shatter loss during harvesting

Drying on ground collects foreign materials and stones damage mills

Field and storage pests may damage or destroy the crop

Mixed colored grains lower the market value

Grain quality indicators

Pest damage
Disease and discolored grains
Broken grains
Mixed or off color grains
Foreign materials

Post harvest handling tools are essential to meeting legume grain industry standards

Legume marketing and sales

Grain legumes may be sold to top-end buyers in bulk, local institutions in bags or in local markets (right top and bottom).

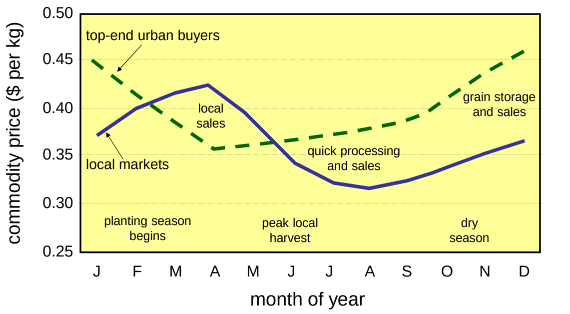
Beans, cowpea, green gram and pigeonpea marketed in 90 kg bags, groundnut marketed in 110 kg bags.

Active cross-boarder trade in grain legumes with Uganda importing to Kenya. Kenyan farmers have an advantage to substitute these imports

RPK demonstrated that beans may be locally marketed in 5 kg bags

Grain legume sales at a local market (above) and meeting forward contracts through collection points and delivery by railroad (below).

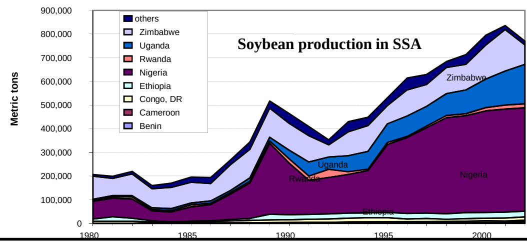
Commodity price trends must be considered in developing a marketing strategy



Actions are best timed to price fluctuation throughout the year

Huge potential for production and marketing of soybean

- Nigeria is largest African soybean producer, (47%). South Africa has the largest market (85% of SSA imports).
- 1.6 m tons in soybean is imported for animal feed
- Food food relief programs import soybean for protein fortification
- Kenya imports more than 30,000 tons of soybean per year, half of that from Uganda, for animal feeds and protein fortification



Value-added processing of grain legumes

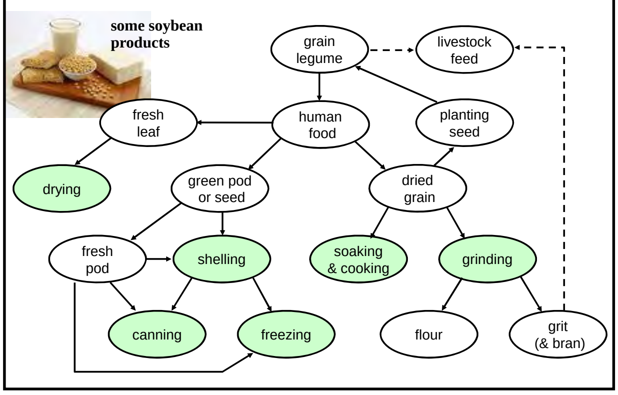
Different legumes have various options for value added processing. Soybean may be processed into numerous products.

Milling is a first step to producing many value added products, costs about KSh 5 per kg and adds about KSh 15 value.

Preparation of chicken and dairy feeds another value addition option. Chicken feed contains about 1/3 coarsely ground soybean

Pressing soymilk from boiled soybeans. Soymilk greatly improved child nutrition and its production is a viable cottage industry.

Marketing and value-added processing of grain legumes



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Processing food legumes

- Fresh or dried leaves of cowpea or bean may be steamed or boiled
- Wilting and drying picked leaves greatly reduces their perishability.
- Immature green pods of many legumes may be cooked
- Pods are also processed by canning and freezing.
- Full-sized, immature green seeds are shelled and then cooked or processed.
- Dried grain can be either soaked and cooked, or ground into flour and grit.
- Legume flour is often combined with cereal flour to increase its protein content.
- Oilseed is pressed, particularly groundnut and soybeam, resulting in vegetable oil and press cake.
- Soybean is processed into crunchies (boiled, fried), soy sauce, nato, tofu, tempeh and noodles.

Key concepts

- Several options are available to increase BNF through grain legume enterprise
- Grain legumes may be cultivated as intercrops, in rotation or as relay crops
- Grain legumes often require inputs of P, lime or other nutrients to be fully productive
- Conservation agriculture relies upon legumes and BNF but is difficult to practice in non-mechanized, mixed farming
- Post-harvest handling requires to use of simple tools that improves food quality and allows grain to meet industry standards
- Expanding legume markets stimulates investment in seed, fertilizer and other farm inputs
- Many processing options are available to add value to grain legumes that are well suited to cottage industry

N2Africa Master Farmer Training

Module 9. Mobilizing communities toward better utilization of BNF technologies

- Community extension: The Master Farmer concept
- Participatory Research and Extension (PRAE)
- Working with agricultural researchers
- Acquiring information and accessing BNF technologies
- Organizing field demonstrations and farmer field days
- Empowering women through legume enterprise
- Stimulating farmer-to-farmer technology transfer
- Organizing collective marketing actions
- Conducting community-based seed production

The Master Farmer serves as

- **An example** of improved farming to group members and the wider community
- **A catalyst** that encourages farmers to change non-productive farming practices
- **An advisor** that strengthens group organizational and planning capacities.
- **A trainer** in basic technical skills of improved farming.
- **A linkage** between the farmers' group and rural development efforts.

Master farmers must visit individual farms, including the poorest households, to better understanding their needs and opportunities

Participatory Research and Extension (PRAE)

PRAE involves farmers and their local organizations in all stages of research and development; defining research agendas and protocols, conducting field operations, evaluating results and disseminating important findings.

Ensures that local technical knowledge is utilized as appropriate

Motivates farmer participation and opens them to new ideas

Allows technologies to be better compared and adapted to local conditions

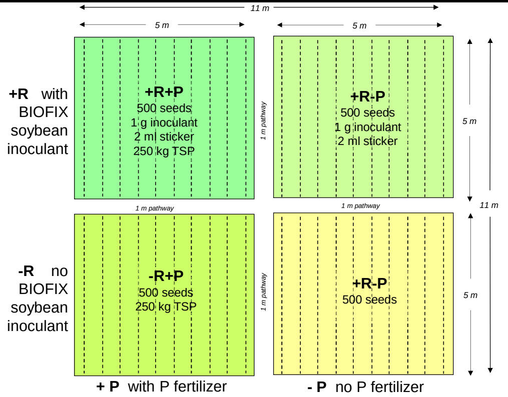
Empowers farmers as diagnostic problem-solvers in the future

Stimulates farmer-to-farmer exchanges and technology dissemination

Changes from conventional to participatory agricultural extension

Conventional Approach	Participatory Approach
Telling farmers what to do	Discussing ideas with farmers
Forcing agricultural change within rural agendas	Working with farmers for change
Supervisors know best	Learning from farmers
Modern methods are always best	Traditional knowledge has value
Disseminating top-down recommendations	Providing feed-back to communities
Use of contact farmers and isolated demonstrations	Promoting farmer-to-farmer exchange

Partner	Role change (*from ... to*)	Contribution
Farmers	*from* passive recipients *to* active participants	direct knowledge of local farming opportunities and ultimate success indicators
Master farmers and grassroots officials	*from* overlooked asset *to* key development partner	community liaison and pilot technology adoption
Extension agents	*from* top-down recommendations *to* facilitating farming options	information, training and group facilitation skills
Agricultural researchers	*from* detached observation *to* interactive problem solving	knowledge of mechanisms and technical options
Private sector interests	*from* seeking easy profits *to* providing producers with quality inputs and fair markets	providing product information, input recommendations and market prices
NGOs	*from* organizing top-down campaigns *to* facilitating participatory actions	project management, resource acquisition and group liaison skills, training of trainers
Local government	*from* political expediency and opportunism *to* community service	access to public resources and advancing supportive policies
Donors	*from* project-to-project operations and hidden agendas *to* supporting longer-term rural development	guidance on development agendas and funds for rural development actions



A simple 2x2 experimental design for on-farm testing of inoculants and fertilizer by Master Farmers

Guidelines for successful collaboration between farmers belonging to self-help groups and researchers conducting on-farm studies (1)

Cooperating farmers should

- Make their own observations concerning field trials and express them at group meetings and to research partners
- Organize local field days that demonstrate the tested technologies to their communities
- Make a genuine effort to understand the scientific basis for treatment selection and sampling procedures so that promising results can become adapted into farm practice

Guidelines for successful collaboration between farmers belonging to self-help groups and researchers conducting on-farm studies (2)

Cooperating farmers should not

- Falsify data collection records, disguise experimental failures or exaggerate claims for compensation
- Remove crop harvests without the knowledge and agreement of research partners
- Expect researchers to engage in lengthy social interactions during intensive field campaigns

Guidelines for successful collaboration between farmers belonging to self-help groups and researchers conducting on-farm studies (3).

Researchers should

- Involve cooperating groups and farmers in an earlier stage of research planning
- Rely upon simplified experimental designs and relatively few treatments and explain which treatments are intended as candidate improved technologies
- Establish a clear timetable and division of responsibility for field operations, data collection and recordkeeping
- Interpret their research findings into terms understandable by client farmers, particularly their costs and returns
- Be prepared to modestly compensate cooperators for their efforts and harvest removal
- Encourage farmers to conduct their own satellite experiments adjacent to the field trials

Guidelines for successful collaboration between farmers belonging to self-help groups and researchers conducting on-farm studies (4)

Researchers should not

- Perform unplanned on-farm field operations without the knowledge and consent of cooperators
- Fail to keep appointments or rearrange schedules without consulting cooperators
- Ignore collaborator's impressions of different management practices, particularly unrealistic reliance upon additional labor, land or expenses
- Exclude acknowledgement of community groups and key individuals within their publications

Farmer Associations

Farmer associations (FAs) form to access information, learn new technologies and pool limited resources

Need for FAs related to weak of formal extension services

Willingness of farmers to assist one another is a comforting feature of rural life.

Planning group activities is primarily the responsibility of the group's officials and committees

Poor planning results in activities that are not cost effective or fail to achieve significant impacts as anticipated.

Regular meetings promote group cohesion and continuity

Regular elections provide opportunity to members to confirm their support for group leaders.

Transparent handling of finances and operations is necessary

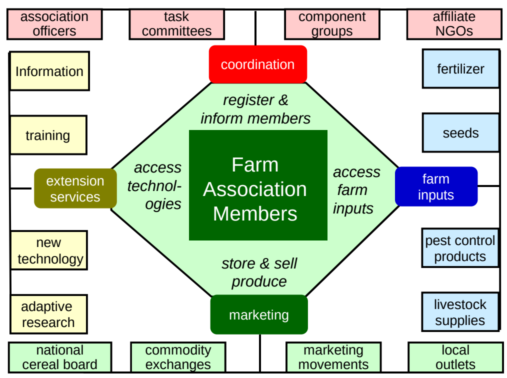
Treasurers must be familiar with standard accounting procedures

Establishment of working groups inspires greater participation

Balanced roles among men and women maintains group cohesion and recruitment

The social dimension of a group's activities must not be overlooked

Operations of an empowered farmer association: focus upon services to members



Acquiring information and accessing BNF technologies

Information. Visit the *N2Africa.net website*. Make your information needs available to local extension officers and agri-dealers. *Develop a local library.*

Improved legume seed. Legume seed is not readily licensed by seed companies but some varieties available from Kenya Seed Co., Western Seed Co.(Kitale) and Lelvet Seed (Nakuru). *Initiate community-based seed production.*

Inoculants. Commercial suppliers are best. BIOFIX is produced by MEA in Nakuru (telephone 020-4453701; website info@mea.co.ke). *Promote the 2-step method.*

Sticker. Gum arabic is the best sticker when used as a 20% to 40% solution. It is included within BIOFIX. Sugar solution is a poorer alternative. *Mix stickers immediately before using.*

Technologies. N2Africa will expand every year until 2013 bringing new BNF and grain legume technologies to west Kenya. *Test and refine new legume enterprise technologies.*

Farmer Field Days

Field days conducted by farmer associations are a means to spread important messages to both members and the larger community.

They also have a strong social component where farmers celebrate their efforts, the community socializes, local entertainers may be invited to perform.

A single field day can target many client groups: farmers, educators and students, local agri-business, neighboring farmer organizations, local government and sponsors.

WeRATE field days for STEP long rains 2009

Organization	Location	Attendance
Hagonglo	Hagonglo	381
	Siaya	241
	Kisumu-West	189
	Rarieda	233
CYEEP	Shikulu	240
	Mutaho	468
	Lurambi	396
BUSSFFO	Bumula	271
RASCOBAP	Seme West	978
ARDAP	Lugulu	479
RPK	Emuhaya	257
SASFA	Izava North	285
Nambale FU	Nambale	276
Butula FU	Bujumba	300
	Tingolo	284
Total	15 field days	5278

Organizing an effective field day

- ☑ **Form an organizing committee to plan activities and seek participation and funds**
- ☑ **Plan and announce the venue well in advance**
- ☑ **Build the field day around field demonstrations and exhibits**
- ☑ **Conduct field day at a centrally located location**
- ☑ **Solicit outside participation from schools, business, local extension, etc.**
- ☑ **Post legible signs to alert and guide the public**
- ☑ **Arrange for snacks and entertainment but full lunch at larger events may be too much**
- ☑ **Consider including a walking tour of neighboring farms**
- ☑ **Arrange tables for exhibitors**
- ☑ **Post signs and informed members to describe field demonstrations**

Group discussions and entertainment (above) should be balanced with exhibits and field demonstrations (below).

Some common errors

Do not conduct continuous entertainment or MC chatter as this detracts from technical information

Do not delay the opening of the field day because of late arriving dignitaries

Do not allow association officers or local politicians to dominate proceedings, give credit where it is due

Do not detract from important, planned technical messages, arrange specific times to display demonstrations and exhibits

Sometimes smaller is better. A field day can be held for members only and combined with an association general meeting.

Sponsor grain legume cooking contests

Conduct contest during farmer field days or agricultural shows

Arrange for participation in advance and select a variety of entries

Establish and distribute rules

Compile recipes for addition to a project cook book

Start cooking early so that entries are ready at the height of the field day

Attracts many interested observers who sample entries

Entries are judged and modest prizes awarded

Stimulates household interest in new legume crops and varieties

Potential to improve diets and diversify production

Cooking contest participants are provided a work space and fire but are expected to bring all vessels, utensils and ingredients

Suggested rules of a Grain Legume Cooking Contest

1. Entries must primarily consist of locally-produced grain legumes and vegetables that are boiled, fried or steamed and must be prepared start-to-finish within three hours using no more than two cooking vessels.
2. Grain legumes may be pre-soaked but not pre-cooked.
3. Each contestant is provided similar cooking facilities but must supply their own pot, utensils and ingredients.
4. Only one entry is allowed per participant in a single contest. Every entry must be accompanied by a list of ingredients and recipe and will be judged shortly after preparation in the presence of the contestant.
5. The following ingredients are strictly forbidden; meat, fish, cheese, canned products, noodles, arrowroot corms and cassava roots (due to the lengthy cooking time necessary to detoxify). Cooking fat from animals may be used at the contestant's discretion. Use of grain legume products such as soymilk or flour is encouraged.
6. Entries are permitted the use of non-indigenous plants, herbs and spices, but excess dependence upon non-traditional ingredients will be penalized during judging.
7. There are three judges, including a head judge, drawn from the scientific, academic or epicurean communities who evaluate the entries on the basis of taste, texture, presentation and any other criteria they deem important.
8. Contestants may be called upon to sample their own entries before judging, and the judges may ask questions of contestants concerning the preparation of the entry. The decision of the judges is final.

Large impacts achieved by addressing women's interests

Distribute input samples for women's enterprises, stimulating new enterprise and demand for inputs

Package fertilizer into smaller quantities to become more affordable to women farmers and poorer households

Expand women's rights to intercrops including nitrogen-fixing grain legumes (women own the understorey)

Promote small animal enterprise and access to manures

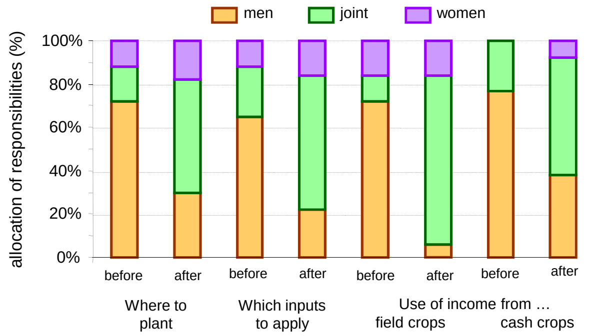
Offer special incentives through women's groups or chapters, engage them in field day events

Introduce labour saving technologies and transport options

Promote the importance of joint decision making in farm planning

Train and recruit more women as association officers and service providers

The effect of rural enterprise development on household decision making over three years (after Kaaria *et al.* 2008)



transformation from traditional farming to market-oriented agriculture is having a large effect upon gender roles within rural households

Gender equality has four steps

Empowerment brings knowledge and skills to the community, allowing women to explore new ways of farming and caring for their families.

Engagement encourages women to build mutual support and assures gender balance within community development actions.

Enhancement applies new skills among women seeking household gains, particularly towards income generation and improved nutrition and health.

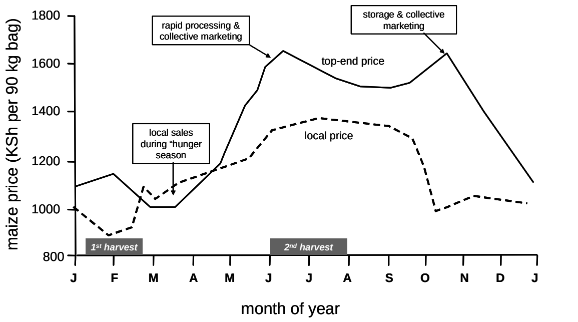
Emergence moves women toward social and political action that reinforces their gains and transforms social and cultural values that constrain the wellbeing of their families.

Steps in conducting collective marketing

☑Receive mandate from members
☑Identify commodity targets and potential buyers
☑Develop accounting and payment mechanisms
☑Appoint a sales representative
☑Establish industry standards of buyers
☑Adopt protocols and tools for quality control
☑Identify collection points and transportation
☑Establish short-term storage facilities
☑Arrange forward contracts
☑Deliver commodity to buyer or market
☑Reimburse members and report activities

Collective marketing requires compliance with industry standards by all members. Use of post-harvest tools and procedures assures quality control.

Understanding local and top-end price trends throughout the year



Master farmers and association officers should maintain a record of commodity prices throughout the year and use this information to develop storage and sales strategies

Community-based seed production of grain legumes

Many improved grain legume varieties are now in Kenya including promiscupus soybean (SB19 and SB20), climbing bean (Tamu and Mavuno), bush bean (New Rosecoco, KK series), Lablab cv. Rongai, Golden Gram, rosette resistant groundnut (CG3) and others

Seed companies are very slow to license and market these legumes because they are self pollinating and less profitable than hybrid maize and other seed

Farmer organization have the right to produce seed for their members as long as the seed are not marketed through commercial channels

One disadvantage of local seed production is the lack of expertise in seed treatment, storage and quality assurance

Master Farmers can lead community-based seed production efforts within their organizations

This production may be centralized (on a few larger fields) or conducted by many farmers on smaller plots, alternate fields to reduce build up of pests and diseases

Steps in community-based seed production

- ☑ **Identify needed legumes and seek farmer participation *(form seed production committee)***
- ☑ **Establish seed sharing and reimbursement policy *(N2Africa can help)***
- ☑ **Identify best varieties and set seed production targets**
- ☑ **Estimate expected yields and calculate needed land area *[(seed target/expected yield) = needed land area]***
- ☑ **Recruit farmers committed to seed production *(meet total land area needed for seed production targets)***
- ☑ **Acquire seeds *(40 kg per ha)*, fertilizer (2 bags P per ha), inoculant (200 g per ha) and sticker (400 ml per ha)**
- ☑ **Convene meeting of participating farmers to formalize participation and distribute inputs *(farmers sign agreement)***
- ☑ **Inspect seed fields for plant health *(reject infested fields)***
- ☑ **Arrange for bags and seed treatment chemicals *(label bags)***
- ☑ **Collect, inspect, treat and bag legume seed *(report inventory)***
- ☑ **Distribute legume seed among association members in compliance with seed sharing and reimbursement policies**

Key concepts

- ➢ **Master farmers serve as key examples, catalysts, advisors, trainers and linkages for agricultural development**
- ➢ **Participatory Research and Extension provides guidelines for local extension activities**
- ➢ **Master farmers may conduct simple experiments to guide local farming practices**
- ➢ **Services provided by Farmer Associations include access to information, technologies, farm inputs and markets**
- ➢ **Field days are a great way to disseminate technology, recruit new members and build farmer association recognition, but need not be large**
- ➢ **Women's special interests must be addressed within farmer associations and should be directed toward joint decision making rather than segregation of roles**
- ➢ **Gender equity involves empowerment, engagement, enhancement and emergence**
- ➢ **Collective marketing and seed production are two means of expanding services offered to members of farmer associations**

Seed Inoculation: Master Farmer Training Practical

Prepared June 2010 by Paul L Woomer of FORMAT for the N2Africa Project. Based in part upon "Applied BNF Technology", University of Hawaii NIFTAL Project (Singleton *et al.* 1990). Queries and comments may be sent by email to *plwoomer@gmail.com*.

Purpose. To demonstrate the preparation of stickers, methods of coating seeds with inoculant and a seed pelleting technique.

Conceptual Background. Sticker materials are recommended to bind the rhizobia to the seed. The stickers used in the following demonstrations are gum arabic and sugar, and are compared to water. Both of these adhesives must be dissolved in water before use. Two seed coating methods are used. The ***slurry method*** and the ***two-step method***. In the ***slurry method***, inoculant is first mixed with the sticker. The resulting slurry is then applied to the seeds. The ***two-step method*** requires seed coating in two stages. First, the seeds are coated with the sticker. The inoculant is then added and coated onto the sticky seeds. Note that the amounts of sticker used for each method vary with seed size (Table 1) and in this practical soybean seeds are used.

Under certain conditions, it is advisable to ***pellet inoculated seeds*** with a protective layer of powdered calcium carbonate or rock phosphate. This treatment is most commonly done with seeds of pasture legumes, but may also be practiced with grain legumes, particularly where grown in highly weathered and nutrient depleted soils. The pellet is applied after seed coating by either the slurry method or the two-step method. The seeds are rolled in the pelleting material immediately after inoculation while they are still wet and sticky.

Table 1. The amounts of sticker, inoculant and mineral coating required for selected grain legumes.

legume	seed	----- slurry method -----		----- two-step method -----		---------- two-step pelleting ----------		
seed	weight	sticker	inoculant	sticker	inoculant	sticker	inoculant	coating
	g/seed	ml/kg seed	g/kg seed	ml/kg seed	g/kg seed	ml/kg seed	g/kg seed	g/kg seed
soybean	**0.14**	**30**	**10**	**20**	**10**	**40**	**10**	**200**
bush bean	0.42	22	10	19	10	33	10	160
climbing bean	0.45	20	10	18	10	30	10	150
groundnut	0.50	18	10	16	10	25	10	100
cowpea	0.14	30	10	25	10	40	10	200

Materials. The amounts of materials needed should be gauged according to the number of participants in the exercise. The list of materials below is based on 15 to 21 participants divided into three groups.

1. 500 ml bottled water (x9)
2. Tablespoon for measuring (x3)
3. Teaspoon for measuring (x3)
4. Two liter plastic bags (x12)
5. Wooden stirring spoon (x3)
6. Small plastic funnel (x3)
7. Marking pen (x3)
8. Plastic buckets, 3 liter capacity (x3)
9. Plastic bucket, 20 liter capacity with lid
10. Gum Arabic, granular (3 x 200 g)
11. Sugar, granular (3 x 100 g)
12. Agricultural lime (calcium carbonate), finely powdered (3 x 200 g)
13. Soybean inoculant (3 packs x 100 g)
14. Soybean seed (12 kg in 1 kg bags)
15. Paper sheets (x27)

Note that measurements are provided in grams, liters and milliliters. In the field it is more practical to convert these volumes and measurements into more convenient units. One level teaspoon holds five ml of sticker and one heaped teaspoon of inoculant contains five grams. Three teaspoons make one tablespoon.

1. Preparing the sticker

Gum arabic. Heat 500 ml water in plastic containers by placing them in the sun (or on the dashboard of a auto) for 1 hour prior to the demonstration. Open bottle, remove 200 ml of water, add 200 g of gum arabic (or 5 teaspoons) using the plastic funnel and shake until dissolved. Set aside to cool. This procedure results in a 40% gum arabic solution. Mark the plastic bottle as containing gum arabic solution. If the weather is cloudy and cool, it may be necessary to warm the water over a stove to dissolve the gum arabic, and replace it into the plastic bottle using the funnel.

Sugar. Remove about 100 ml of water from a 500 ml water bottle. Add 100 grams of sugar using the plastic funnel. Shake until dissolved. This procedure results in a 20% sugar solution. Mark the plastic bottle as containing sugar solution. It is not necessary to warm the water before dissolving the sugar into it.

2. Inoculating legume seeds using the slurry method

Preparing the slurry._For coating soybean seed, slurry consisting of 1 part of inoculant and 3 parts sticker is recommended. For demonstration and practice of this procedure, only a small amount of seed will be coated. Remove 10 g of BIOFIX inoculant (two heaping teaspoons) from the packet and place it into a 300 ml container. Add 30 ml of water (or two level tablespoons). Mix the inoculant and the water until uniform mixture is achieved

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Slurry inoculation. Place one kg of soybean seeds (about 1200 ml or 2½ 500 ml mugs and place them into the 3 liter bucket. Add 40 ml of the slurry. Stir the seeds with a wooden spoon until they are uniformly coated with the inoculant slurry. After coating, spread the seeds onto clean paper and allow them to dry. Mark the paper sheet as holding a slurry-water preparation. Repeat the seed coating procedure with slurries made from other sticker solutions to achieve the treatments as summarized below:

- 1 kg of soybean seed coated with 40 ml of a slurry prepared by mixing 10 g of BIOFIX inoculant with 30 ml of 40% gum arabic solution. Mark the paper sheet as holding a slurry-gum arabic preparation.
- 1 kg of soybean coated with 10 ml of a slurry prepared by mixing 10 g BIOFIX inoculant with 30 ml of sugar solution. Mark the paper sheet as holding a slurry-sugar solution preparation.

After coating compare the three different slurry preparations, inspect them for evenness of coating and for adhesion quality. The best coating is usually achieved with gum arabic. Sugar should be second best. Water as an adhesive appears good initially but the inoculant tends to flake off the seed after drying. *Conclusion, whenever possible, a gum arabic sticker should be used for seed coating.* The slurry method of legume seed inoculation described in this section is presented in Illustration 1.

Illustration 1. The slurry technique first mixes the inoculant and adhesive and then combines them with the legume seed.

3. Inoculating seeds using the two-step method

Place 1 kg of soybean seeds into a plastic bag. Add 20 ml of water (1 level teaspoon plus 1 level teaspoon). Inflate the bag and twist it shut in such a way that the walls of the bag are rigid. Shake the bag vigorously for about one minute until the seeds are uniformly coated. Open the bag and add 10 g of BIOFIX inoculant (two heaping teaspoons). Close the bag as before and shake again, but more gently for one minute. Note that too vigorous or prolonged shaking may dislodge the inoculant from the seeds. Immediately after coating, spread the seeds on paper and allow them to dry in a shady place. Mark the paper sheet as holding a 2-step-water preparation. Repeat the coating procedure with the following treatments:

- 1 kg of soybean seed wetted with 20 ml of the 40% gum arabic solution and then coat with 10 g of BIOFIX inoculant. Immediately after coating, spread the seeds on paper and allow them to dry in a shady place. Mark the paper sheet as holding a 2-step-gum arabic preparation This procedure is described in Illustration 2.
- 1 kg of soybean seed wetted with 20 ml of 20% sugar solution and then coat with 10 g of BIOFIX inoculant. Immediately after coating, spread the seeds on paper and allow them to dry in a shady place. Mark the paper sheet as holding a 2-step-sugar solution preparation.

There should now be six different preparations of inoculated seed spread on marked paper sheets. Compare the three different two-step inoculated seeds to one another and the slurry inoculations (Table 2). When we compare the two-step and slurry treatments, the seeds from some of the preparations appear darker in color. This indicates that more inoculant was applied to each seed by this method. Rank the six preparations by appearance on a scale of 1 (no inoculant on seed) to 5 (darkest appearance).

Illustration 2. The two-step procedure first combines legume seed and adhesive, and then mixes them with the rhizobial inoculant.

Comment. The two-step method allows for more inoculant to be applied to the seed, especially when gum arabic is employed as an adhesive. If we used for instance, 30 ml of the sticker, we could coat as much as 100 g of inoculant onto 1 kg seeds, which results in 10 million rhizobia per seed if the inoculant contains one billion rhizobia per gram. Such a rate is, however, excessive as it is not cost effective for farmers under normal conditions. To apply more than this amount of sticker is not practical because the seeds would clump if more than 30 ml of sticker per kg of soybean seeds is applied

Table 2. A template for comparing the results of different seed inoculation procedures.

Adhesive	Inoculation procedure	
	Slurry	Two-step
	------------- ranking (1 to 5) ----------------	
Water		
Gum Arabic solution (40%)		
Sugar solution (10%)		

4. Inoculating larger amounts of seed

The upper limit for inoculating seed using plastic bags is about five kg using the two-step method, otherwise the risk of puncturing the bag and spilling seed and inoculant grows too great. A more useful container for larger amounts of seed (e.g. 10 kg batches) is a 20 liter plastic basket with a lid. In this case, place 10 kg of seed into the plastic bucket and add 200

Illustration 3. Seed coating with limestone may be performed following inoculation with rhizobia but requires that additional adhesive be applied.

ml of 40% gum arabic solution. Close the lid and shake for one minute. Open the container and inspect to assure that the seeds are evenly coated, not clumped together and that no sticker is clinging to the walls. Add 100 g of inoculant (or an entire packet of BIOFIX inoculant) and again close the lid. This time shake more gently for one minute, open the lid and inspect seeds for uniformity coating. If coating is not complete, immediately continue shaking for 30 seconds. After coating, spread the seeds out on a clean canvas. After the seeds have dried, place them back into the bucket and store under cool, shaded conditions until sowing as soon as possible. Even larger amounts of seed (e.g. 20 to 40 kg) may be inoculated using a large plastic or canvas sheet, mixing the seed and adhesives and inoculants by rolling.

5. Pelleting Seeds

Pelleting after slurry application. Make a slurry from 40 ml of gum arabic solution and 10 g of inoculant. Place one kg of soybean seeds in a 3 liter plastic bucket and add the slurry. Stir the mixture until uniformly covered. Spread the seeds on a clean paper sheet and add 200 g of finely ground limestone (or rock phosphate). Roll the seeds on the paper sheet until they are evenly pelleted. Spread the seeds across the paper sheet and allow them to dry (see Illustration 3).

Pelleting after the two step method of inoculation. Place one kg of soybean seeds into a plastic bag and add 40 ml of gum arabic sugar sticker. Close bag and shake until the adhesive evenly coats the seed. Add 10 g of inoculant and shake gently for one minute. Open the bag and add 200 g of limestone and again shake gently until all seeds are uniformly coated. Spread pelleted seeds on paper and allow to dry.

Compare the two preparations for evenness of coating, firmness of pellet and amount of calcium carbonate adhering to the seed. Note that to accommodate the pelleting material, more sticker must be applied. Water alone is unsuitable for pelleting because it does not produce a firm, evenly coated pellet.

Amplifying farmer training. Each of the Master Farmers is provided a set of materials and instructions so that they may repeat the inoculation demonstration within their own associations. To do this, a package is prepared that contains the following materials:

1. 500 ml bottled water (x3)
2. Tablespoon for measuring
3. Teaspoon for measuring
4. Two liter plastic bags (x4)
5. Wooden stirring spoon
6. Small plastic funnel
7. Marking pen
8. Plastic bucket, 3 liter capacity
9. Plastic bucket, 20 liter capacity with lid
10. Gum Arabic, granular (200 g)
11. Sugar, granular (100 g)
12. Agricultural lime (calcium carbonate), finely powdered (3 x 200 g)
13. BIOFIX Soybean inoculant (1 package x 100 g)
14. Soybean seed (9 kg in 1 kg bags)
15. Paper sheets (x9)
16. Inoculation protocol

The seed inoculation is conducted as a demonstration by the Master Farmer and records are kept concerning the time, place, number of participants and overall impressions of the training activity. These results are reported to the N2Africa Inoculant Delivery Specialists through the Farm Liaison Officer.