Agriculture Knowledge, Learning Documentation and Policy (AKLDP) Project, Ethiopia

Technical Brief

February 2016

Improving Crop Yields in Ethiopia

Early impacts from *Rhizobia*-inoculated legume seed

Introduction

Since time immemorial farmers have been seeking ways to produce more food from the same field. The incentives to intensify production increase as populations grow and land-holdings are progressively sub-divided. In Ethiopia a recent report states that in the last decade land holdings have declined by an average of 1.4% per year or 14% in total.[i] In response, famers have innovated: the area of fallow is reduced; the use of fertilizers has increased; the area planted to high yielding cereals has expanded; and the area planted to legumes has decreased.

As the area of arable land planted to legumes has reduced, farmers have become increasingly interested in boosting legume yields. There are several ways to do this, such as using organic and inorganic fertilizers, using improved seed, or applying bio-fertilizers. But what are "bio-fertilizers"?

Bio-fertilizers

- Bio-fertilizers are composed of a simple, milled peat/lignite base that is used to carry *Rhizobia* bacteria.
- At the time of planting, bio-fertilizers are usually mixed with a sugar solution in which the seed is soaked. The sugar solution ensures the bio-fertilizer adheres to the coating of the seed and that the *Rhizobia* quickly colonize the interior of the plant after germination.
- *Rhizobia*-based bio-fertilizers[ii] increase the rate of root nodule formation in legumes and as a result, increase the rate of fixation of atmospheric nitrogen (N_2). This fixed nitrogen is transformed into a more useable form of nitrogen (N) that supports plant growth and productivity.
- Critically, bio-fertilizers do not contain any chemicals that are harmful to the living soil.
- Once the legume is harvested, the root nodule breaks down and releases the *Rhizobia* and nitrogen back into the soil.
- The *Rhizobia* can persist in the soil or can re-infect legume plants that are planted in following years. In the same way, the nitrogen released into the soil after harvest can subsequently be used by other crops known as 'follow-on' crops, and this typically results in higher yields.

Assessment of bio-fertilizers

In October 2014, the AKLDP and SNV launched the Cereals and Legumes Working Group in Ethiopia. This aimed to establish a platform for policy makers, researchers, project implementers and private sector actors involved in cereals and legumes to share good practice and inform cereals and legume strategy development. The February 2015 meeting included a presentation by Dr. Asfaw Hailemariam, Menagesha Biotech Industries PLC (MBI) on the benefits of *Rhizobia*-inoculated legume seed or bio-fertilizers. The following plenary discussion recommended MBI develop an evidence base for the benefits of bio-fertilizers, including yield increases in legumes and follow-on cereal crops.

In November 2015, the AKLDP asked a senior Ethiopian researcher[iii] to undertake a field assessment of the impacts of bio-fertilizers on faba bean (*Vicia faba)* and chickpea (*Cicer arietinum*). The assessment included a literature review, meeting stakeholders and fieldwork in two *kebeles*[iv] in each of four *woredas* – Lemunabilbilo and Digelunatijo, Arsi zone and Ade'a and Gimbichu, East Shewa zone. The fieldwork focused on faba bean in the two *woredas* in Arsi zone, and chickpea in East Shewa zone. During the fieldwork, the researcher conducted focus group discussions (FGDs) with 138 farmers– including 18 women – of which 116 had used *Rhizobia*-inoculated seed. Development Agents, *woreda* experts, researchers and private sector representatives were also interviewed. The Field Assessment focussed on understanding cropping systems, the use of and benefits of bio-fertilizers on legume and follow-on cereal crops yields, and reviewed barriers to the up-take of bio-fertilizers.

Assessment Findings

The Field Assessment found that despite a long history of research on bio-fertilizers in Ethiopia dating back to the early 1980s, commercially available bio-fertilizers did not become available for farmers until 2010, following the launch of MBI. Subsequently, the National Soil Laboratory (NSL)[v], other research centers and some development projects[vi] have started to market and distribute bio-fertilizers. Therefore, *Rhizobia*-inoculated seed is available to some extent in Ethiopia for faba bean, chickpeas, lentils, field pea, haricot bean, soybean and mung bean.

Woreda officials estimated average land holdings of 2.5ha in Arsi zone and 2.0ha in East Shewa zone; average family size was estimated to be six persons. Land holding averages are however rather misleading as *woreda* officials also reported a growing number of landless households, estimated at approaching 50% in some kebeles. However, it was also difficult to assess the size of farm holdings accurately as used different descriptions of their land and that these were approximations e.g. '*kert'* – the stretch of a farmer's stride and '*timad*' – the area a pair of oxen can plough in a day. As a result, the field assessment was not able to accurately assess yield per area.

Cereals continue to dominate arable cropping with a mix of wheat for bread and barley in Arsi zone and wheat for bread and pasta, and teff in East Shewa zone. Faba bean and field peas are also gown in Arsi zone and chickpeas and lentils in East Shewa zone. It was not possible to estimate trends in the planting area of pulses in Arsi and East Shewa zones, but national-level CSA 2014/2015 production data[vii] indicates that the area planted to pulses in Ethiopia is in overall decline. In the last 5 years the area planted to faba bean, field pea, grass pea and lentils has fallen by 18%, 16%, 19% and 21% respectively. In contrast, the area planted to chickpea has increased by 4% in the same period.

The FGDs confirmed that farmers planted other crops including teff, linseed and mustard. Crops are used for both home consumption and sale, with farmers reporting sales of up to 60% of faba bean[viii] in Arsi zone and 80% of chickpeas in East Shewa zone. Typically, legumes are sold for higher prices than cereals. This price differential enables farmers to sell legumes and buy back larger volumes of cereals. This trade increases the availability of calories at household level.

Aware of the importance of soil fertility, and soil borne pests and diseases, farmers routinely practice rotations. In Arsi zone commonly used rotations included: cereals, pulses, oilseeds and cereals; cereals, pulses, cereals and cereals; and cereals, pulses, cereals and fallow. In contrast, rotations in East Shewa zone included wheat, pulses, teff and pulses and wheat, pulses, teff, teff and pulses. Over the last decade, population increase has resulted in increased pressure on land holdings and a decline in the size of farm-holdings. While data is not available for the study area, IFPRI (2015)[ix] estimate that at the national level average holding size has declined by 14% in the period 2005 to 2015. This decline in holding size has resulted in many farmers abandoning the traditional practice of 'fallowing'[x] in favour of an increase in the application rates of inorganic fertilizer. Fertilizer is used not only on cereal crops, but increasingly for legumes and oilseeds in Arsi zone.

The use of bio-fertilizers

Woreda records for bio-fertilizer use are incomplete. However, a review of available records confirmed that since 2010 farmers in Lemunabilbilo *woreda,* Arsi *zone* have used more than 4,550 packets of bio-fertilizer[xi] for faba bean and 1,700 packets for field-peas. Appropriately used, this is sufficient to plant 40% of the total area cultivated under these crops in the *woreda*, in the period to 2015. Similarly, records in Aed'a *woreda*, East Shewa confirm that since 2010 bio-fertilizer has been used by more than 7,500 farmers, including 100 female-headed households.

The field assessment also confirmed that in 2015, the Agricultural Growth Program (AGP) distributed 1,600 packets of bio-fertilizer – 1,200 for chickpea and 400 packets for lentils – in Gimbichu *woreda*, East Shewa to plant 300ha chickpeas and 100ha lentils. In addition to distributing bio-fertilizers, *woreda* officials confirmed that basic farmer training now includes basic information on the use of bio-fertilizers and that in Lemunabilbilo and Digelunatijo *woredas*, Arsi zone more than 5,760 farmers – including 1,360 female-headed households and 4,170 farmers – including 1,000 female-headed households respectively have received this training. Bio-fertilizer trainings and demonstrations have also been supported by various agriculture research centers including Kulumsa and Debrezeit.

In 2015, the MBI reported total sales of 74,900 packets of bio-fertilizers for faba bean, haricot bean, field-pea, soya bean, lentils, chickpeas and mung bean or enough bio-fertilizer to inoculate seed to cover 18,700ha or 1.5% of the total arable area planted to legumes in Ethiopia. Bio-fertilizer for faba bean accounted for 24% of the sales while chickpea accounted for 26% of the sales.

Changing yields following use of bio-fertilizers

All FGDs reported that under normal conditions, inoculated seed produced vigorous seedlings, strong stemmed plants, fewer sterile flowers, and plump and well filled seeds and pods.

Under normal rainfall conditions, farmers reported the use of bio-fertilizers typically resulted in substantial yield increases of faba bean in Arsi zone (Table 1), with the highest increase of 59% recorded in Burkito-Alkesa *kebele*. Substantial increases were also reported for wheat follow-on crops of 40% to 168%, and barley follow-on crops of 35% to 50%, although relatively few farmers planted barley. In *kebeles* where few farmers were interviewed, large increases in wheat and barley follow-on crops were reported consistently, but no statistical analysis was conducted.

The field assessment also notes that in parallel with the development of bio-fertilizers, regional bureaus of agriculture had introduced improved agronomic practices – certified seed, land preparation and pest management – and that these practices may also have contributed to yield improvement. It is not therefore possible to attribute all yield improvements to the use of bio-fertilizers.

Of interest, farmers in Arsi zone reported they had experimented with bio-fertilizers and used inoculated faba bean seed in subsequent plantings with a view to repeat increased yields. However, this practice is not recommended by the extension services as *Rhizobia* bacteria remains active in the soil for several years after the use, and the early repeat use of bio-fertilizers is therefore neither required nor advised.

Table 1: Farmer estimates of changing faba bean and 'follow-on' cereal yields in Arsi Zone, before and after using bio-fertilizers

Crop, *kebele*	Median yield before bio-fertilizer (q/ha)	Median yield after bio-fertilizer (q/ha)[a]	Median change in yield (q/ha) (95% CI)[xii]
Faba bean			
- Bekoji-Negesso	17.5	26.6	9.88 (5, 18)*
- Lemu-Dima	22.0	31.0	9.00 (6, 14)*
- Sagure-Mole	15.6	27.0	10.38 (7, 15)*
- Burkitu-Alkesa	13.0	32.0	20.00 (14, 26)*
Wheat follow-on crops[b]			
- Sagure-Mole	33.1	48.0	13.88 (5.75, 21.50)*
Barley follow-on crops[b]			
- Bekoji-Negesso	32.0	40.0	11.00 (4, 18.75)*

* Significant difference at 95% confidence level; if the 95% confidence interval does not include zero, the difference is significant at that level.

[a] It was assumed that changes in yield after the use of bio-fertilizer could not be attributed solely to the use of bio-fertilizer – see text for further details.

[b] Wheat follow-on yields were recorded from farmers in Bekoji-Negesso, Lemu-Dima and Burkita-Alkesa *kebeles*, but statistics were not calculated due to small sample sizes; barley follow-on crop yields were recorded in Lemu-Dima *kebele* but again, statistics were not calculated due to the small sample size; see text for further details.

Table 2: Estimates of changing chickpea and follow-on cereal yields in East Shewa Zone, before and after using bio-fertilizers

Crop, *kebele*	Median yield before bio-fertilizer (q/ha)	Median yield after bio-fertilizer (q/ha)	Median change in yield (q/ha) (95% CI)[xi]
Chickpea			
- Katila	29.8	32.00	9.50 (-1.5, 20)
- Habruseftu	32.0	40.0	12.00 (3, 15)*
Teff			
- Katila	10.5	28.8	18.00 (6, 22.5)*
- Habruseftu	28.0	28.0	0 (-4, 4)
Wheat			
- Habruseftu	42.0	45.5	2.00 (-2, 6)

* Significant difference at 95% confidence level; if the 95% confidence interval does not include zero, the difference is significant at that level.

No changes in chickpea yields were recorded in Hidi or Deko *kebeles*, Aed'a *woreda.*

In East Shewa, changes in chickpea yields were

In East Shewa substantial increases in chickpea yields were evident in two *kebeles* after the use of bio-fertilizer (Table 2), but increases in the yields of follow-on teff and wheat crops were inconsistent, with many farmers reporting no change. They attributed this to poor quality seed, and erratic and poor rainfall. However, farmers in East Shewa zone had reduced the second 'top-dressing' of urea fertilizer from 75 to 50kgs on the basis there is more residual nitrogen after the use of bio-fertilizers; this practice is continuing with no apparent negative yield reductions.

Increased chickpea yields in Katila and Habrusefu *kebeles* (Table 2) were countered by farmers from Hidi and Deko *kebeles* (Ade'a *woreda*), who reported little or no yield increases. Farmers attributed this to poor seed quality seed, and erratic and poor rains.

Other benefits of bio-fertilizers

Yield increases have the potential to improve food security and increase household income, assuming that the cost of adopting new technologies does not out-weigh potential gains. However, the field assessment confirmed that the costs of using bio-fertilizer were minimal as the cost per packet – adequate for a quarter hectare – is Eth birr 55 with an additional Eth birr 8 for sugar that is mixed with the bio-fertilizer to ensure that it 'sticks' to the seed. Farmers also reported that the additional labour required to prepare the bio-fertilizer with water and sugar was less than '*the time taken to clean the soil from the wings of the maresha*[xiii] *plough at the end of each furrow*,' and therefore negligible.

It should be recognised that the field assessment interviewed relatively small numbers of farmers and relied on farmer-reported yields. However, a conservative estimate was that yield increases could result in an additional Eth birr 5-10,000/ ha over two years i.e. from increased faba bean yields in the first year and follow-on wheat or barley yields in the second year.

Farmers also reported other benefits:

- increased size and plumpness or *tiruzer* of faba bean seeds resulting in higher sale prices;
- increased soil fertility – more organic matter as plants are harvested at ground-level leaving roots and nodules in the soil – supporting a transition away from 'fallowing' and supporting an increase in 'productive farm holding size';
- reduced use of fertilizer.

In addition, women reported that:

- *tiruzer* faba beans are easier to cook resulting in reduced firewood/biomass use;
- legumes have an important role in household nutrition, in particular of poorer households who are less able to access animal sourced proteins; legumes are prepared in sauces *or shiro-wot* and snacks.

Therefore, the full economic benefit of the use of bio-fertilizers is substantially more than the Eth birr 5-10,000/ha associated with productivity increases alone.

Barriers to increased up-take

Barriers to the take-up of bio-fertilizers can be summarized as follows:

Training: while basic agronomic training includes the promotion of bio-fertilizers in some areas, farmers reported that the training was superficial and did not provide detailed information on the associated benefits and challenges.

Extension: the number of demonstration plots on model farmer fields is modest and so many farmers remain unaware of the potential impact of bio-fertilizers. In addition, it was found Farmer Training Centers had little technical resource information on bio-fertilizers or indeed access to bio-fertilizer related training materials.

Availability: farmers in Arsi reported that in 2015, bio-fertilizers only became available in the first week of July, which was late for the main planting season in mid-June. In other areas, farmers reported they had to travel to major market towns to buy bio-fertilizers, with reported travel distances of up to 30km. In response, some farmers had organized group purchases[xiv] from research centers and MBI. However, farmers also noted the irregular supply of bio-fertilizer from research centers and that even when Development Agents were engaged, this did not necessarily ensure that adequate bio-fertilizer was provided to meet the full order

Pricing and coordination: farmers commented on different pricing e.g. projects might distribute bio-fertilizer free of charge in the first year on the understanding that charges will be introduced in the second and subsequent years. However, due to weak coordination, new projects operating in the same area may again distribute bio-fertilizer for free after earlier projects have transitioned to charges. In addition, different projects may also charge different rates in year two onwards. Farmers reported that in 2015 different projects were marketing bio-fertilizer at a range of rates from Eth birr 30-50 per packet.

Quality: researchers and other key informants highlighted the lack of regulation with different *Rhizobia* strains marketed for the same legume crop, but without adequate customer information regarding the appropriate use. For example in 2015, three different *Rhizobia* strains – 110, 1035 and 1018 – were available for faba bean producers in Arsi zone.

Other: the up-take of bio-fertilizers may be compromised by other factors including unresolved disease and seed issues as well as changing weather patterns.

Conclusions

- Faba bean – there were high levels of farmer confidence in the use of bio-fertilizers to increase faba bean yields and the yields of follow-on cereal crops.
- Chickpeas - the benefits associated with bio-fertilizers for chickpeas were more variable, and in some *kebeles*, difficult to assess due to poor seed, and erratic and poor rainfall.
- Other benefits associated with the use of bio-fertilizers were widely reported - reduced fertilizer use, improved soil fertility, more efficient use of biomass for cooking *tiruzer* faba beans.
- The benefits of use of bio-fertilizer use extend beyond increased yields and income to include improved dietary diversity, and reduced workload for women.
- Despite the benefits, there are multiple barriers to the wider up-take of bio-fertilizers e.g. inadequate extension, availability, pricing and coordination issues, and the urgent need for the appropriate regulation and quality control.

Recommendations

Based on these conclusions, the AKLDP recommend the early establishment of a 'Bio-fertilizer Platform' to champion the following improvements:

- A strengthened regulatory system that approves the production of new *Rhizobia* strains and requires clear instructions on their use, including for which crops, in which areas and for which agro-ecologies.
- The development of improved farming training and associated extension modules through farmer training centers, model farmers and most importantly farmer-to-farmer groups that should include women-headed households.
- The phased sustainable increase in supply of approved bio-fertilizers to priority areas primarily through the private sector.
- The issuing of recommended price ranges for *Rhizobia* products by the extension services to help farmers understand appropriate pricing structures.
- The improved coordination of all research and extension within an agreed bio-fertilizer strategy.
- Additional research with farmers, including quantitative data collection on yields of legumes and follow-on cereal crops, to strengthen the evidence-base.

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Endnotes

[i] IFPRI, Cereal Productivity and its Drivers: The case of Ethiopia, in press
[ii] Rhizobia strains are isolated and tested in the laboratory with different legume plants and the most efficacious in terms of nodule formation are multiplied-up to use as bio-fertilizers.
[iii] Dr. Nigussie Alemayehu
[iv] The lowest tier of local government, rather like a parish in some neighboring countries.
[v] Not in 2015 as the plant was being renovated.
[vi] N2Africa is a large scale, science-based "research-in-development" project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops www.n2africa.org/
[vii] CSA, 2014/2015. Agriculture Sample Surveys www.csa.gov.et/index.php/about-us/8-home
[viii] Some of which is historically exported.
[ix] See End Note i.
[x] Fallow is a traditional method that leaves arable land unploughed for a year or two years in order the soil is 'rested'. These areas are typically grazed by livestock and the resultant manure and urine help enrich the soil and restore fertility.
[xi] A packet of bio-fertilizer is adequate to inoculate seed to plant up to 0.25ha.
[xii] Statistics calculated using Confidence Interval Analysis software version 2.2.0.
[xiii] A local plough used widely throughout Ethiopia. The '*maresha*' is typically pulled by plough oxen.
[xiv] Farmers in Chole Woreda, Arsi organized themselves to purchase bio-fertilizers from Kulumsa Agricultural Research Station.