Opportunities for sustainable intensification of small-landholder cropping systems

Enhancing biological nitrogen fixation of leguminous crops grown on degraded soils in Uganda, Rwanda, and Tanzania

Mark Westgate PI

Global Pulse Researchers Meeting
Kigali, Rwanda
February 13-17, 2012
Critical problems limiting legume yields in Sub-Saharan Africa (NAP 2008)

• Declining soil fertility and inefficient cropping systems unable to utilize available resources effectively and efficiently

• Limited accessibility and affordability of quality seeds, non-seed inputs and other yield-improving technologies

• Effects of drought and other weather related factors compromise productivity and quality

• Diseases (root rot, anthracnose, angular leaf spot, common bacterial blight, viruses, rust, ascochyta blight) and insect pests (bean stem maggots, aphids, storage weevils)

**Approach:**
Integrate key scientific disciplines to **bridge basic research discovery with practical applications** for improving bean germplasm and on-farm yields

![Venn Diagram](image)

**Target:** Biological Nitrogen Fixation
Biological Nitrogen Fixation (BNF) by common beans lags behind other major legumes.

Rates of BNF on farm are typically a small fraction of genetic potential.

Adapted from Peoples et al. 2009
Why is greater BNF (and yield) not realized?

- BNF $\sim$ rhizobia x host x environment x crop management
  - Host/rhizobium specificity
  - Susceptibility to abiotic stresses
  - Difficulty in selecting for the trait
  - Cultural norms, lack of incentive, Ag policies
Challenge--develop legume ideotypes adapted to climate change

• What shoot characteristics can be altered to stabilize BNF and increase grain yield?

• What root/nodule characteristics will maintain BNF in adverse soils?

• What soil biological characteristics can be managed to enhance BNF and grain yield?
I. Agronomics: Evaluate yield response of improved bean varieties to commercial inoculants and management

- Impacts of soil fertility/crop management
- Evaluate indigenous inoculation potential
- I.D. phenotypic traits associated with high BNF
Yield at Namulonge (low altitude) and Mbarara (medium altitude) 2011.

Mak = Bio-fixer, USA = BU Biostacked, NBO = Bio-N-fix, Con = no inoculation

<table>
<thead>
<tr>
<th>Site</th>
<th>Variety</th>
<th>Inoculant</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mak</td>
<td>USA</td>
<td>NBO</td>
<td>Con</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(kg/ha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Namulonge</td>
<td>K132</td>
<td>569</td>
<td>372</td>
<td>347</td>
<td>654</td>
</tr>
<tr>
<td></td>
<td>Kanyebwa</td>
<td>556</td>
<td>508</td>
<td>406</td>
<td>453</td>
</tr>
<tr>
<td></td>
<td>K131</td>
<td>671</td>
<td>775</td>
<td>1030</td>
<td>817</td>
</tr>
<tr>
<td>Mbarara</td>
<td>K132</td>
<td>1900</td>
<td>1867</td>
<td>1278</td>
<td>1256</td>
</tr>
<tr>
<td></td>
<td>Kanyebwa</td>
<td>2033</td>
<td>2100</td>
<td>2133</td>
<td>1633</td>
</tr>
<tr>
<td></td>
<td>K131</td>
<td>1744</td>
<td>1994</td>
<td>1449</td>
<td>1822</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;0.05&lt;/sub&gt;</td>
<td></td>
<td>398</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td></td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Current varieties have high yield potential
- Inoculation is beneficial at high yields
- Yield response is variable across treatments/varieties
Failure to control plant density = low yield

- Blue = P-response trials, Uganda
- Red = Seed composition studies, Iowa

How, why, and when?
II. Soil microbiology: evaluate constraints to successful host–rhizobium symbiosis

http://www.uoguelph.ca/~mgoss/seven/nodules.jpg

1. Plant root releases elicitors of Nod gene expression.
2. Bacterium releases Nod factor.
3. Plant root demonstrates ion fluxes, expresses nodulin proteins, is infected, and undergoes nodule morphogenesis.

Figure 16.16
Overview of events leading to formation of legume–rhizobium symbiosis.

B&MBP
Approach:

- **Evaluate indigenous rhizobia populations:**
  most probable number (MPN) assay on trap crop. Characterize community by 454 sequencing 16S rDNA, nifD

- **Quantify nodule rhizobium source(s):**
  Inoculant or native? Assay nodule DNA with PCR-RFLP
"effective" rhizobia populations vary dramatically at HC and US sites (number g\(^{-1}\) soil)

<table>
<thead>
<tr>
<th>Soil Source</th>
<th>Othello</th>
<th>A55</th>
<th>G122</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kamuli, Uganda</td>
<td>8</td>
<td>0</td>
<td>3</td>
<td>3(\text{e})</td>
</tr>
<tr>
<td>Morogoro, Tanzania</td>
<td>210</td>
<td>550</td>
<td>91</td>
<td>284(\text{d})</td>
</tr>
<tr>
<td>Selian, Tanzania</td>
<td>200</td>
<td>1600</td>
<td>350</td>
<td>717(\text{c})</td>
</tr>
<tr>
<td>Kigali, Rwanda</td>
<td>79</td>
<td>340</td>
<td>340</td>
<td>253(\text{d})</td>
</tr>
<tr>
<td>Musanze, Rwanda</td>
<td>48</td>
<td>11000</td>
<td>41</td>
<td>3696(\text{a})</td>
</tr>
<tr>
<td>Rubona, Rwanda</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>4(\text{e})</td>
</tr>
<tr>
<td>Nyagatere, Rwanda</td>
<td>240</td>
<td>3800</td>
<td>2400</td>
<td>2147(\text{b})</td>
</tr>
<tr>
<td>Patterson, USA</td>
<td>63</td>
<td>810</td>
<td>20</td>
<td>298(\text{d})</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>107(\text{b})</td>
<td>2263(\text{a})</td>
<td>406(\text{b})</td>
<td></td>
</tr>
</tbody>
</table>

- Othello—pinto bean, A55—Middle American, G122—Andean
- **Significant Location and Genotype effects**
N assimilated by N2-fixation varies among Andean and Middle American varieties. A number of Andean lines with high PNF potential are available to breeders.
III. Genomics: Identify genetic markers and genomic regions associated with BNF and other agronomic traits

- Analyze unique bean populations for SNPs (single nucleotide polymorphism), BNF phenotyping to identify candidate markers
Andean Diversity Panel: 300+ Andean bean lines selected based on their importance to major bean breeding programs and consumers.

- Each line will be SNP genotyped to ID genomic regions associated with TOI and parent selection.
- INITIALLY- for mapping of markers for pheno-typic traits related to variation in BNF.
- 0.9 Version of bean genome sequence available soon....use to ID genes controlling traits.
Targets in the shoot

- Stimulate/maintain ureide catabolism
  - allantoate amidohydrolase

- Incorporate plastid-based glyoxylate catabolism

- Decrease plant sensitivity to neighbors (Red/Far-red)
Targets in the roots

- Increase/maintain malate availability to bacteroids

- Maintain ureide export from non-infected cells (beans)

- Stabilizing nodule permeability to $O_2$

Buchanan et al. 2000

Gordon et al. (1997)
Targets in the soil

- Modify root exudates to capitalize on “enabling interactions” between roots and soil microbes
- Stimulate production of root-generated and microbe-generated molecules that induce “systemic tolerance” to abiotic stresses
Outcomes

• Strengthened Partnerships between US and HC Research Organizations

• Improved bean germplasm and practical tools to advance superior lines.

• Basic new knowledge to inform variety development, inoculum preparation, and certified seed programs.

• Well trained young scientists in a variety of agricultural disciplines
“Taking it to the Farmer”

• Widespread adoption of our scientific advances to intensify pulse-based cropping systems ultimately will be determined by cultural expectations and agricultural policies

  – Trustworthy markets drive ‘productivity initiative’ on farm

  – Government policies on land management and seeds systems have major impacts on farming practices

  – Yield/area is not always the most important criterion small-holder farmers use to select bean varieties.