Market analysis of inoculant production and use

Milestone 1.3.3

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Putting nitrogen fixation to work for smallholder farmers in Africa

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Summary

Milestone 1.3.3 requires a "complete market analysis for inoculant in representative areas of the three hubs, including cost/benefit analysis at smallholder level; leading to recommendations for private sector engagement". The Action Sites in Kenya and Zimbabwe offer the best opportunity to analyse these costs and benefits because these countries rely upon a locally-produced, commercialized inoculant and N2Africa has established close working relations with their manufacturer. Furthermore, an economic analysis of inoculant use by small-scale farmers was performed in these two countries and Malawi. Inoculants of 100 g are produced for \$1.34 and \$3.20 in Kenya and Zimbabwe, respectively, and retailed at 46% and 36% profit. Inoculants from Kenya routinely meet standards of 1x 10^9 cells per gram (at inoculant production factory, for 2011-12 season, the average rhizobial counts were 1.16 x 10^9 C.F.U. per gram of bagasse based inoculant) but likely does not meet their advertised six month shelf life. Across multiple trials in Kenya, Malawi and Zimbabwe, inoculants represent a small fraction of the input costs of soyabean cultivation (1 to 4% depending on rate) but result in substantial gain (457 kg ha^{-1} ± 48%). Return to investment in soyabean input packages that include inoculants range from 2.3- to 5.2-fold, compared to only 1.5- to 2.5-fold for ones that do not. West Africa does not produce inoculants but there is 556,000 ha of soyabeans grown in Nigeria and Ghana alone. Production of 334 tons of inoculant worth \$8.3 million stand to increase soyabean value by over \$105 million per year. A factory for production of legume inoculants is under development in Nigeria and two contrasting approaches to inoculant manufacture are discussed.

1 Benefit and cost analysis of soyabean inoculant production and use in Kenya

The Action Site in Kenya relies upon a locally-produced, fully-commercialized inoculant (BIOFIX). West Kenya has two growing seasons per year allowing for more rapid generation of production and economic data, and farmers working with N2Africa have strong access to soyabean markets so that costs and commodity prices are readily determined. This case study first presents the production and marketing of BIOFIX inoculant, then the economic returns to inoculant use on soyabean by smallholders during the long and short rains growing seasons.

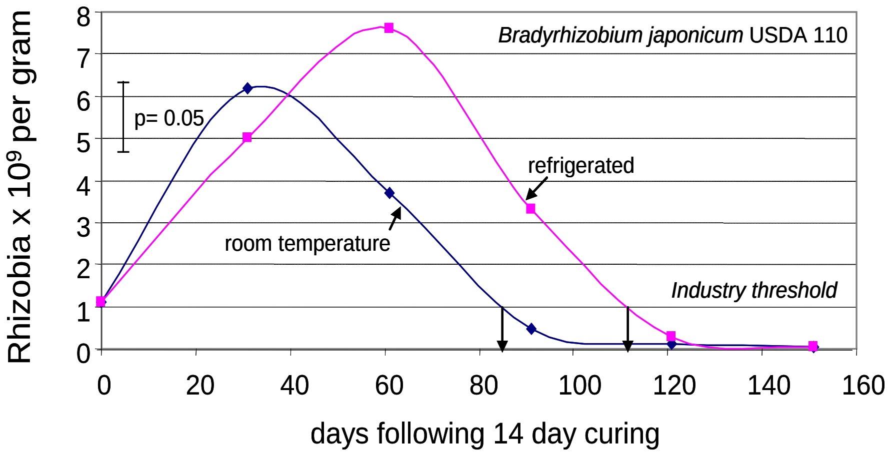

Figure 1.1: Viability of BIOFIX for soyabean over its time suggests the product shelf life is only 3 to 4 months

Table 1.1: Breakdown of production costs and profits[1] of inoculant based upon BIOFIX offered to N2Africa for $1.34 per 100 g packet

Item	$ per 100 g packet
Retailer mark up	1.16
Manufacturer profit	0.62
Labour and quality control	0.22
Marketing and accounting	0.13
Equipment depreciation	0.10
Monthly facilities	0.08
Broth production	0.07
Packaging	0.07
Carrier preparation	0.05
Total	**2.50**

[1] MEA would not disclose the royalty payments agreement with MIRCEN

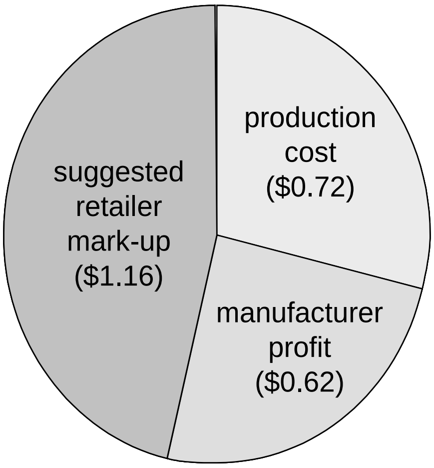

Figure 1.2: Estimated manufacturing costs of BIOFIX inoculant, manufacturer's target profit and suggested retail mark-up in Kenya

BIOFIX inoculant is manufactured by MEA Fertilizers Ltd. at its factory in Nakuru, Kenya. Production began in 2010 after licensing the process and brand from the University of Nairobi MIRCEN. Briefly, broth cultures are raised in five litre flasks containing YMB aerated with filtered pumps. Liquid cultures are mixed with finely-ground, sterilized "filter mud" obtained from a sugar processing factory and cured at room temperature for two weeks. BIOFIX offers a full range of products for bean, soyabean, pea, alfalfa and other economic legumes in packets of 10, 20, 50 and 100 grams, all marketed with the appropriate quantity of powdered gum arabic adhesive. Quality control services are provided by the University of Nairobi as per licensing agreement and the resulting population of rhizobia currently recovered from cured samples in the factory averages 3.2 x 10^9 cells per gram (CV = 34%). This population meets internationally recognized targets but recent evidence suggests that its shelf life is less than the posted 6 months, and should be reduced to 4 months. This suggests that BIOFIX should be sold during the season it is produced, and not carried into the next, even when stored under refrigeration (Figure 2.1). Approximately 400,000 packets were marketed during 2011.

A breakdown of production costs and profits of BIOFIX, based upon a 100 g packet, is presented in Table 2.1 and Figure 2.2. Total production and marketing costs are estimated to be $0.72. At a sales price of $1.34 per 100 g this allows a manufacturers profit of $0.62 per unit. The suggested retail price is $2.50 per packet, resulting in a retailer profit of $1.16. When asked for details on production costs and returns, MEA Fertilizers Ltd. only offered information on their wholesale price and suggested retail price (and did not respond to further queries for more detailed information). Consequently, the production costs of BIOFIX were calculated based upon familiarity with MEA's production process and operations. If we assume that the average size of packets marketed was 50 g, and that profits are proportionate to packet size, then MEA produced about $268,000 of inoculants in 2011 and early 2012. MEA's target production in 2013 is one million packets.

Returns to smallholder's use of BIOFIX inoculant on soyabean were calculated based upon yield and price information during the 2011 long rains (Tables 2.2 and 2.3) and the following 2011-2012 short rains (Tables 2.4 and 2.5) growing seasons. During the long rains we compared four managements involving inoculation and fertilizers with all plots sprayed with fungicide to control soyabean rust. Total production costs ranged between $178 to $291 per ha including labour (Table 2.2). Labour costs were estimated by assigning time and wage for different field tasks in consultation with farm association leaders. We assume that land is tilled using oxen and if hand tilled this adds several days additional field labour (but not necessarily additional labour costs). Soyabean yields ranged between 758 and 1680 kg per ha depending on management resulting in net returns of $267 to $708 (Table 2.3). The best returns were obtained from applying inoculants and Sympal blended fertilizer offering a benefit:cost ratio of 3.43. Note that Table 2.3 also contains information on total days of labour (35 to 39 days per ha). Data for the management receiving neither fertilizer nor inoculant (SB19 spraying only) was based upon an earlier baseline study and no error terms were available. The Sympal blend was developed by N2Africa in Kenya, contains P, K, Mg, Ca and S, and was subsequently commercialized by MEA Fertilizers based upon these findings.

Table 1.2: Estimated production costs of soyabean in west Kenya during the 2011 long rains growing season

management	Seed & inoculant	fertilizer & fungicide	labour	bagging	total
	--------------------	--------------------$ ha^{-1}	--------------------	--------------------	--------------------
SB19 spraying only	39	46	87	5	176
SB19 SSP no BIOFIX	39	122	89	6	256
SB19 SSP w/BIOFIX	55	122	94	8	279
SB19 Sympal w/BIOFIX	55	130	96	10	291

Table 1.3: Grain yield and economic returns to soyabean production in west Kenya during the 2011 long rains growing season (based on 25 farms). Numbers in parentheses denote the Coefficient of Variation (%)

management	SB19 yield	gross return	net return	benefit:cost	labour days
	t ha^{-1}	--- $ ha^{-1} ---		ratio	ha^{-1}
SB19 spraying only	0.76	444	267	2.51	35
SB19 SSP no BIOFIX	0.96 (34)	569 (34)	313 (64)	2.22 (34)	37
SB19 SSP w/BIOFIX	1.30 (48)	776 (48)	497 (73)	2.78 (47)	38
SB19 Sympal w/BIOFIX	1.68 (46)	999 (46)	708 (64)	3.43 (44)	39

Table 1.4: Estimated production costs of soyabean in west Kenya during the 2011-2012 short rains growing season. All managements receive Sympal fertilizer at 100 kg per ha

management	seed & inoculant	fertilizer & fungicide	labour	grading & bagging	total cost
	------------------------------	------------------------------	$ ha^{-1}	------------------------------	------------------------------
SC Samba no BIOFIX	57	86	82	4	229
SC Samba + BIOFIX	73	86	83	7	248
SB19 no BIOFIX	39	130	94	6	269
SB19 + BIOFIX	55	130	95	7	287
SB19 + BIOFIX + Zn	55	130	96	9	290

Table 1.5: Grain yield and economic returns to soyabean production in west Kenya during the 2011-2012 short rains growing season (based on 20 farms). Numbers in parentheses denote the Coefficient of Variation (%)

management	grain yield t ha^{-1}	gross return ----- $ ha^{-1} -----	net return	benefit: cost ratio	labour days ha^{-1}
SC Samba no BIOFIX	0.67 (57)	399 (57)	171 (131)	1.73 (55)	35
SC Samba + BIOFIX	1.12 (70)	664 (70)	416 (111)	2.64 (67)	36
SB19 no BIOFIX	0.93 (67)	554 (67)	285 (128)	2.04 (65)	37
SB19 + BIOFIX	1.06 (78)	638 (78)	344 (142)	2.17 (76)	38
SB19 + BIOFIX + Zn	1.39 (65)	829 (65)	539 (99)	2.83 (63)	39

An economic analysis of five different soyabean managements by smallholders was repeated during the 2011-2012 short rains growing season (Tables 2.4 and 2.5). Two soyabean varieties were compared, SC Samba and SB19, with the former variety more specific in its nodulation requirement and noted for rust resistance; in contrast to promiscuously-nodulated and rust-susceptible SB19. In this case, all managements received Sympal fertilizer but only SB19 was sprayed with fungicide. One management included zinc oxide in its Sympal blend. These managements resulted in total production costs ranging from $229 to $290 per ha (Table 2.4). Soyabean yields ranged between 670 and 1392 kg per ha depending on management resulting in net returns of $171 to $539 (Table 2.5). The best returns were obtained from applying inoculants and Sympal plus zinc blended fertilizer offering a benefit:cost ratio of 2.83. Note that Table 2.5 also contains information on total days of labour (35 to 39 days) per ha. The short rains growing season offered lower yield and reduced economic returns, in large part because of its difficult growing season. Rains started over two weeks earlier than expected, interfering with the harvest from the previous long rains, and ended earlier than expected. These conditions resulted in late planting of the trial and late season drought. Nonetheless, two managements resulted in benefit:cost ratios of greater than 2.6. We also note with interest the yield improvement from adding zinc to the Sympal fertilizer blend led to its inclusion into the blend the following season.

The large CVs among farms in Tables 2.3 and 2.5 flag variability in the performance of soyabean under various managements. During the 2011 long rains, only 12% of farms were able to triple their investment in SSP fertilizer alone, while 58% did so with a combination of BIOFIX inoculants and Sympal fertilizer (Figure 2.3). The average 23% increase in returns (Tables 2.3 and 2.5) from more complete fertilization was observed between these technologies with 20% of cases obtaining greater than four-fold returns to the best management. The consistent return to inoculation of SB 19 at returns greater than 2:1 call the efficacy of that variety's reputation for promiscuous nodulation. Similar but more consistent response to inoculation was observed with SC Saga in the less productive 2012 short rains (Figure 2.4). In this case, 50% of farms applying BIOFIX inoculant obtained benefits of 2:1 while only 28% of non-inoculated soyabean were profitable at a similar level. One caution in interpreting Figures 2.3 and 2.4 is that dependent variables were smoothed by separate sorting, so that each cumulative frequency (set of horizontal points) no longer represents an individual farm, compromising further analysis but necessary to identify straightforward thresholds of returns.

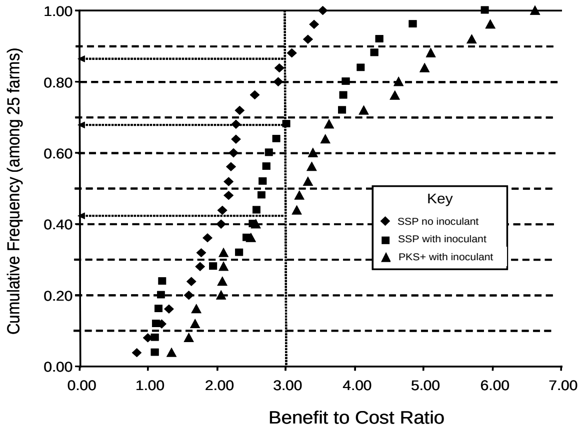

Figure 1.3: Cumulative frequency of the benefit-to-cost ratios in response to inoculation and more complete fertilization of soyabean 19 in west Kenya

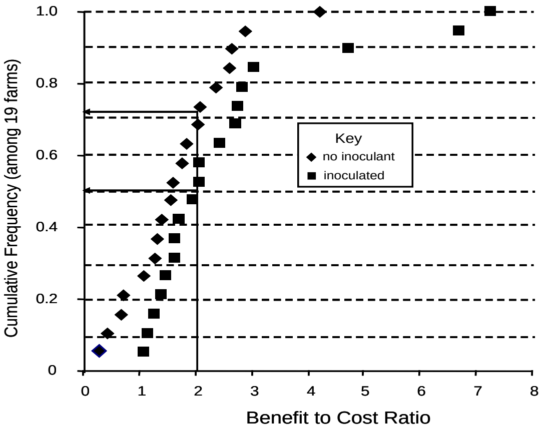

Figure 1.4: Cumulative frequency of the benefit-to-cost ratios in response to soyabean inoculation of cv, Saga in west Kenya

Knowledge of the best managements and their input requirements, costs, resultant yields and returns allows calculation of benefits to smallholder farmers responding to incentives offered by the N2Africa Project and our private sector partners in Kenya (Table 2.6). Briefly, farmers are encouraged to produce soyabean on 1/2 acre (2000 m^2) during each growing season (twice a year). This requires 24 kg soyabean seed, 40 kg of Sympal fertilizer, 200 g of BIOFIX inoculant and about 16 days of labour. Soyabean yields are 624 kg per year and marketed through local collection points for $9 (about $0.14 per kg). Total production costs throughout the year are $118. Fertilizer is the largest single cost ($40) and inoculant one of the least costs (<5% of total). A household earns $212 per year from the one acre (0.4 ha) enterprise, enjoying a benefit-to-cost ratio of 2.8:1. But this profit is considerably less than $465 per year targeted in the N2Africa Vision Statement. Keeping in mind that the average area planted in field crops is 0.7 ha per farm with two crops per year, smallholders can conceivably double their commitment to soyabean production, resulting in economic benefits nearly equal to the target value. Note from Tables 2.3 and 2.5 that these benefits are not possible without investment in rhizobial inoculants. It costs to invest in soyabean production, and its management requires expertise, but the returns to investment are substantial. Future attention should perhaps address tradeoffs in entering soyabean production (and growing less of something else) and the residual benefits to crops following soyabean.

Table 1.6: Costs and returns from participating in farmer collective soyabean marketing on 0.2 ha twice a year in west Kenya

SB 19 seed	$16
BIOFIX inoculant	$5
fertilizer	$40
fungicide	$8
labor	$37
processing	$3
loan &marketing fees	$9
total cost	$118
Gross Return	$330
Net Return	$212
Benefit:cost ratio	2.8

2 Benefit and cost analysis of soyabean inoculant production and use in Zimbabwe and Malawi

Rhizobial inoculants for grain legumes in Zimbabwe are produced by the Chemistry and Soils Research Institute, Department of Research and Specialist Services at Marondera. The department enjoys a monopoly in the production of the rhizobial inoculants in the country. Once produced, the inoculants are distributed countrywide by the department of Agricultural Technical and Extension services, seed houses and agro-dealers. Although these latter two are minor distribution channels they do distribute/sell inoculants to farmers.

An analysis of inoculant production costs and returns was conducted by F. Gutsa and A. Chiwawa for the DR&SS. Costs were compiled from operations in the preparation room, formulation materials, formulation process, packaging, marketing and retailing as well as general costs. The cost elements for the respective processes were gathered and used to calculate the price for a sachet of rhizobial inoculant. The Legume Inoculant Factory packages the inoculant in a standard sachet that has a capacity of inoculating a hectare of any specific legume crop. The costs determinants used are the factors or inputs used for the production of 80 000 units (packets) of rhizobial inoculants. The following assumptions were made and considered in the calculation.

1. For every batch of rhizobial inoculants produced, it is expected *a priori* that at least 25% will have defects and will be discarded.
2. This therefore means that for the Legume Inoculant Factory (LIF) to produce 80 000 sachets it has to meet the cost of extra production to replace sachets with defects.
3. Marketing costs are 20% of the total production costs.
4. Fixed costs are 5% of the production costs and these include maintenance of equipment and structures.
5. The proposed markup is 56.25% of total costs.

Table 2.1: Costs and returns of parastatal inoculant production by DR&SS at Marondera, Zimbabwe

Cost Elements and Calculations	Amount (US$)
Production Material and Processes	$41,124
Preparation Room and Processes	$9,110
Sales Office Materials and Processes	$1,460
General Materials and Costs	$98,343
Discards [30%* Variable Costs]	$45,011
Marketing Costs (20%* Variable Costs)	$30,007
Miscellaneous costs @5% of Variable Costs	$7,502
Total Variable Costs (TVC)	$232,557
Fixed Costs (FC)	$23,255
Total Cost (TC)	$255,813
Total units Produced (X)	80,000 units
Cost per Sachet (Cost per unit=TC/X)	$3.20
Markup (M)	$1.80
Thus, the selling price (P) is	$5.00
Breakeven Quantity [X^o :P*X^o-TVC=FC]	51,163 units
Gross Income (GI)= [X*P]	$400,000
Total Contribution= (GI-TVC)	$167,442
NET PROFIT (NP)= [Total Contribution-FC]	$144,187

The $3.20 is the break-even price that is the price at which total costs of production are equal to total revenue. In other words, DR&SS neither makes a profit nor a loss by selling at $3.20. Gutsa and Chiwawa conclude that the DR&SS factory can readily increase output levels if a dynamic business model is adopted. First it must establish vigorous marketing strategies encompassing nationwide distribution, and promote itself as a brand. This will involve capacitating agro dealers in terms of their knowledge of benefits of rhizobium, its usage and storage, field demonstrations and entering into public-private partnerships with farm input suppliers. Also, development of internal e-commerce and business application involving online adverts posted on the website run by the factory will open up regional and international markets for the product other than relying only on local and not so effective demand. It is further recommended that a booklet or information on the advantages of using rhizobial inoculants over the use of ammonium nitrate fertilizer be made available to the farming community.

Table 2.2: Production costs of soyabean in Zimbabwe

management	seed	fertiliser	inoculant	labour	bagging	total
	----------------------------	$ ha^{-1}	------------------------------			
no inputs	160	0	0	265	26	451
SSP only	160	80	0	265	27	532
inoculant only	160	0	5	255	29	449
SSP+inoculant	160	80	5	245	32	522

Table 2.3: Grain yield and economic returns to four soyabean input managements in Zimbabwe

management	yield kg ha^{-1}	total cost	gross return	net return	benefit: cost ratio
		--------	$ ha^{-1}	--------	
no inputs	1570	451	879	428	2.0
SSP only	1663	532	931	399	1.8
inoculant only	1853	449	1037	588	2.3
SSP+inoculant	2106	522	1179	657	2.3

The analyses is based on a stratified sample of 61 Lead and Satellite Farmers growing soyabeans in the 2011-12 season in Zimbabwe.

It could be added that in recent years more and more smallholder farmers in the communal areas in Zimbabwe have become involved in soya bean production which requires a change or adjustment in the promotion and distribution of inoculants (as in the past it was mainly large scale commercial farmers who were cultivating soyabeans).

An analysis was also performed of smallholder practice based upon four input managements (Tables 3.2 and 3.3). Again, costs were based upon seed, fertilizer, inoculant, labour and bagging with some important differences noted between Zimbabwe and Kenya as the former has higher seed and labour costs, and lower fertilizer and inoculant costs (Table 3.2). When yield and gross returns are considered, and interesting pattern of profitability and benefits emerge (Table 3.3). Smallholder farmers realize a low returns to investment without the use of legume inoculants and higher benefit if they produce soyabean using inoculants only as opposed to a combination of SSP and inoculants. The cost to benefit ratio for seed and inoculant treatment shows that each dollar spent on this technology will generate $2.3 (an extra $1.31 after recovering costs). Interestingly, the results reveal that the least paying technology is soyabean production using SSP compared with seed only. These results show that soyabean production without using either inoculant or SSP generates an extra $0.95 compared to $0.75 when using SSP. The probable explanation is that SSP alone is unable to place nitrogen availability as the most limiting condition, and a fertilizer blend such as Sympal is likely to improve soyabean performance. Another consideration is placement as most farmers simply drop the seed and fertilizer in the same planting hole and it is posible that nutrient release may burn the seed and compromise yield. Compounding this effect, released SSP may compromise the viability of inoculant rhizobia, resulting in poorer nodulation and nitrogen fixation.

Table 2.4: Production and returns to investment of soyabean cultivation in Malawi

management	soyabean Yield* kg ha-1	total cost	gross return	net return	benefit: cost ratio	labour days per ha
		----------	$ ha^{-1}	----------		
no inputs	661(24)	106	312	206	2.96	51
P fertilizer only	672(20)	207	317	111	1.53	52
inoculant only	1237(70)	113	584	471	5.17	51
P + inoculant	1132(57)	213	534	321	2.50	52

*Figures in brackets refer to number of farms used to calculate yield. Data was collected on farmer's fields in Dedza, Dowa, Kasungu, Lilongwe, Mchinji, Mzimba, Salima and Ntcheu districts in 2011/12 growing season.

Lack of response to P fertilizers was also observed in Malawi. Unlike Zimbabwe, total production costs in Malawi are low, ranging between \$106 to \$213 per ha. This reduction is largely due to the low cost of labour (about \$57 ha^{-1}), that is only 64% and 21% of that in Kenya and Zimbabwe. These reduced costs lead to profitable returns even with low yields (Table 3.4). Note again that P fertilizer is not boosting yield, suggesting that its formulation is incorrect (as the first increments of the correct fertilizers usually offer the largest agronomic efficiencies).

3 A novel approach to calculating the value of legume inoculants

The preceding evidence demonstrates that inoculants may be profitably commercialized and they are an integral, and relatively inexpensive component of soyabean production systems (Tables 2.2 to 2.5). But so too are improved varieties, fertilizers and rust management, and inoculation alone is unlikely to succeed in raising farm productivity. Nor do these economic analyses take into account the value of biological nitrogen fixation resulting from inoculation. A different sort of economic analysis that includes not only inoculant costs and crop value, but also increased nodulation and nitrogen fixation resulting from inoculant use is included in Table 4.1.

Table 3.1: Economic returns to BIOFIX inoculant use in west Kenya during the 2011 long rains growing season

management	no inputs	SSP only	SSP & BIOFIX	Sympal & BIOFIX
BIOFIX inoculant applied (g ha^{-1})	0	0	500	500
inoculant cost ($ ha^{-1})	0	0	12.5	12.5
crop value ($ ha^{-1})	388	497	671	860
estimated value of BNF ($ ha^{-1})	64	82	111	142
Nodules per ha ($x10^6$)	2.4	3.6	5.6	9.2
BNF per nodule (mg N)	18	15	13	10
value 1000 inoculant nodules ($)	na	na	0.10	0.08
Nodules produced per g inoculant	na	na	4000	7200
total value per g inoculant ($)	na	na	0.41	0.54
benefit:cost of inoculant	na	na	16	22

Table 4.1 describes the costs and benefits of applying inoculants to soyabeans receiving either SSP or Sympal fertilizer. First it calculates the cost of inoculant (rate x price) and its resulting benefits (crop + fixed N). Then it examines the increase of nodulation (from 2.4 to 9.2 million nodules per ha) and calculates the value of 1000 nodules resulting from inoculant (between $0.08 and $0.10). Then the number of inoculant nodules resulting per gram of inoculant is calculated (between 4000 and 7200), allowing for the value generated by applying one g of inoculant (containing about 410 million rhizobia) to be calculated (between $0.41 and $0.54 per g) and compared to the cost of one gram of inoculant (about $0.025) resulting in a benefit to cost ratio of 16 to 22, depending on choice of fertilizer. In summary, one gram of BIOFIX inoculant costs the smallholder farmer about $0.025, $0.006 and $0.011 of which is taken as profit by the manufacturer and local agro-dealer, respectively (calculated from Table 2.1), and then results in as much as $0.54 to farmers in terms of increased crop production and substitution of increased BNF for fertilizer nitrogen.

4 Increasing inoculant supply

It was the N2Africa's initial intention to stimulate the commercialization of inoculant production in East, Southern and West Africa within four years but its planners under-estimated the enormity of this task. While the program greatly assisted inoculant production where it was already initiated (Kenya and Zimbabwe), and encouraged some laboratories to explore new inoculant production techniques and quality control procedures (DR Congo, Malawi and Rwanda), its other target countries lacked the necessary capacities in rhizobiology to stimulate new inoculant production at commercial scales. This is particularly the case for West Africa where program success has led to the importation of inoculants from Europe, often at costs too high and in package sizes too large for poor farmers & smallholders – who do not need large packages. In this way, the N2Africa Program has positioned Africa to develop commercial inoculant production by demonstrating the need and demand for them, and providing basic training in rhizobiology and product quality assurance, but could not undertake the next step in supporting new commercial ventures.

IITA is now ready to take this next important step through its newly-founded Business Incubation Platform (BIP). Its intention is to develop profitable agribusiness models and facilities that may be both replicated by, and taken over by the private sector after a period of exploring different production approaches. It recognizes the private sector as a key player in the supply of farm inputs and implements, and particularly in the case of biotechnologies, that commercialization is often dependent upon reduced costs of applications, availability of intellectual protection instruments, and the consolidation of needed materials and services leading to more ensured rates of return from private sector investment. The production of legume inoculants in West Africa using elite rhizobial strains and quality control procedures identified through IITA's and N2Africa's research programs by technicians and scientists it has trained, and that are marketed through business channels developed through its outreach activities is clearly a candidate for this business incubation approach.

4.1 A core Facility

Successful adoption through private sector investment requires that an inoculant production approach be in line with currently available and serviceable technologies and equipment. The schematic design of an open-spaced, flow-through inoculant production factory appears in Figure 5.1. This factory approach is essentially scaled-up laboratory procedures that inject sterile, prepackaged carrier with rhizobial broth, cure them to friability and then combine inner and outer packages (Figure 5.2). It has seven main "workspace" rooms devoted to 1) carrier bulk storage and preparation, 2) safe laboratory material and mother culture storage, 3) production of starter cultures and in-house quality control operations, 4) larger-scale fermentation of broth cultures and injection into sterilized carrier, 5) supervisor's office, 6) curing of packets and packing for sales and shipment and 7) manager's office to arrange ordering of materials, coordination within the larger BIP and inoculant sales. Details on each workspace are available from N2Africa. It is this approach that has resulted in successful intermediate-scale commercial production in Kenya and the UK.

This factory design permits ready flow of materials to finished product. Raw carrier material enters through the back of the factory and is processed and sterilized well away from microbiological activities. The factory contains a "core" with limited access for purposes of sanitation and security. The supervisor's office is central to the facility with ready views of the transfer, injection and curing rooms. Admittedly, this factory relies upon proven technologies and equipment from several decades ago, and tends to substitute labour for more advanced machinery, which in turn reduces its productive capacity. The advantage of this approach is greater purity in smaller more controlled batches. This allows for injection of broth cultures at 10^8 and subsequent growth in the curing package. This more microbially controlled approach permits entry into production of other biofertilizer products as well. But this approach has several disadvantages: it requires double bagging, product size is predetermined, double sterilization often required and it is more labour intensive. The greatest disadvantage rests in repeated handling of small packages as carrier is bagged, sterilized, sealed, injected, kneaded, cured, double bagged and packaged. Over time, this sort of facility should become semi-automated to allow for greater quantities produced.

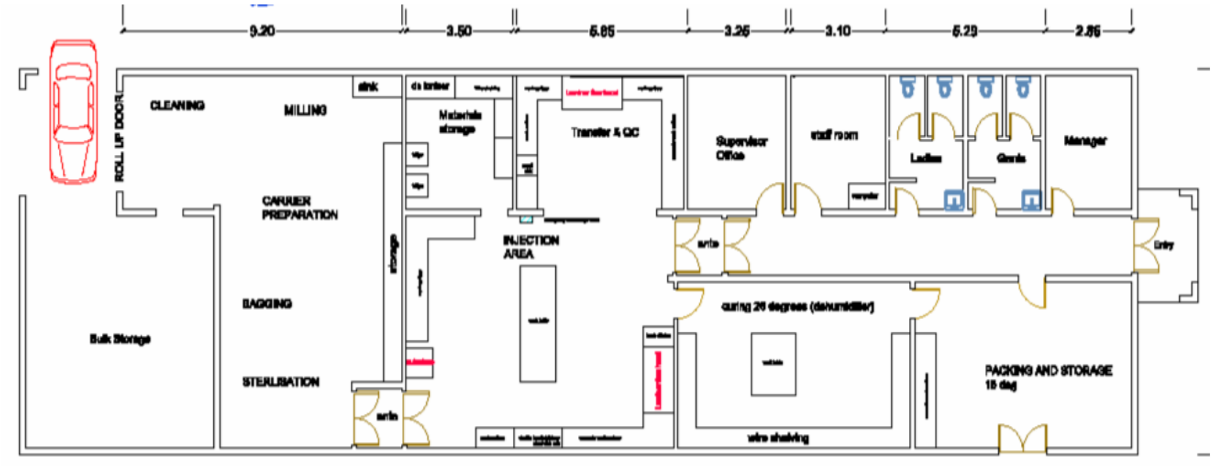

Figure 4.1: The design of a legume inoculant production facility suitable for entrepreneurs in developing countries under construction at the IITA Business Incubation Center

4.1 Larger-scale production options

An alternative approach is available that handles materials in bulk, dries and grinds carrier at a larger scale and requires less on hand labour (Figure 5.2). These processes were developed in the US mid-west to accommodate massive seasonal demand for soybean inoculants. Briefly, air dried carrier is flash dried at 120 º to 170 ºC in a rotary drier, and then ground to about 200 microns. It is placed in a rotary mixer and combined with rhizobial broth, and then cured in large trays. Afterward, it is single bagged for sale.

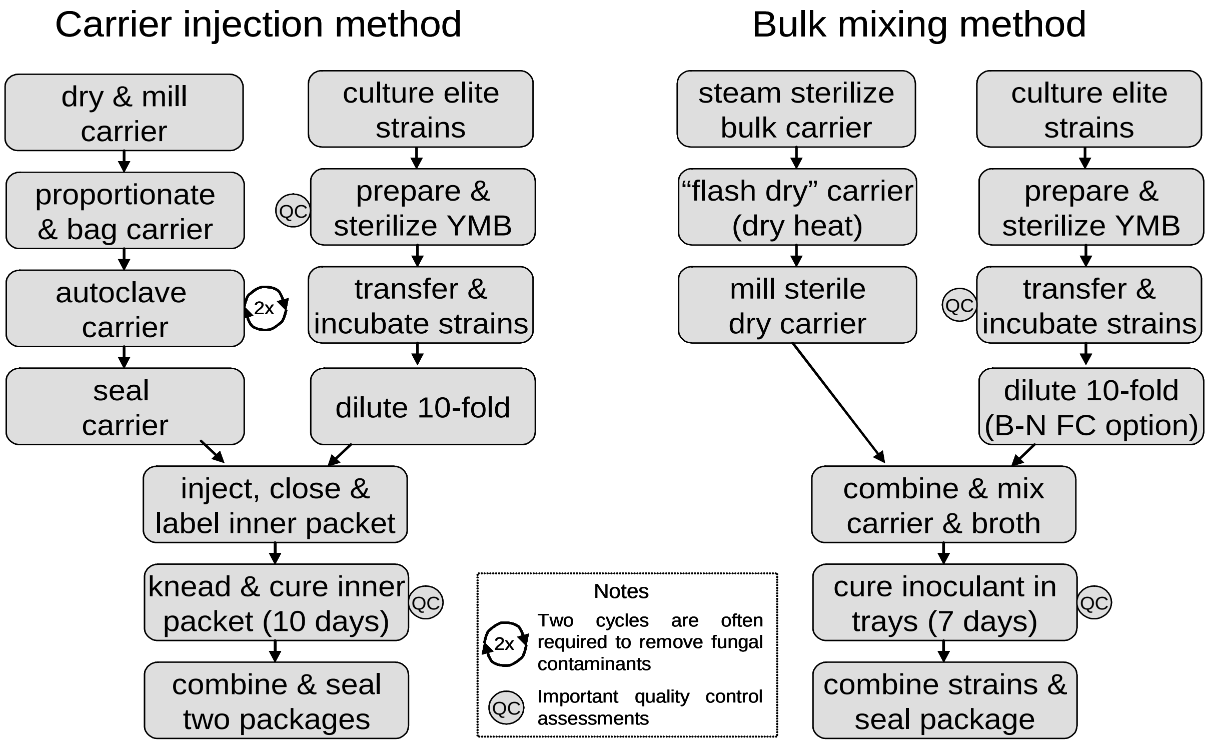

Figure 4.2: Two alternative options for commercial inoculant production: the carrier injection method (left) and the bulk mixing approach (right). Each offers its own advantages and disadvantages, but the latter offers greater potential for scaling

This approach offers several advantages over injection. Most importantly, packages are handled only once and single bagged, allowing for mixed strain inoculants and packaging on demand. It is more labour efficient as workers operate large equipment rather than manipulate individual bags. Greater gas exchange in trays allows for more rapid curing. Its main disadvantage is greater exposure to contamination and the product cannot be marketed as pure. Also start up is more expensive because rotary driers, grinders and mixers are larger equipment than utilized in carrier injection. Another risk is that curing in large trays may result in poor aeration, allowing for competitive advantage to contaminants. Covering of trays as a countermeasure to contaminant entry further reduces aeration and increases curing interval. Despite these risks, bulk production of inoculants appears the better option in factory operations targeting large markets.

A unique opportunity is assuming a modular approach, with separate operations for carrier preparation, broth preparation and mixing/packing. Carrier preparation may be conducted near its source, or commercial sterilization services. It may even be purchased in one ton lots of finely ground peat from northern climates (e.g. BioAPT from American Peat Technologies, Atkin, Minnesota, USA). It is important that when rhizobia are introduced to carrier that they be rapidly growing and dividing. Broth cultures may be diluted 100 fold prior to combination with carrier. They may also be obtained by resuscitating filter concentrates containing 10^{15} cells per litre, equivalent to what is produced in a 1000 litre fermentor (e.g. BIO-NEXT, Wichita, Kansas, USA). Only 1 ml of these concentrates is added to 100 l diluent resulting in about 225 kg of inoculant ready for curing. Combining carrier and broth in mixers offers advantages in terms of productive capacity, but also increases risk of contamination, and subsequent growth of contaminants during curing. For this reason, inoculants are considered only semi-pure but high populations of rhizobia (e.g. 5×10^{9} cells gram^{-1}) can nonetheless be achieved using lower cost procedures.

4.2 Economic viability of inoculants in West Africa

While technical and ergonomic improvements in factory operations is important, all is for naught if the industry itself is non-viable. Indeed, even the design of the factory and its capacities is intended to address known demand for inoculant supply to improve the lives of a large number of poor farming households embarking upon soyabean production. To address these factors, we must first anticipate the cost of factory production and both manufacturer's and retailer's profit margins, the potential demand for inoculants by farmers and the benefits that accrue from their use. While the description of these production costs (and their reduction) is a major goal of the Business Incubation Platform, some preliminary estimates that could signal profitable inoculant production in West Africa may be generated based upon evidence collected by the N2Africa Program.

A spreadsheet utility was developed to better understand inoculant demand, production costs and profits (see Table 5.3). First the proportion of inoculant production costs are calculated. These are originally based upon estimates for BIOFIX from MEA Ltd., but users may substitute any other costs or margins, which in turn affects inoculant sales price. Next, soyabean production and its inoculant requirements are calculated for up to three countries, in this case Kenya, Nigeria and Ghana. Users must input soyabean yield, production area, inoculation response, commodity price and seed and inoculant application rates. Key outputs from this module include yield increase from applying inoculants, their total value, seed needed to sustain production and, most importantly the amount of inoculants required. A third module then calculates inoculant value, production costs and profits based on outputs from the two previous sections. Its output also calculates the benefit to cost ratio from inoculant use by farmers.

The utility was then used to generate three scenarios, one for west Kenya, Nigeria and Ghana. The Kenya scenario was based upon the planned import substitution of about 100,000 tons of soyabean per year requiring 36 tons of inoculant worth $900,000 (Table 5.3). It was used as a "control" condition to establish inoculant production costs and in designing and troubleshooting the spreadsheet utility since all needed user inputs were known, and will not be discussed further.

It is the outputs from Nigeria and Ghana that are of interest to the business incubation in West Africa by IITA. Nigeria seeks to produce inoculants for 30,000 tons of seed grown on 500,000 ha. Inoculation will result in an additional 150,000 tons of soyabeans worth $93 million per year and requires that 300 tons of inoculants be produced and marketed. These inoculants will cost about $2.5 million to produce and are valued at $7.5 million with the difference divided between the manufacturer and retailers. Farmers return on investment in inoculant use is 12.4-fold or about $186 per ha.

Table 4.1: Projection of inoculant requirements and profitability in Nigeria and Ghana

Inoculant production costs and mark-up			
	$/100 g	proportion	
retail mark-up	$1.06	0.42	
manufacturer profit	$0.62	0.25	
labor & QC	$0.22	0.09	
marketing & acounting	$0.13	0.05	
equipment depreciation	$0.10	0.04	
royalities	$0.10	0.04	
monthly facilities	$0.08	0.03	
broth production	$0.07	0.03	
packaging	$0.07	0.03	
carrier preparation	$0.05	0.02	
	$2.50	1.00	
Soyabean production and inoculant requirements			
Scenario	**West Kenya**	**Nigeria**	**Ghana**
soyabean yield (t/ha)	1.60	1.20	1.40
soyabean area (ha)	60000	500000	56000
soyabean production (t)	96000	600000	78400
inoculation response (%)	25	25	25
yield increase (t)	24000	150000	19600
soyabean price ($/t)	$620	$620	$620
increase soyabean value ($)	$14,880,000	$93,000,000	$12,152,000
seed rate/ha (kg)	60	60	60
total seed (kg)	3600000	30000000	3360000
inoculation rate (kg/kg)	0.01	0.01	0.01
inoculant required (kg)	36000	300000	33600
100 g packets required	360000	3000000	336000
Inoculant value, production costs and profit			
cost per 100 g packet ($)	2.50	2.50	2.50
total value of inoculant ($)	$900,000	$7,500,000	$840,000
production costs (%)	32.80	32.80	32.80
production costs ($)	$295,200	$2,460,000	$275,520
manufacturer's profit (%)	24.80	24.80	24.80
manufacturer's profit ($)	$223,200	$1,860,000	$208,320
retail mark up (%)	42.40	42.40	42.40
retail mark up ($)	$381,600	$3,180,000	$356,160
inoculant benefit:cost	16.5	12.4	14.5

Ghana seeks to produce inoculants for 3360 tons of seed grown on 56,000 ha. Inoculation will result in an additional 19,600 tons of soyabeans worth $12 million per year and requires that 30 tons of inoculants be produced and marketed. These inoculants will cost about $275,000 to produce and are valued at $840,000. Farmers return on investment in inoculant use is 14.5-fold or about $218 per ha. In combination, the annual requirements for soyabean inoculants in Nigeria and Ghana is 334 tons per year that will directly generate manufacture's profits of about $2.1 million and increase the value of soyabean production by $105 million per year. It is important to note that the Business Incubation Center alone does not intend to produce the needed volume of inoculants, but rather requires replication by private sector investors to reach this end. Furthermore, this scenario does not include the potential for sales elsewhere in Africa and the need for inoculant by legumes other than soyabean.

5 Conclusions and recommendations

Both the production and use of legume inoculants on soyabean are economically viable. The paucity of commercial production of inoculants is not easily understood considering that the manufacturing technology is basic, and little different from widely distributed fermented beverages. Perhaps a lack of peat deposits or other suitable materials in Africa limits accessibility to highest quality carrier, and the technical skills and capacity for investment in industrial microbiology are limiting attraction to investment. Difficulties in identifying ready markets may contribute to this constraint. Nonetheless, the initiation and growth of an inoculant industry parallel to expanding soyabean production is seen as necessary and inevitable if the latter is to exceed. That inoculation of soyabean is so inexpensive and results in visible crop improvement will reinforce this trend.

Designing new inoculant production facilities is, however, no easy task. The least expensive investment is based upon decades old carrier injection approaches that are difficult to expand, but perhaps most readily replicated. Factory-scale require larger investment in equipment and produce a lower quality but still efficacious, product that allows for stepwise increase but is difficult to transition from carrier injection. The latest technical advance considers carrier preparation, broth fermentation and product mixing and packaging as not only three different operations, but as separate enterprises. Both finely ground peat carrier and 10^{15} cells per litre filter concentrates are marketed, and readily combined in factories relying upon less complex operations. All inoculants, regardless of their manufacture, must be subject to rigorous quality control but this is indeed the subject of other N2Africa Program milestones under Activity 3.3.

Based on information in this report, the following recommendations are offered:

1. To small-scale farmers, soyabean production is most profitable when inoculated, but not necessarily fertilized. Low yields should be corrected through improved varieties and fertilizer blends, but even "promiscuous" soyabeans require benefit from inoculation.
2. To agrodealers, stock and promote soyabean inoculants where soyabeans are being grown, but take care to offer quality products. Do not trust inoculants toward the end of their expiry date.
3. To entrepreneurs and investors, there are profits to be made from manufacturing legume inoculants particularly for soyabean in West Africa, but these must be of high quality and available to legume growers at the time and place where other recommended inputs are purchased. There is no option for lower-quality-lower-pricing as with many consumer goods.
4. To manufacturers, up-scaled laboratory procedures, particularly carrier injection, are OK for pilot and small-scale operations but are difficult to expand into full factory production as the approaches differ in terms of when the product is packaged. Opportunity exists to modularize operations between carrier preparation, broth production and mixing and packaging.
5. To donors and development planners, support projects designed to incubate inoculant production but care must be taken to match production capacity to markets based upon the importance of legume production and its response to inoculation in a given area.

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List of project reports

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

31. Existing rhizobiology laboratories upgraded
32. N2Africa Baseline report
33. N2Africa Annual country reports 2011

34. Facilitating large-scale dissemination of Biological Nitrogen Fixation
35. Dissemination tools produced
36. Linking legume farmers to markets
37. The role of AGRA and other partners in the project defined and co-funding/financing options for scale-up of inoculum (banks, AGRA, industry) identified
38. Progress Towards Achieving the Vision of Success of N2Africa
39. Quantifying the impact of the N2Africa project on Biological Nitrogen Fixation
40. Training agro-dealers in accessing, managing and distributing information on inoculant use
41. Opportunities for N2Africa in Ethiopia
42. N2Africa Project Progress Report Month 30
43. Review & Planning meeting Zimbabwe
44. Howard G. Buffett Foundation – N2Africa June 2012 Interim Report
45. Number of Extension Events Organized per Season per Country
46. N2Africa narrative reports Month 30
47. Background information on agronomy, farming systems and ongoing projects on grain legumes in Uganda
48. Opportunities for N2Africa in Tanzania
49. Background information on agronomy, farming systems and ongoing projects on grain legumes in Ethiopia
50. Special Events on the Role of Legumes in Household Nutrition and Value-Added Processing
51. Value chain analyses of grain legumes in N2Africa: Kenya, Rwanda, eastern DRC, Ghana, Nigeria, Mozambique, Malawi and Zimbabwe
52. Background information on agronomy, farming systems and ongoing projects on grain legumes in Tanzania
53. Nutritional benefits of legume consumption at household level in rural sub-Saharan Africa: Literature study
54. N2Africa Project Progress Report Month 42
55. Market Analysis of Inoculant Production and Use

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