Putting nitrogen fixation to work for smallholder farmers in Africa

Biological Nitrogen Fixation and Grain Legume Enterprise: Guidelines for N2Africa Master Farmers








CIAT-TSBF and FORMAT

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Front cover photographs: top row, left to right, untreated soybean seed, two-step seed inoculation, soybean seed inoculated with rhizobia; middle row, N2Africa demonstration package of BNF technologies, healthy soybean plants, Master Farmer trainers field visit; bottom row, a well-nodulated bean root, farmers receiving a N2Africa demonstration package, improved legume seed and inoculants offered for sale. Photographs by K.E. Giller, S. Koala and P.L. Woomer.

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Prepared for the N2Africa Project by CIAT-TSBF and FORMAT, Nairobi, Kenya
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or visit our website *www.N2Africa.org*

Welcome to N2Africa

This project is *putting nitrogen fixation to work for smallholder farmers in Africa*. It is linking the protein and nitrogen needs of poor African farmers directly to massive atmospheric reserves and providing them with new income-generating crop production enterprises. By increasing production of four grain legumes; bean, soybean, cowpea and groundnut, the project is helping farmers to practice renewable soil fertility management and adopt profitable new farm technologies and value-adding enterprises.

Projected benefits from the N2Africa Project

Project impact	Target
Number of countries	8
Number of households	225,000
Average legume yield	+ 945 kg per ha
Increase in BNF	+ 46 kg N per ha
Household benefits	+ $465 per year

Improving the welfare of farm households by delivering improved grain legume varieties and new biological nitrogen fixation (BNF) technologies throughout sub-Saharan Africa is the ultimate goal of this project. In its first phase, the N2Africa project is working with 225,000 households in eight countries and we invite you to become one of these farmers. This extension manual allows you to better understand the field practices and advantages of improved grain legume production in mixed, smallholder farms so that you can better participate and benefit from your involvement in the N2Africa project.

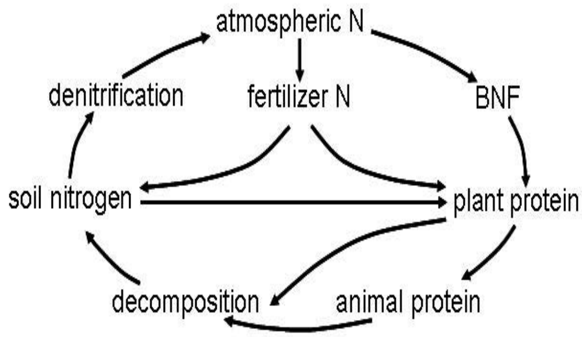
The Master Farmer Concept

The N2Africa project is meeting its technology outreach objectives through empowering a network of Master Farmers. Master Farmers serve as an example of improved farming to neighbors, group members and the wider agricultural community, a catalyst that encourages farmers to change non-productive farming practices, a problem-solver with practical field diagnostic skills, an advisor that strengthens group organizational and planning capacities, a trainer in basic technical skills of improved farming and a linkage between the farmers' group, extension agents and rural development efforts.

Regular feedback from the Master Farmer to the group ensures member involvement in planning and implementation, and encourages further farmer-to-farmer testing, adaptation and adoption. Important additional roles of Master Farmers include assisting local extension agents in developing new group activities and organizing group discussions on the suitability and needed refinement of new farm technologies from one season to the next.

N2Africa Master Farmers have a practical understanding of the management of nitrogen, legumes, rhizobia and biological nitrogen fixation (BNF) including skills in rhizobial inoculant handling and application (see page 17). They design, install and interpret diagnostic tests in farmers' fields and are able to work with other farmers and their organizations to promote grain legume enterprise. Master Farmers visit neighboring farms, including the poorest households, to better understand their needs and opportunities and continue to develop and share their skills as they grow in experience.

Nitrogen on the Farm



A simplified nitrogen cycle where BNF results in a direct pathway from the atmosphere to plants

Most nitrogen (N) resides in the atmosphere in inert form. Biological nitrogen fixation captures that nitrogen for use by soil organisms, plants and animals before it is returned to the atmosphere (see diagram). A key strategy is to recycle N internally within the farm. Successful nitrogen management optimizes inputs, retains crop residues and directs nitrogen losses toward harvest products. N is a vital constituent of protein and protoplasm in plants and animals and necessary for growth and reproduction. The typical N deficiency symptom in plants is yellowing (chlorosis) of the lower leaves. Under extreme deficiency, leaves are pale, fall prematurely, affected plants are stunted and yields are extremely low. Grain legumes offer an excellent source of proteins essential to human nutrition, typically yielding less than cereals and root crops but their protein content is much greater.

The nitrogen reserve of agricultural soils must be replenished regularly in order to maintain crop production. Major causes of N deficiency include insufficient N in the soil solution, leaching, waterlogging and plant competition for limited N reserves. Remedial measures include improved drainage of waterlogged fields, weeding to eliminate competition and liming to adjust the pH. Replacement of soil N is accomplished by the addition of inorganic fertilizers and by biological nitrogen fixation (BNF). Mineral nitrogen fertilizers are produced industrially by chemically fixing N_2 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. In contrast, 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

Biological Nitrogen Fixation

Some bacteria convert atmospheric N to ammonia in a process called biological nitrogen fixation (BNF). In the rhizobium-legume symbiosis, rhizobium bacteria provide the plant with fixed N needed for its growth. BNF is an inexpensive, renewable resource option for smallholder farmers, permitting them to redirect limited farm investment toward other pressing household needs. There are four ways to increase nitrogen fixation on the farm; 1) increase the area of land cropped with legumes, 2) increase legume productivity through better management and fertilizer, 3) grow more productive legume varieties, and 4) inoculate legume seed with rhizobium inoculants. Farmers should not choose only one of these options, but rather practice as many as possible. Another indirect means of increasing BNF is equally important. Better linkage to markets increases profits, allowing farmers to better invest in legume enterprise and BNF.

Root Nodules and the Legume-Rhizobium Symbiosis

One characteristic of tropical food legumes, including bean, cowpea, groundnut and soybean, is their association with rhizobium bacteria to form root nodules, the site of BNF. Root nodules may be spherical, elongate or branched depending upon the host legume (Figure 1). Larger nodules with red interiors usually fix more nitrogen. Various legumes show preference for certain rhizobia, assigning these bacteria to different **cross-inoculation groups** according to the legumes they nodulate. Some legumes are promiscuous, nodulating with many different rhizobia, others have specific requirements. Specific hosts are more likely to respond to inoculation with rhizobia.

Nodulation of legumes by rhizobia involves a complex process of biochemical recognition, infection, nodule formation, N transformation and senescence. First, rhizobia multiply near the host roots, the two exchange biological signals and rhizobia attach to the root. Then rhizobia enter the root and nodule primordia develop and swell. As the nodule forms, the host plant provides energy in the form of sugars from photosynthesis, BNF results and fixed N is exported to the plant. Crown nodulation, where abundant nodules form on the upper main root, is considered optimal for many crops. Root nodules that form but fix little N are described as ineffective. **Ineffective nodules** are often small and typically have green or white interiors.

The activity of BNF is greater when nitrogen in the soil is less, forcing the legume to obtain its nitrogen from the atmosphere. BNF by grain legumes ranges from less than 40 kg per ha for bush beans to more than 200 kg per ha for soybean. Green manure, pasture and agroforestry legumes have potential to fix even more N (200 to 300 kg per ha per year). In addition to being grown for their seed, grain legumes are beneficial when grown in rotation with other crops, providing between 25 and 75 kg N to the soil through the decomposition of crop residues left in the field.

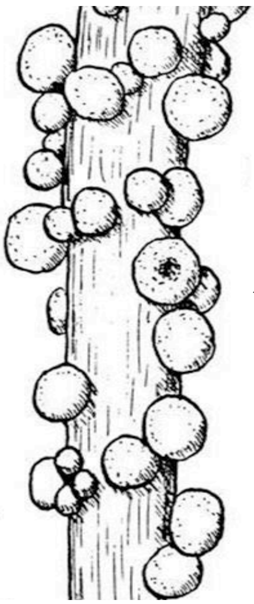
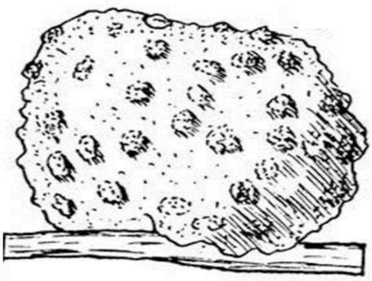
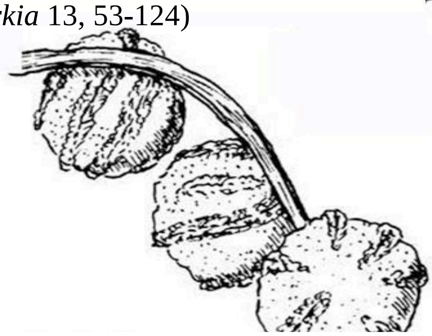
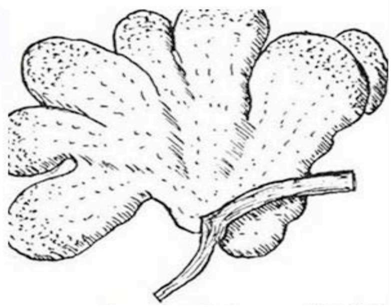





Figure 1. Legume root nodules have many shapes but common characteristics. They may be flattened (left), spherical (below), globular (upper right) and elongate or branching (lower right). Nodules contain rhizobia and serve as the site of BNF (after H.D.L. Corby, 1988, *Kirkia* 13, 53-124)

N2Africa Target Grain Legumes and their Management

Common bean (*Phaseolus vulgaris*) is a bushy or climbing annual with trifoliate, slightly hairy leaves and small, white, yellow or purple flowers bearing long, smooth pods forming large, kidney-shaped seed. Many varieties and land races exist. It is grown from the equatorial uplands to temperate regions but performs poorly in the hot, humid lowlands. Current yields in sub-Saharan Africa (SSA) average 530 kg per ha with potential yields exceeding 2000 kg. It requires moderate rainfall followed by a dry ripening interval and is sensitive to extreme soil acidity. Beans are often intercropped with cereals, usually maize and are susceptible to a wide range of pests and disease. Propagation is by its rapidly germinating seed with about 2500 seed per kg. The leaves, young pods, young and mature seeds and seed sprouts are edible. Bean is associated with several species of rhizobia but not those common in most African soils and this crop often responds to inoculation with rhizobial inoculant. Bush varieties have a lower potential for BNF (about 35 kg N per ha) than longer duration climbing beans (up to 125 kg N per ha).

Soybean (*Glycine max*) is a bushy annual up to 120 cm in height with hairy trifoliate leaves and small flowers forming clusters of short, hairy pods. Roots are deep and bear many round nodules. It is grown from the lowland to upland tropics and tolerates moderately acid soils and short-term drought. It performs poorly under cool and shaded conditions. Current yields in SSA average 830 kg per ha with potential yields as great as 5000 kg. Soybean rust, a brown fungus attacking leaves, poses a serious threat to production and the crop is best grown in rotation. Newer varieties have some resistance to this disease. Propagation is by seed with about 7000 seed per kg. Soybean has many industrial uses and is an important source of vegetable oil and protein. It has edible green and mature seeds with seeds ranging in color from cream, yellow, pale green to black. It also is valuable as a source of livestock feed and hay. Most soybean varieties have very specific rhizobium requirements and often respond to seed inoculation but more promiscuously nodulating varieties were developed recently. Crown nodulation is preferred. Soybean has a high capacity for BNF (more than 200 kg N per ha) that meets both the needs of the crop and provides strong residual benefits.

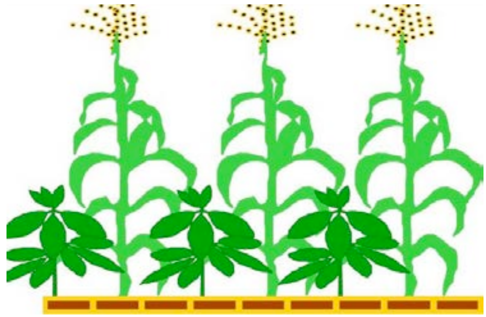
Cowpea (*Vigna unguiculata*) is an erect, trailing or climbing annual with trifoliate leaves and white, yellow or violet flowers producing long, slender, smooth pods containing round or cylindrical seeds. The roots are branching. It is grown throughout the tropics and subtropics. Current yields in SSA average only 340 kg per ha with potential yields of about 2000 kg. Cowpea tolerates heat, drought and soil acidity but is sensitive to waterlogging. It is susceptible to many insects including white fly, aphids and weevils. Cowpea is propagated by seed with about 7000 seed per kg. The leaves, young pods, young and mature seeds are edible and the crop residues are palatable to livestock. The rhizobia associated with cowpea are common in most tropical soils and form root nodules that are round to irregular in shape. Cowpea can fix up to 120 kg N per ha and offers strong residual benefits to following crops, particularly from the longer-duration, trailing varieties.

Groundnut (*Arachis hypogaea*) is an erect (bunch type) or trailing (runner type) annual herb 60 cm in height with pinnate leaves and fleshy stems. Flowers are yellow, forming at lower nodes and fertilized fruit peg into the soil. The pod is rounded, corky and dry. Groundnut is strongly tap rooted and lacks root hairs. Groundnut requires about 600 mm of rainfall followed by dry ripening. New varieties are available that resist groundnut rosette virus, a disease that severely limits crop yields. Current yields in SSA average 950 kg per ha with potential yields of 2500 kg. It is best suited to sandy loams, is acid tolerant but requires calcium in the soil for successful pod fill. Propagation is mainly by seed (1200 seeds per kg) but stem cuttings are also able to root. Groundnuts are eaten raw, boiled or roasted and milled into peanut butter. Seeds are also pressed for vegetable oil. Leaves and stems are particularly palatable to livestock because foliage remains green through seed ripening. Groundnuts are associated with rhizobia that are common to tropical soils and form numerous, very small, flattened root nodules throughout the root system. Nitrogen fixation in groundnut is about 150 kg N per ha and offers strong residual benefits to following crops.

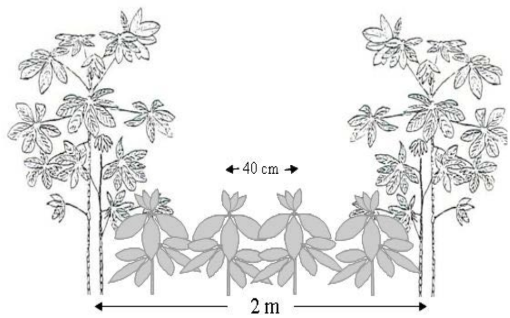
Management of grain legumes. Several options are available to increase BNF through grain legume enterprise. Grain legumes may be cultivated as intercrops, in rotation or as relay crops. **Intercropping** permits farmers to grow a wider range of food legumes as under-storey intercrops with cereals or cassava. 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. Groundnut and soybean both benefit from this arrangement.

Legumes may also be grown in **rotation** with other crops once in three or four seasons in monomodal climates or every other season under bimodal rainfall conditions. Rotation replenishes soil nutrients and improves the availability of organic resources, particularly when legume varieties have traits appreciated by farmers. Rotation also reduces pests and disease. **Relay cropping** involves planting a crop into the same land where another is already established. It is most viable when one crop is shorter duration than the other and is replaced after harvest with yet another crop. Maize-bean intercropping is relayed after bean harvest by planting a green manure or root crop, as maize dries the relay crop's canopy closes. Legumes may also be relayed with cassava. In non-humid areas, relay crops must be drought resistant and carefully timed to the rains.

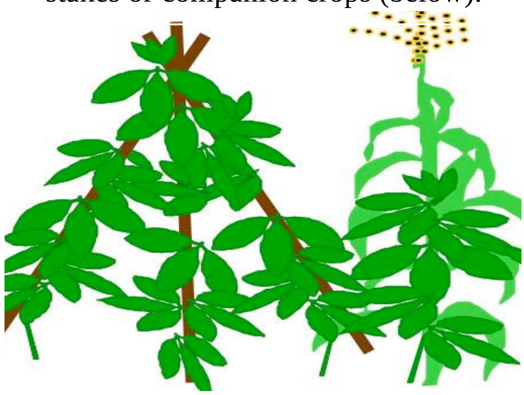
Climbing bean varieties are available that have multiple disease resistance, greater BNF, and higher yields than bush beans. They require staking, a practice considered too expensive by many farmers. An alternative is to intercrop climbing beans with maize, or rotate maize and climbing beans, retaining the maize stalks for support. More aggressive climbing beans can, however, out-compete companion maize.



Intercropping arrangements of maize and grain legumes with alternate (above) and staggered rows (below).



Cassava may also be intercropped with grain legumes (above). Climbing beans require support from either stakes or companion crops (below).



Management of Biological Nitrogen Fixation

BNF by grain legumes may be managed through good field practices that allow the crop to better achieve its potential and that reduce stress from the climate and soil. These practices include adoption of improved crop varieties, judicious use of mineral fertilizers, adjusting plant density and timely weeding. In many cases, native rhizobia cannot satisfy plant demand for BNF and legume seeds must be inoculated with an elite strain of rhizobia at planting. Establishment of effective BNF depends on optimizing all of these components and is best diagnosed in the field by recovering and observing root nodules.

There are several environmental constraints to BNF. Extreme temperature kills rhizobia in the soil and reduces root nodulation, requiring that stress tolerant legumes such as cowpea or groundnut be grown. Drought also kills rhizobia in soil and reduces BNF. This effect is minimized by growing deep-rooted legumes such as groundnut. Legumes are quite sensitive to salinity. Rhizobia perform well in waterlogged soils but legumes grow poorly due to oxygen deficiency and toxic minerals. In this case, legumes with shallower roots, such as beans and soybeans, perform better than crops with taproots.

Environmental constraints to BNF include soil acidity and Al toxicity, particularly in highly weathered tropical soils. This condition is readily corrected by liming. Liming also provides calcium, another nutrient required by plants in large amounts. Cowpea and groundnut are moderately tolerant to soil acidity. After nitrogen, phosphorus (P) is the second most limiting nutrient in African soils. Rhizobia are tolerant of low phosphorus but nodulation and BNF are very sensitive to its limitation. P deficiency is expressed as purpling of lower leaves and stunted plant growth. Phosphorus deficiency may be corrected by applying phosphate fertilizers such as super phosphate or ground phosphate rock. Single-super phosphate is the most widely available source of fertilizer P and contains sulfur as well. Ground rock phosphate is the least expensive but often fails to react with soils to deliver its nutrients during the first season. Triple super phosphate is the most concentrated but expensive P source. Which source is best depends upon soil properties, local availability and prices. Several micronutrients including zinc, molybdenum, cobalt and boron are necessary for BNF but these deficiencies are rare, occurring mostly in sands, extremely acidic and alkaline soils or under waterlogging.

Nodulated legumes can use mineral nitrogen from the soil and fertilizer but this nitrogen source reduces BNF. Legumes take up mineral N readily from the soil and this tends to suppress BNF. Yet the cost of producing legumes through BNF is much less than with fertilizer nitrogen and more profitable for the farmer. Nonetheless, legumes grow best if there is some mineral N available as nodules form and a small amount of **starter nitrogen** (10 to 30 kg per ha) at planting may increase total BNF over the crop’s lifetime. Note that starter nitrogen increases yields only in soils that are extremely deficient in N and where crop yield potential is high. It should only recommended if there is convincing evidence of economic benefits. Nitrate is a more effective form of starter N than urea. In most cases, farmers are better advised to direct available N fertilizers to cereals or other non-fixing crops grown either as intercrops or in rotation with grain legumes, and allow the legumes to take up whatever residual N remains.

Making the best use of legume inoculants

- ☑ Use the correct inoculant for each legume. Check the label for the legume species you are planting and the product's expiration date.
- ☑ Protect inoculant from sun and heat to keep it alive. The ideal storage temperature is between 4^o and 26^o C.
- ☑ Store inoculant in tightly closed bags and remove it with clean utensils.
- ☑ Use a sticker when inoculating seeds. Smaller seeds require more sticker.
- ☑ Use the recommended amount of inoculant. Use no less than 10 g per kg of seeds. Smaller seeds have greater surface area and require more inoculant.
- ☑ Inoculate seeds just before planting. Cover the inoculated seeds shortly after planting to protect rhizobia from the sun and drying.

Rhizobial Inoculants and Legume Seed Inoculation

In many soils, the nodule bacteria are not adequate in either number or effectiveness. Under these conditions, it is necessary to inoculate legume seed with elite strains of rhizobium bacteria. These bacteria are raised in the laboratory and combined with a carrier material, such as peat, compost or filter mud, to produce legume seed inoculant. The process of adding this inoculant to the seed is called inoculation. Rhizobia associated with soybean and common bean are generally lacking from African soils and responses to inoculation are likely. Rhizobial populations in hot, dry soils are low and legumes grown in these soils often benefit from inoculation as well. In general, inoculation is required when new legumes are introduced to an area or in fields where no legumes have been cultivated for several years. In contrast, many African soils contain large populations of compatible but less effective rhizobia capable of inducing nodulation without providing much benefit to the legume host. In some cases, large inoculant rates of elite rhizobia may counteract these native rhizobia.

Number of rhizobia per soybean seed using different stickers.

Sticker	Cells per seed
Gum arabic	2,500,000
ME cellulose	2,000,000
Honey	500,000
Water	450,000
Sugar	400,000

Seed inoculants are easy to apply and effective under most field conditions but inoculants are perishable and quickly lose their viability when exposed to a temperature of 40^o C or more. Otherwise, inoculants retain their effectiveness for six months or even longer when refrigerated. Sticker materials (adhesives) are needed to bind the rhizobia to the seed. Gum arabic, obtained from the African tree *Acacia senegal*, is an excellent sticker when applied as a 15-30% solution in water. Methylethyl (ME) cellulose (4% solution) is an industrial adhesive that also performs well but is not widely available in Africa. Different amounts of sticker are required for various legume seed depending upon their size. More adhesive is required for smaller seed. Other stickers include 10% sugar solution, 10% honey solution and water. Two different approaches to inoculating seeds are available. Sticker and inoculant are mixed together and then combined with seed

Figure 2. Inoculating legume seed with rhizobia using the slurry technique.

using the slurry technique while the two-step method starts by coating seeds with sticker alone. The procedure for **slurry inoculation** follows (see Figure 2).

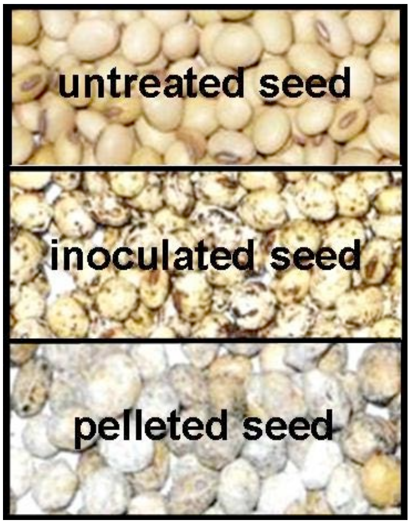
1. Mix 100 g of inoculant and 300 ml of sticker solution.
2. Place 10 kg of soybean seed into a 20 liter bucket.
3. Add 400 ml of the inoculant-adhesive slurry.
4. Stir the seeds with a large spoon until evenly coated.
5. Spread the seeds onto a clean surface to dry.
6. Inoculate and dry seeds under shade and plant inoculated seeds as soon as possible.

In the **two-step approach**, seed is first coated with sticker and then inoculant applied (see Figure 3).

1. Place 5 kg of soybean seeds into a plastic bag.
2. Add 100 ml of gum arabic sticker.
3. Inflate the bag and twist it shut.
4. Shake the bag gently for about one minute.
5. Open the bag and add 50 g of inoculant, shake again, but more gently for one minute.
6. Immediately after coating, spread the seeds onto a clean surface and allow them to dry under shaded conditions. Plant inoculated seeds as soon as possible.

The two-step technique requires less adhesive, results in better coverage of inoculant and is most appropriate for smaller amounts of seed. Too vigorous or prolonged shaking may dislodge the inoculant from the seeds. If seeds are treated with pesticide, be careful not to inhale them when inflating the bag. Do not add excessive sticker as this causes seeds to clump upon drying.

Figure 3. Inoculating legume seed with rhizobia using the two-step technique.



It is possible to combine small amounts of strategically applied mineral fertilizers with inoculated grain legume seed by **pelleting** with finely ground limestone or rock phosphate following 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 about 40%. The amount of required adhesive and mineral coating varies with the size of the legume seed with smaller seed needing more adhesive and binding with greater amounts of fertilizer (Table 1). Note that strongly acidic or alkaline minerals, such as super phosphate, sulfur or hydrated lime should **not** be applied as pellets as these materials react with soil moisture and may injure rhizobia.

Table 1. Sticker and mineral coating required to pellet different grain legume seed following the two-step inoculation technique.

legume	seed	---------- two-step pelleting ----------		
seed	weight	sticker	inoculant	coating
	g/seed	ml/kg seed	g/kg seed	g/kg seed
soybean	0.15	28	10	200
bean	0.42	26	10	160
groundnut	0.50	20	10	120
cowpea	0.12	30	10	220

On-farm Technology Testing

Master farmers must be able to design, install and interpret simple field tests, either in collaboration with researchers or on their own. These tests are intended to identify which constraints limit grain legume productivity and what measures are required to correct the situation. A key test is whether native rhizobia are sufficient or rhizobial inoculation is necessary.

Another important test asks if legumes also respond to the addition of mineral fertilizer. A simple 2x2 field design examining inoculation (+R) and phosphorus (+P) response appears in Figure 4. Each of the four plots is identified with a code that describes its management, occupies 25 m^2 and contains 10 rows of legumes five meters in length. Plants in each plot are evaluated in terms of crop vigor, grain yield and root nodulation. If all plots perform similarly, then there is no response to either rhizobial inoculant or phosphorus addition. If +R plots grow best then inoculation is advised. If +P plots grow best then phosphorus-bearing fertilizers are needed. If the +R+P plot perform best, then a positive interaction between inoculation and phosphorus inputs is suggested and both practices should be conducted. Similar sorts of field tests may be designed using other fertilizers depending upon the local conditions. Field tests comparing both inoculant and N fertilizer evaluate the effectiveness of inoculants and the need for starter N.

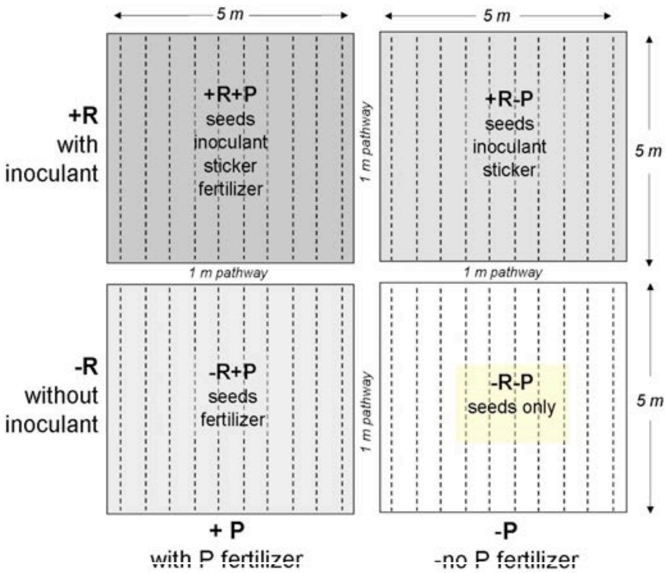


Figure 4. A 2x2 field design testing for legume response to seed inoculation and P fertilizer.

Straightforward agreement between farmers and agricultural researchers can greatly enhance the value of on-farm technology tests. Farmers should make their own observations on field trials and express them to researchers. Farmer groups should organize field days that demonstrate the tested technologies to their communities and be assisted by research partners to do so. Cooperating farmers should not falsify data, disguise experimental failures or exaggerate claims for compensation. Nor should they remove crops from plots without the knowledge of researchers. Researchers must involve farmers in all stages of planning, establish a clear division of responsibility for field operations and recordkeeping and interpret their findings in terms understandable to farmers, particularly their costs and returns. As Master Farmers gain skills in field diagnosis, it is important they conduct their own trials that better adjust new technologies to their more site-specific conditions and client needs.

Disseminating BNF Technologies

Farmer field days organized by local groups are a great way to spread important technical messages to both group members and the larger community. A single field day can target many client groups: farmers, educators and students, local agri-business, neighboring farmer organizations, local government and sponsors. These events also have a strong social component where farmers celebrate their collective efforts and socialize with friends and neighbors. Simple guidelines can improve the impacts if these field days.

- ☑ Form an organizing committee to plan activities, identify an accessible venue and seek participation and funds.
- ☑ Plan and announce the venue well in advance.
- ☑ Build the field day around field demonstrations and exhibits.
- ☑ Solicit outside participation from schools, agri-businesses, local extension officers and other farmer associations. Arrange for guest speakers.
- ☑ Post legible signs to alert and guide the public.
- ☑ Arrange tables for exhibitors and snacks and entertainment for participants. Do not feel obliged to provide a full meal.
- ☑ Conduct a walking tour of technology adoption on neighboring farms.
- ☑ Post signs and designate well-informed members to explain field demonstrations.

Do not delay the opening of the field day because of late arriving dignitaries or conduct continuous entertainment or microphone chatter as this detracts from important technical messages. Sometimes smaller is better. A special field day may be organized for group members only and combined with an association general meeting or discussion on new group initiatives.

Large impacts are achieved by addressing the interests of women farmers as technical innovators and homemakers. Nutrition initiatives are best directed toward women. Households must expand women's rights to intercrops and promote the importance of joint decision making in farm planning. Projects can offer special incentives through women's groups and introduce labour saving technologies. The private sector can stock inputs needed to stimulate new enterprise and repackage fertilizer into smaller quantities to become more affordable to women farmers and poorer households. Opportunities must be opened to train and recruit more women as Master Farmers, association officers and agricultural service providers. Women's empowerment must not be viewed as a threat to established gender roles but rather a means to improve households and communities. Half of the Master Farmers trained by N2Africa are women.

Conducting Community-Based Seed Production

Several improved grain legume varieties are being promoted through the N2Africa Project and we are relying upon participating organizations to conduct seed bulking through community-based activities. These improved legumes include promiscuously nodulating soybean, disease-resistant climbing bean, rosette-resistant groundnut and others. Historically, seed companies in Africa are very slow to license and market improved grain legumes because they are self pollinating and less profitable than hybrid cereal and other seed. N2Africa aims at generating greater demand for commercially produced legume seed but in the meanwhile it requires local seed production to meet its impact targets.

Indeed, farmer organizations have the right to produce seed for their members as long as the seed are not marketed through commercial channels. Master Farmers should lead community-based seed production efforts within their respective organizations and the N2Africa Project will assist them in this area. This production may be centralized on a few, larger fields or conducted by many farmers on smaller plots with care taken to alternate fields to reduce build up of pests and diseases. Care must also be taken to identify and exclude seed affected by pests and disease (see the following section on post-harvest handling). Stored seed should be treated with fungicide and insecticide to protect its quality until the following growing season. The steps necessary for community-based seed production by a local organization follow.

1. Form a seed production committee to identify needed legumes, explore farmer participation and scope local regulations.
2. Establish a transparent community-based seed sharing and reimbursement policy and draft a seed production agreement.
3. Identify best varieties and set seed production targets.
4. Estimate expected seed yields and calculate needed land area [(seed target/expected yield) = needed land area].
5. Recruit farmers committed to seed production matching needed land area. Exceed targets by a safety margin (e.g. 20%).
6. Acquire seeds (40-60 kg per ha), fertilizer (2 bags P fertilizer per ha), inoculant (400-600 g per ha) and sticker (800-1600 ml per ha).
7. Convene a meeting of cooperating farmers to formalize member participation, distribute inputs and identify criteria to accept or reject seed from specific fields.
8. Farmers sign a seed production agreement and field operations begin.
9. Growers should regularly inspect seed fields for uniformity and remove plants that appear different from the others. Seek help from Master Farmers as required.
10. Growers should regularly inspect fields for plant health and treat pest and disease threats. Seek help from Master Farmers as required.
11. Arrange for bags and seed treatment chemicals and produce labels that clearly identify seed variety and chemical seed treatment.
12. Collect, inspect, treat, bag, label, inventory and report available seed.
13. Distribute legume seed among association members in compliance with local seed sharing and reimbursement policies and applicable plant health regulations.

Post-harvest Handling of Grain Legumes

Post-harvest handling assures that grain legumes provide quality food and meet buyers' standards. Grain quality standards consider moisture content, pest damage, shriveled, discolored, broken and off-color grains and the presence of foreign materials, especially stones. Excess moisture reduces seed viability and predisposes grain to fungi producing dangerous mycotoxins. Drying grain on the ground collects foreign materials and stones that may damage mills. Field and storage pests may destroy untreated grain. Mixed colored grains lower the market value. Also, each bag is expected to meet a specified weight. Tools necessary to meet industry standards include handheld moisture meters, tarpaulins for drying, sieves for removing off-sized materials and weighing scales.

Grain Legume Marketing Strategies

Grain legumes may be sold to top-end buyers in bulk, local institutions in bags or at local markets. Beans, cowpea and soybean are typically marketed in 90 kg bags, and groundnut marketed in 110 kg bags. In some cases, beans, cowpeas and groundnuts may be locally marketed in 5 kg bags. Active cross-border trade in grain legumes exists and local farmers may target import substitution within their marketing strategies. Large amounts of soybean are imported into Africa and huge potential for collective soybean marketing exists as the imports pose an unnecessary use of foreign reserves.

Initiating collective marketing is complex and requires several steps. First a group must identify commodity targets and potential buyers, develop accounting and payment mechanisms, appoint a sales representative, identify the industry standards of likely buyers and adopt post-harvest practices that meet these standards. Actions are best timed to price fluctuation throughout the year (Figure 5). The group must establish collection points and arrange transport, develop storage facilities, arrange forward contracts, deliver produce to buyers, reimburse members and report activities. Special care must be taken to meet industry standards as just a few sub-standard bags of grain ruins buyer's acceptance of large orders. Indeed, efficient collective marketing greatly improves the wellbeing of farmers otherwise unable to reach better markets.

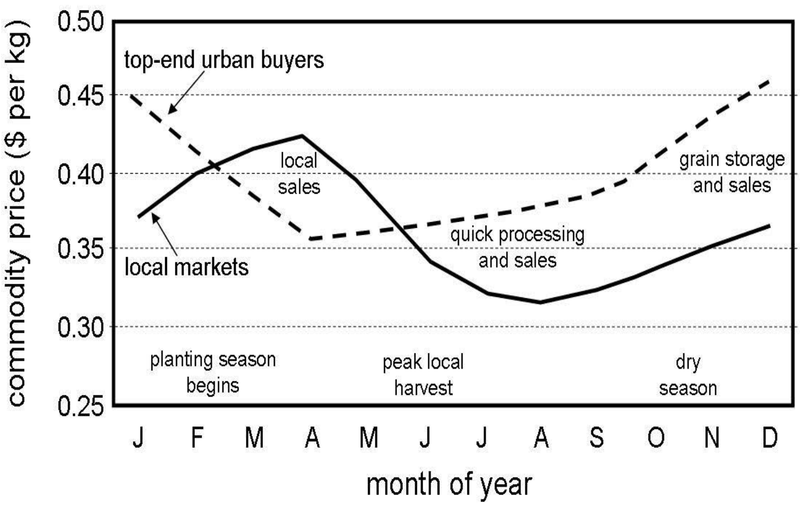


Figure 5. Commodity price trends must be considered in developing a marketing strategy.

Master Farmer's Glossary

Adhesive: a solution used to bind rhizobial inoculants to legume seed, gum arabic (15-30% in water) and sugar (10%) are common adhesives, also called stickers.

Biological nitrogen fixation (BNF): a process performed by bacteria where nitrogen from the atmosphere is converted to biologically active forms.

Carrier material: a solid component of legume inoculants that absorbs and protects rhizobia, making them more easily handled. Peat is the most common source of carrier material.

Collection points: agreed upon locations and times where farmers can receive farm inputs or deliver crop produce for collective marketing.

Cross-inoculation groups: a practical way to classify rhizobia based upon which legumes they effectively nodulate.

Crown nodulation: abundant nodules forming at the top of the main host root.

Forward contracts: formal agreements between produce buyers and sellers that identify the quantity, quality, time, place and price of marketed produce.

Grain legume: an annual crop producing edible seeds in the family Leguminoseae, N2Africa works with bean, cowpea, groundnut and soybean.

Gum arabic: a gummy exudate produced by the African tree *Acacia senegal* that is an excellent adhesive. *Acacia senegal* occurs in East, Northern, Southern and West Africa.

Industry standards: quantitative thresholds describing moisture content, broken, shriveled or discolored grains and foreign materials that are accepted by buyers.

Ineffective nodulation: nodules that do not fix N, usually smaller with green or white interiors.

Inoculant: a product containing live rhizobia and other beneficial organisms mixed with carrier material that is intended for application to legume seed or soil.

Inoculation: the technique of applying adhesive and inoculant to seed with either the slurry or two-step methods. Under some conditions soils may be inoculated.

Master Farmer: a representative of a grassroots organization with advanced farming and training skills. N2Africa relies upon Master Farmers in its outreach activities.

N2Africa: a shortened form of the project *Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa* funded by the Bill & Melinda Gates Foundation.

Nitrogen (N): an element that is abundant in the atmosphere in gaseous form and a necessary component of protein in plants and animals. A substrate for BNF.

Pelleting: a technique that coats finely-ground minerals such as limestone or rock phosphate onto inoculated seed, requires that extra adhesive be applied.

Phosphorus (P): an element necessary for plant growth that is obtained from mineral fertilizers, and is often lacking in many African soils.

Post-harvest handling: the process of shelling, cleaning, packaging and storing grain in a manner that protects food and seed quality and meets industry standards.

Quality control: the process of monitoring and meeting industry standards during post-harvest handling and grain storage.

Rhizobium: a soil bacteria associated with legumes that initiates root nodulation and symbiotically fixes nitrogen from the atmosphere into plant-available forms.

Root nodule: a plant organ forming on legume roots that contains rhizobia and serves as the site of BNF.

Symbiosis: a mutually beneficial association between two different organisms, in this case crop legumes and rhizobium bacteria.

Slurry: a mixture of adhesive and inoculant that is coated onto legume seeds to achieve inoculation, a common larger-scale legume seed inoculation technique.

Sticker: another term for adhesive.

Two-step: an inoculation procedure that first combines seed and adhesive, and then mixes them with inoculant, in contrast to the slurry technique.

Master Farmer Skills Checklist

Necessary skill (a Master Farmer is able to ...)
☐ Access improved varieties of grain legumes
☐ Identify common crop pests and diseases
☐ Access fertilizers needed for grain legume production
☐ Diagnose major nutrient deficiency symptoms
☐ Recommend appropriate intercropping and rotation strategies
☐ Practice and explain basic soil conservation measures
☐ Recommend appropriate staking systems for climbing legumes
☐ Identify effective and ineffective legume root nodules
☐ Select a proper inoculant for cultivated legumes and store it properly
☐ Prepare adhesive solutions for seed inoculation
☐ Inoculate legume seed with rhizobia and test response to inoculation
☐ Pellet inoculated seed with finely-ground mineral fertilizer
☐ Design, install and interpret needed diagnostic field tests
☐ Evaluate the need for lime, P fertilizers and starter N by grain legumes
☐ Adjust recommendations and product information to local conditions
☐ Identify and adhere to grain legume industry standards
☐ Handle legume grains in a manner that protects their quality
☐ Establish and supervise community-based seed production
☐ Assist in the design and operations of collective marketing operations
☐ Explain the goals and activities of the N2Africa project
☐ Respond to the special needs of women farmers
☐ Expand the services offered to members of grassroots farmer groups
☐ Contact local extension officers and researchers for special advice

Back cover photographs. Top row: a cluster of bean root nodules (left), prolific pod production by climbing bean (center) and seeds of bean varieties popular among smallholders in Kenya (right). Bottom: Participants of the N2Africa Training of Trainers Workshop, May 2010. Photographs by K.E. Giller, P.O. Ngokho and P.L. Woomer.



N2Africa is a large scale, research and development project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa. N2Africa is funded by 'The Bill & Melinda Gates Foundation' through a grant to Plant Production Systems, Wageningen University, in the Netherlands. It is led by Wageningen University together with CIAT-TSBF, IITA and has many partners in the Democratic Republic of Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda and Zimbabwe. At the end of the 4-year project we will have: identified niches for targeting nitrogen fixing legumes; tested multi-purpose legumes to provide food, animal feed, and improved soil fertility; promoted the adoption of improved legume varieties; supported the development of inoculum production capacity through collaboration with private sector partners; developed and strengthened capacity for legumes research and technology dissemination; and delivered improved varieties of legumes and inoculant technologies to more than 225,000 smallholder farmers through our Master Farmer Network. For more information on the project, please visit our website at *www.N2Africa.org*.

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Putting nitrogen fixation to work for smallholder farmers in Africa