Sustainable intensification of grain legumes with smallholders in Africa through nitrogen fixation: highlights from the N2Africa project

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Improving Nitrogen Fixation in grain legumes is central to the sustainable intensification of agriculture in sub-Saharan Africa (SSA) and inoculation with effective rhizobia can make an important contribution to this goal. Genetic and phenotypic studies have identified large taxonomic diversity and differences in symbiotic effectiveness between isolates from SSA soils, suggesting that there is potential for developing more effective inoculants from native bacteria. The N2Africa project has pursued two approaches in this regard: First, identification of elite strains from native rhizobial collections with the aim of developing inoculants for local production in SSA and second, promotion of inoculation with effective bacterial strains at scale. Here, we report the genetic and symbiotic diversity of indigenous isolates, success with the search for elite strains and achievements of the project in getting the inoculant technology out to farmers at a larger scale through Private Public Partnership (PPP). Response of crops to inoculation across a large number of smallholder’s farms, covering diverse soil fertility and agro-ecological conditions, was evident. Commonly, increased grain yield of >10% over yield on control plots (a yield level assumed to be visible to farmers) was realized for most farmers. However, observed grain yields on control plots and responses to inoculation on individual farms varied greatly with a relative yield responses ranging from 3% - 100%. The additive benefits and possibilities for a wide scale promotion of inoculant technology to smallholders through a PPP approach will be discussed.

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Putting nitrogen fixation to work for smallholder farmers in Africa

Sustainable Intensification of Grain Legumes with Smallholders in Africa through Nitrogen Fixation: *Highlights from the N2Africa project*

by Endalkachew Wolde-meskel, country coordinator N2Africa project, ILRI-Addis, Ethiopia

N≡N \( \Rightarrow \) NH₄⁺
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No N, not inoculated  Test strain  Reference strain  + N, not inoculated
- The project
- Biodiversity of rhizobia (genetic and symbiotic diversity): *the case of Ethiopia*
- BNF technology benefiting smallholder in Africa
- PPP for scaling out of the technology
Mr. Mulatu, Ethiopia:
Even under the current drought, the inoculated CB podded better
Are you coming also this year to establish demo plots? We are convinced that the tech. works—please bring the inoculants so we grow more for market.
The underlying problem - poor soil fertility

Heterogeneity - what some authors - Scoones/Toulmin/Leach/Fairhead have described as ‘making new soils’ ‘carving new niches out of barren land’ - attractive ideas - man in synergy with nature
Potential solutions - Nitrogen fixing legumes

“But what can we use these crops for?
N.B. Soil fertility improvement is a secondary goal – farmers have consistently rejected green manures, cover crops and fertilizer trees
Inoculated with sterilized soil

Inoculated with untreated soil
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N2Africa - www.N2Africa.org

- Led by Wageningen University; with IITA, ILRI, AGRA and many national partners

- Implemented in 11 countries – Ghana, Nigeria, Ethiopia, Tanzania, Uganda (Core countries) and DRC, Kenya, Malawi, Mozambique, Rwanda, Zimbabwe (Tier 1 countries)

- 1st Phase 2009-2013 – Proof of concept (US$22M)
- 2nd Phase 2014-2018 – Scaling through partnerships; institutionalisation (US$30M)
## N2Africa – target legumes

<table>
<thead>
<tr>
<th>Countries</th>
<th>Target Legume Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Africa</td>
<td>Cowpea, Groundnut, Soybean</td>
</tr>
<tr>
<td>East and Central</td>
<td>Cowpea, Groundnut, Soybean, Common Bean</td>
</tr>
<tr>
<td></td>
<td>Chickpea &amp; Faba bean (in Eth.)</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>Cowpea, Groundnut, Soybean, Common Bean</td>
</tr>
</tbody>
</table>
How to increase the inputs from N$_2$-fixation

- Increase the area of land cropped with legumes (targeting of technologies)
- Increase legume productivity – agronomy and P fertilizer
- Select better legume varieties
- Select better rhizobial strains and inoculate
- Link to markets and create new enterprises to increase demand for legumes
N2Africa is a development to research project

- Delivery and dissemination are the core
- Monitoring & evaluation provides the learning
- Research analyses and feeds back

Registered inocu., in TZ
Registered, inoc., Nigeria
Registered, inoc., in Eth.
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Genotype × Environment × Management

\[(G_L \times G_R) \times E \times M\]

Where:

- **G**<sub>L</sub> = legume genotype
- **G**<sub>R</sub> = rhizobial strain
- **E** = environment
  - climate (temperature x rainfall x daylength etc) - to encompass length of growing season etc
  - soils (nutrient limitations, acidity and toxicities)
- **M** = management
  - agronomy – inoculation, seeding rates, plant density (row spacing etc), weeding,
  - (Diseases and pests are also a function of G x E x M....)
Collection: covering diverse agro-ecological locations (Alt., T°, RF, pH..)

Increasing size of bio-bank
- Ethiopia
- Kenya
- Ghana
- Nigeria
- Zimbabwe
Genomic diversity of Ethiopian rhizobia (AFLP dendrogram)

- 25 clusters (test strains found in 19)
- 11 unclustered positions (7 are test strains)

- Not linked to references (83%)

- References form separate clusters or unclustered

- Ethiopian soils harbour genomically diverse rhizobia not related to reference species

- These may represent taxonomic groups as yet unrecognised and warrant further phylogenetic analysis
Neighbour-joining Phylogeny estimated from partial 16S rRNA (67 test strains)
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New *Mesorhizonium* sp. *M. hawassense, shonense, abyssinica*

IJSEM (2013), 63, 1746–1753

**Concatenated**
- recA
- gyrB
- rpoB
- atpD
- glnII
- gltA

16S rDNA

**nodC**

a. 16S rRNA

b. Concatenated genes

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Rhizobium - (lentil isolates), SAM 40 (2017) 22–33
Bradyrhizobium - Cowpea, Groundnut isolates, SAM 40 (2017) 205–214
II. Diversity in Symbiotic Performances

Screening rhizobia for symbiotic effectiveness and PGP effect, (which strain?)

Symbiotic effectiveness
- In glasshouses
- Under field condition
- V by S by L, Multi-location
Symbiotic effectiveness (glasshouses)

- Soya strains: Naigeria
- Cowpea (V. unguiculata): Ghana
- Common Bean (P. Vulgaris): Ethiopia

Graphs showing the effectiveness of different strains and isolates in nitrogen fixation for various crops in different regions of Africa.
A search for more effective strains (S x V x L)

Overall performances of candidate elite strains, *P. vulgaris* (GY is an average of the three varieties at different Location)

<table>
<thead>
<tr>
<th>Candidate strains and controls</th>
<th>Grain Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB-NAK-91</td>
<td>1600 (check)</td>
</tr>
<tr>
<td>HB-429 (check)</td>
<td></td>
</tr>
<tr>
<td>HB-A-15</td>
<td>2100</td>
</tr>
<tr>
<td>+N-I</td>
<td>1900</td>
</tr>
<tr>
<td>-N-I</td>
<td>1100</td>
</tr>
</tbody>
</table>

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Strains isolated from beans in Kenya were marked with a plasmid-borne \textit{celB} gene and co-inoculated with CIAT 899 marked with \textit{gusA} (blue)

George Mwenda, Murdoch University
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Nodule occupancies following sowing of inoculated bean (10^6 cells of CIAT 899 per seed) into soils with 10^5 cells per g of soil of CIAT 899, NAK 287, NAK 210 or NAK 120

Mwenda, Terpolilli, Howieson and O'Hara Murdoch University, WA

Competition with rhizobia established in soil
Targeting of technology

Which strain? What works where? Why? for whom?

Crop targeted inoculants identified & ready

Registered inocu. in TZ
Registered, inoc., Nigeria
Registered, inoc., in Eth.

Improved varieties available

Targeting

Country
Region
Farming System
Farm (household)
Field
A ‘demonstration’ trial or farmer try-out

- Soybean, no inputs
- Soybean, + P
- Soybean, + inoculation
- Soybean, + P + inoculation

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**I +P Increased average grain yield of N2Africa target legumes**

Mean legume yields obtained on N2Africa’s demonstration trials compared to national average legume yields of three years (Ethiopian Central Statistical Agency 2014-2016 reports).
Effect of Inoculation and/or Inoculant on common bean, Ethiopia, 2015

Mean effects (kg/ha)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>+P+I</td>
<td>2013</td>
</tr>
<tr>
<td>+P</td>
<td>1714</td>
</tr>
<tr>
<td>+I</td>
<td>1572</td>
</tr>
<tr>
<td>Control</td>
<td>1415</td>
</tr>
</tbody>
</table>

SED: 63.6

23 on-farm trials

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On farm grain yield of chickpea with Inoculation and/or P-fertilizer in Ethiopia, 2014 - 2016
Effect of Inoculant and/or P-fertilizer on soybean grain yield (t ha\(^{-1}\)) in Nigeria, 2011 and 2012

Mean effects (kg/ha)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean Effect (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+P+I</td>
<td>1745</td>
</tr>
<tr>
<td>+P</td>
<td>1420</td>
</tr>
<tr>
<td>+I</td>
<td>1415</td>
</tr>
<tr>
<td>Control</td>
<td>968</td>
</tr>
</tbody>
</table>

SED = 48

Cumulative probability of increase (t ha$^{-1}$) in soybean grain yield compared with control, Nigeria, 2011 and 2012

>70% increase of 0.5 t/ha with P+I
30% increase of 0.5 t/ha with P or I alone

Why is it not working? – needs research

On farm chickpea yield increase with I+P evident for most of the smallholder farmers, Ethiopia 2012 - 2015

- Yield advantage of ≥ 1t over the control yield to 25.2% of the target farmers
- 37.4% of target farmers got yield advantage of 0.5 - 1t over the control yield
- 28% obtained yield advantage of 0.2 - 0.5t over control yield

**Cumulative Probability (%)**

**Chickpea Absolute Response to P &/or I (Kg/ha) [Yield of P and/or I minus control yield]**
Non-responsive soils
Pot experiments - Nigeria

Complete Control - P - K - Mg - Ca - S - Micro

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Inoculation and P application on Soybean, Gofa, Ethiopia
Cumulative probability of economic return to use of inputs in soybean (US$ ha\(^{-1}\)) in Nigeria, 2011 and 2012

Inoculation makes P economic!!

Inoculation enhances the nutritional quality in legumes residue

Inoculation improves feed quality

<table>
<thead>
<tr>
<th>Treatment</th>
<th>-P-I</th>
<th>+P-I</th>
<th>-P+I</th>
<th>+P+I</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP (%)</td>
<td>5.6</td>
<td>5.7</td>
<td>5.8</td>
<td>5.9</td>
</tr>
</tbody>
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## Partnerships: A model for sustainability and institutionalization

### The four project pillars

<table>
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<tr>
<th>Capacity Building</th>
<th>Input Demand Information and Delivery of proven legume technologies</th>
<th>Bulking and pulling marketable surplus, strengthening collective marketing, linking with lead firms and stimulate home consumption as an alternative</th>
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<tbody>
<tr>
<td>Stakeholders’ capacity development on improved legume technologies, agribusiness, gender mainstreaming, legume value addition and nutrition</td>
<td>Input demand information and delivery of proven legume technologies</td>
<td>Bulking and pulling marketable surplus, strengthening collective marketing, linking with lead firms and stimulate home consumption as an alternative</td>
</tr>
<tr>
<td>Market Access</td>
<td></td>
<td></td>
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The PPP – for largescale dissemination of the technology

Inputs
• Inoculant
• Chemical Fertilizer
• Improved Seeds
• Agro chemicals

Smallholders (producers)

The nucleus farm, Balegreen Spice and Grain Development, pioneered

• Mechanizing chickpea farming and breaking prolonged cereal mono-cropping
• Out-grower arrangement with 23,000 smallholder farmers to grow Kabuli chickpea
• Stimulated legume technology scale up through
  • Strengthened seed system development
  • Serve as last mile delivery for inoculants from MBI
  • Grain bulking and delivery to ACOS for the Monino Kabuli variety

• Buyers

Role mapping and overview of the South-East Public-Private Partnership Center
Partnerships - components covered

- In total 81 signed partnerships with public & private partners
- Dissemination forms major component of partnerships
- Capacity building, output markets and input supply integral in most partnerships
• N2Africa Phase I - Large scale dissemination of legume technologies to 225,000 farmers

• Phase II targets 600,000 farmers
For updates
www.N2Africa.org

• Lots of video resource materials
• N2Africa Podcaster - Monthly Newsletter
THANK YOU