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

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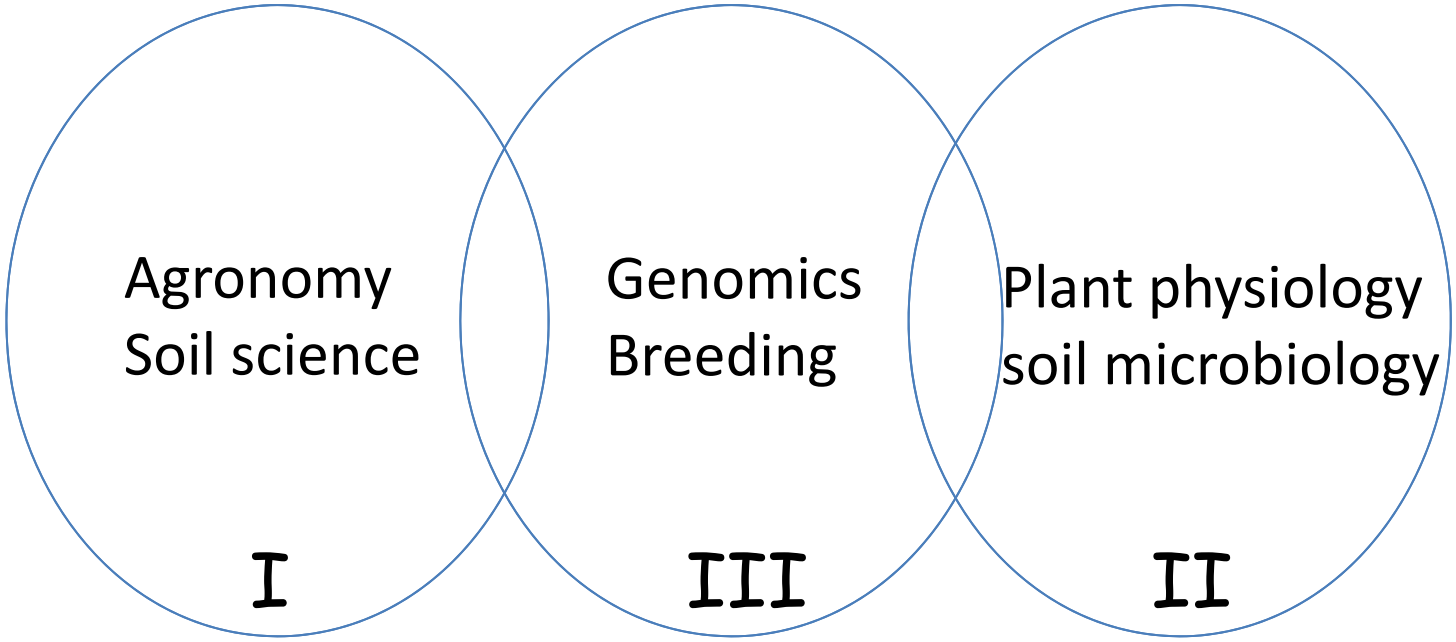
Critical problems limiting legume yields in Sub-Saharan Africa (NAP 2008)

- 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)

National Academies Press. 2008. Emerging Technologies to Benefit Farmers in Sub-Saharan Africa and South Asia.

Approach:

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

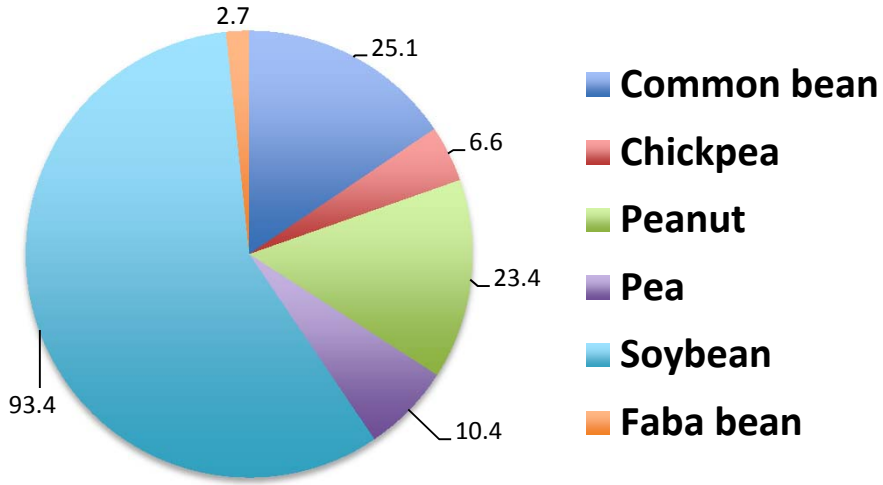


Target: Biological Nitrogen Fixation

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

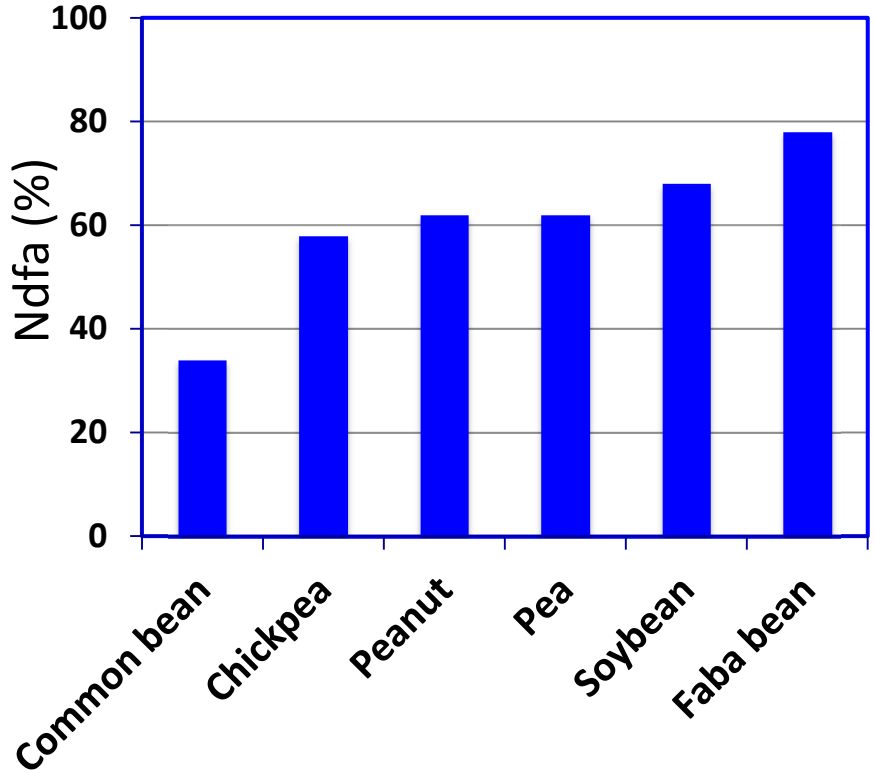
Total area grown (10^6 ha)



(total area 161.6 x 10^6 ha)

Adapted from Peoples et al. 2009

Proportion of shoot N derived from atmospheric N (%)



Why is greater BNF (and yield) not realized?

- BNF ~ 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

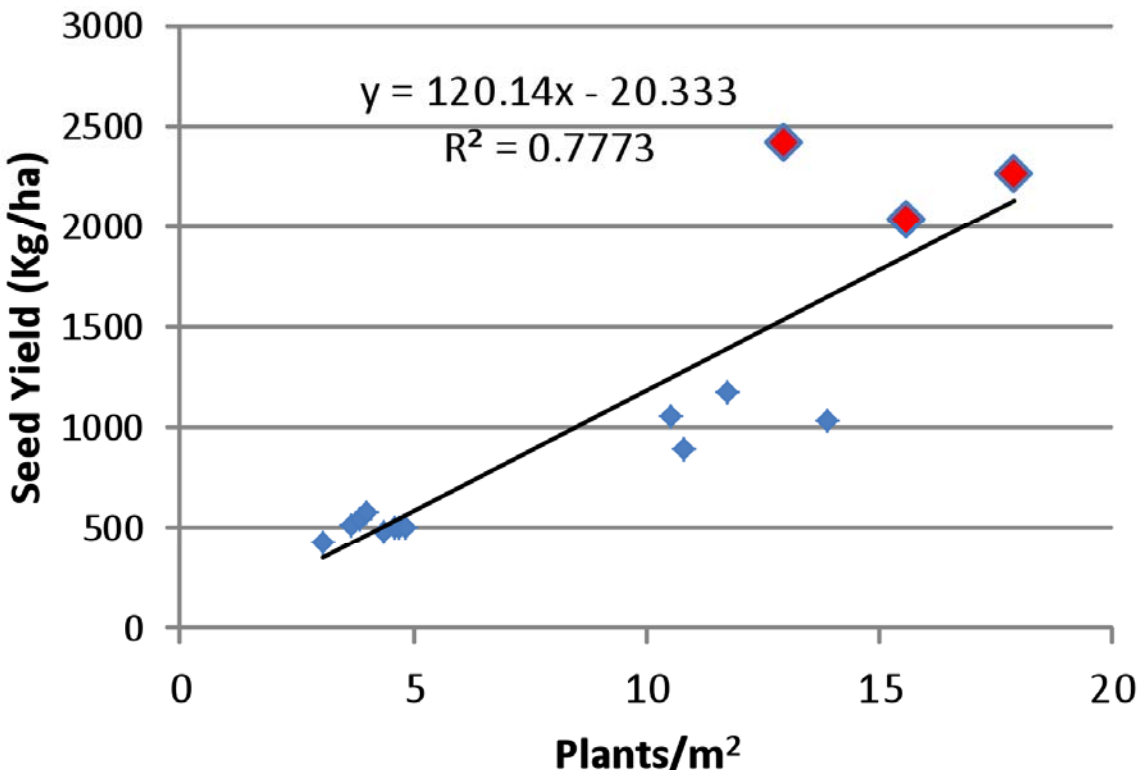
Yield at Namulonge (low altitude) and Mbarara (medium altitude) 2011.

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

Site	Variety	Inoculant			
		Mak	USA	NBO	Con
		(kg/ha)			
Namulonge	K132	569	372	347	654
	Kanyebwa	556	508	406	453
	K131	671	775	1030	817
Mbarara	K132	1900	1867	1278	1256
	Kanyebwa	2033	2100	2133	1633
	K131	1744	1994	1449	1822
$LSD_{0.05}$			398		
CV (%)			42		

- 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

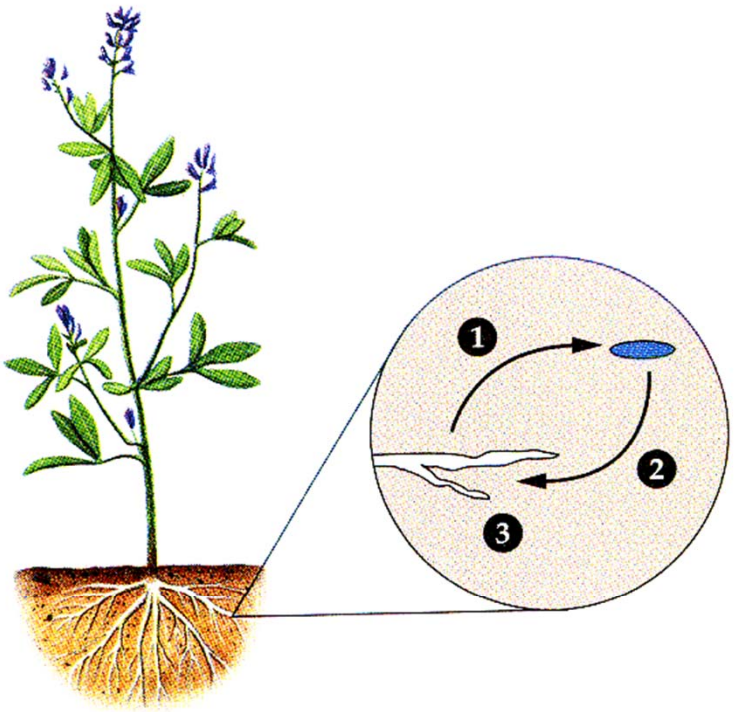


How, why, and when?

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

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

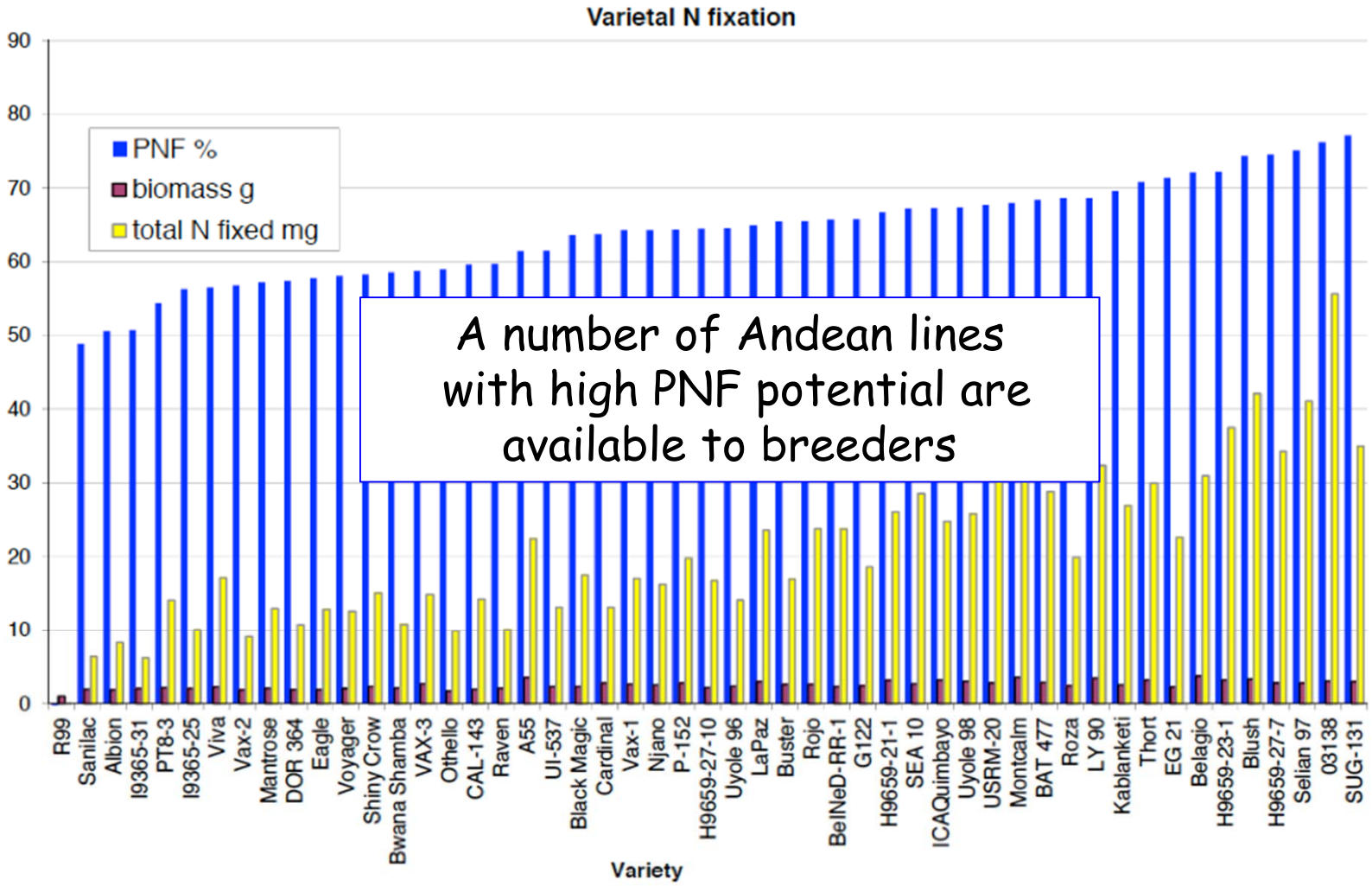
"effective" rhizobia populations vary dramatically at HC and US sites

(number g^{-1} soil)

Soil Source	Othello	A55	G122	Average
Kamuli, Uganda	8	0	3	**3 e**
Morogoro, Tanzania	210	550	91	**284 d**
Selian, Tanzania	200	1600	350	**717 c**
Kigali, Rwanda	79	340	340	**253 d**
Musanze, Rwanda	48	11000	41	**3696 a**
Rubona, Rwanda	9	2	0	**4 e**
Nyagatere, Rwanda	240	3800	2400	**2147 b**
Patterson, USA	63	810	20	**298 d**
Average	**107 b**	**2263 a**	**406 b**	

- 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

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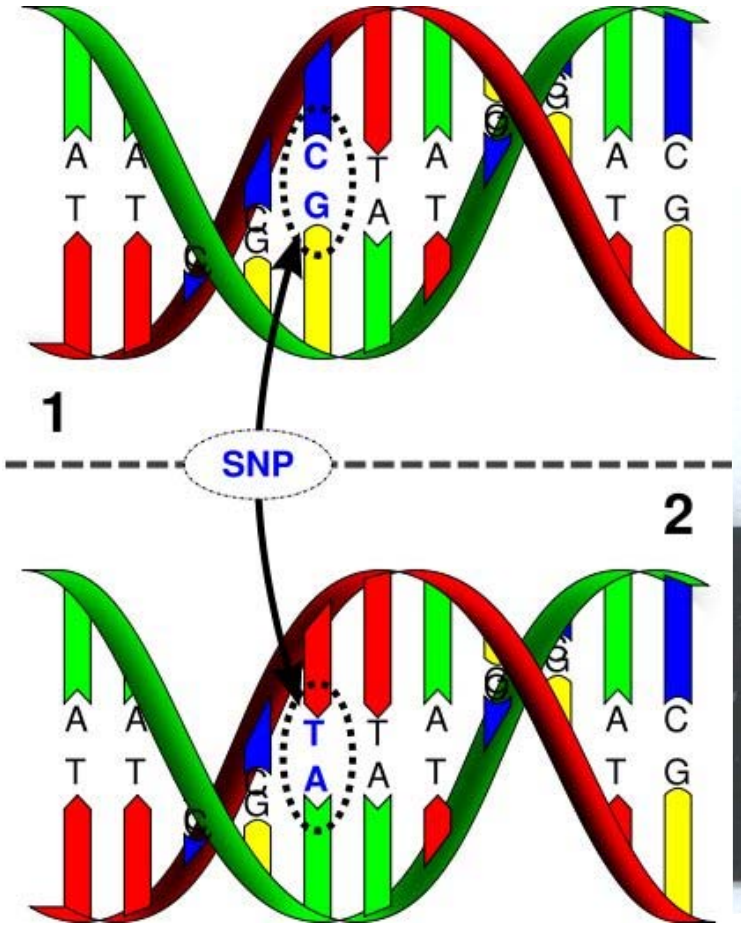
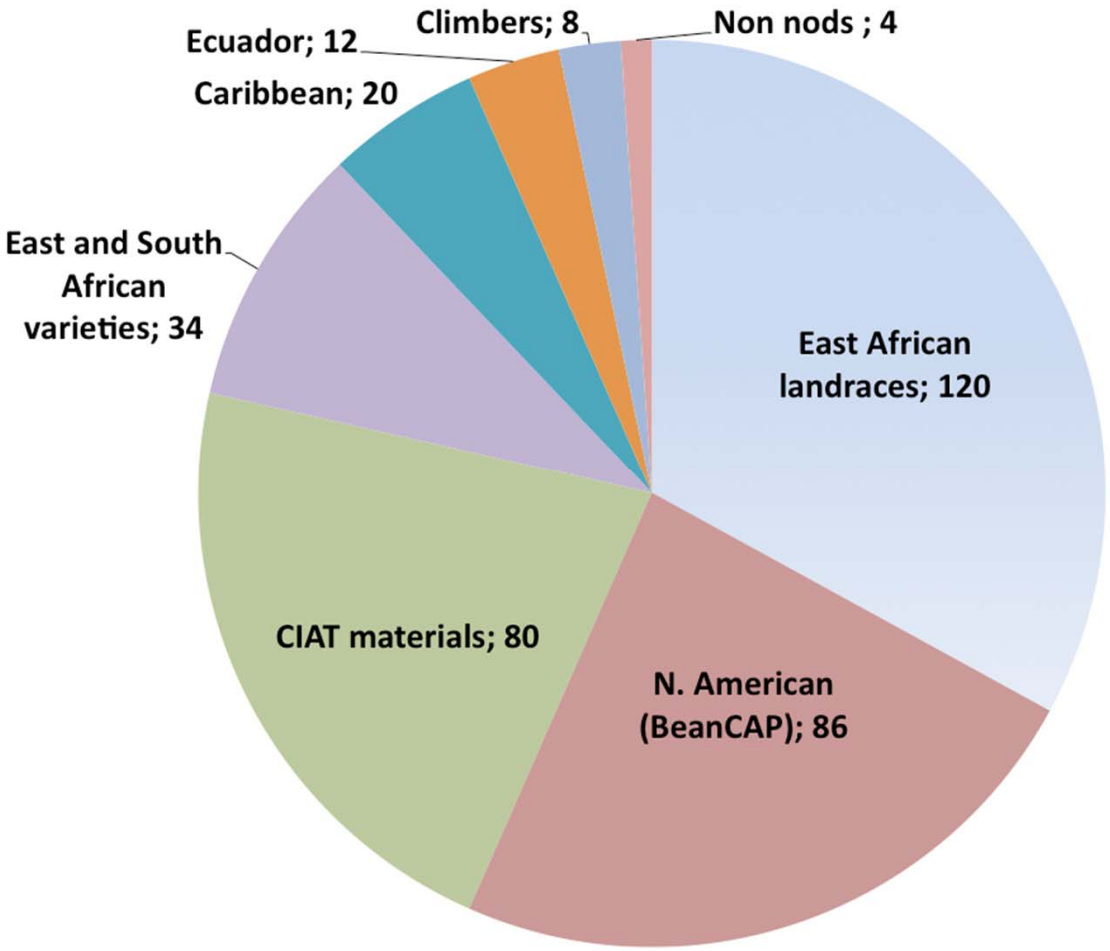
III. Genomics: Identify genetic markers and genomic regions associated with BNF and other agronomic traits

- **Analyze unique bean populations for SNPs** (single nucleotide polymorphism), BNF phenotyping to identify candidate markers



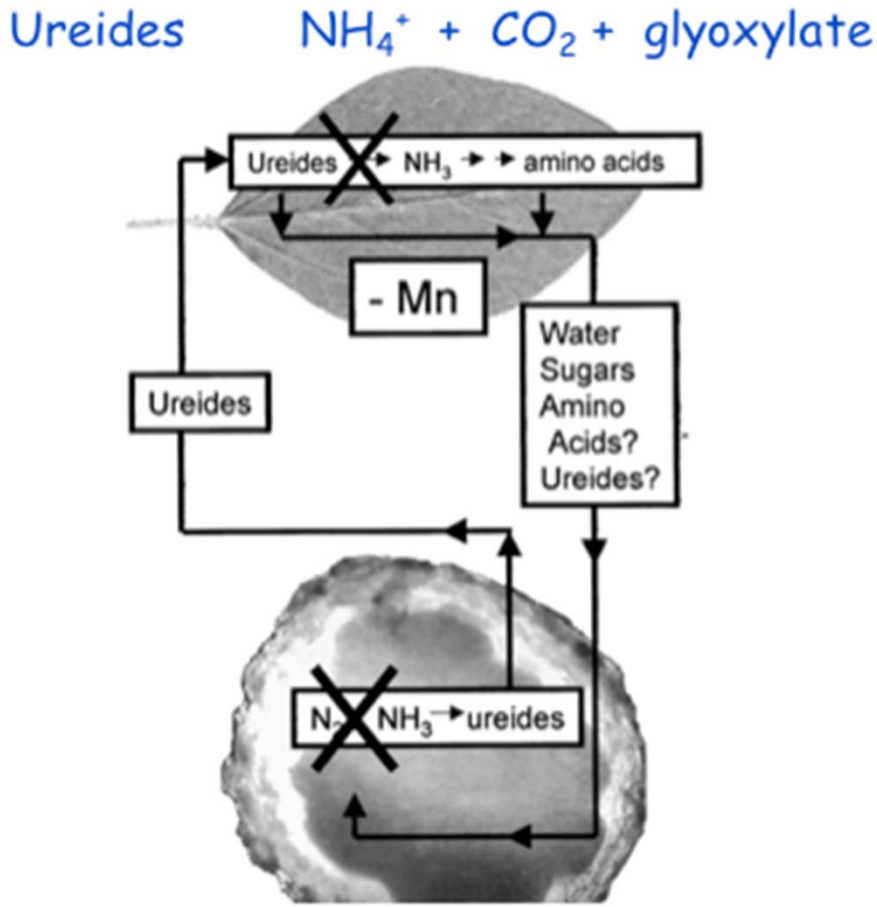
Andean Diversity Panel: 300+ Andean bean lines selected based on their importance to major bean breeding programs and consumers.

- 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)



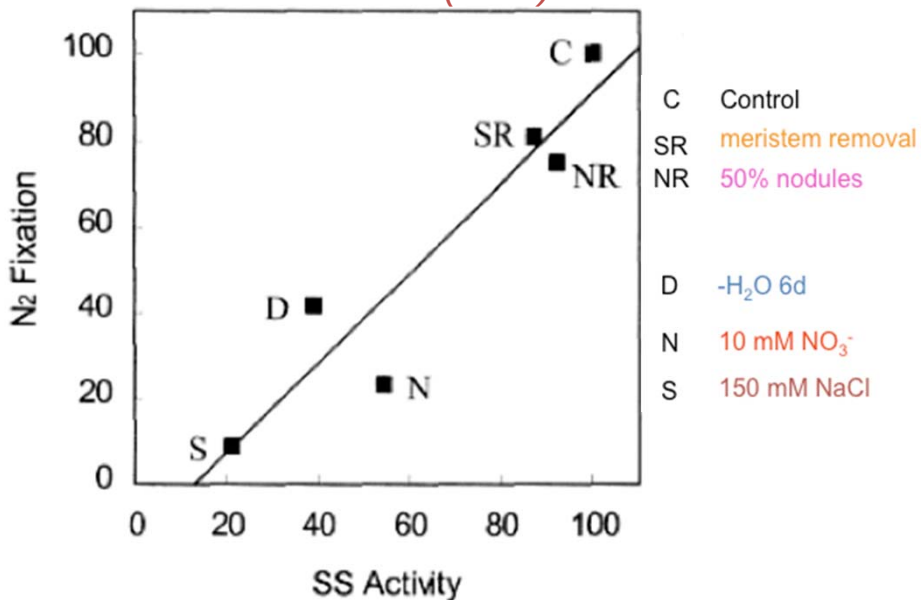
Model of nitrogen fixation response to manganese and ureide accumulation during water deficit

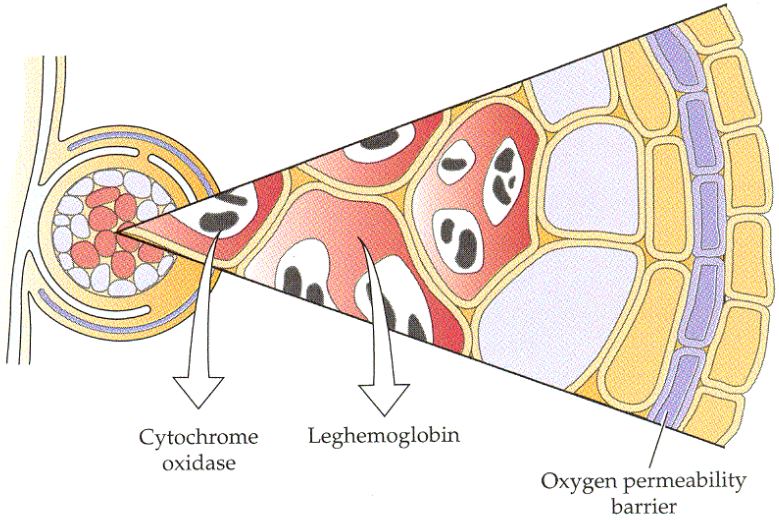
Purcell et al 2000

Targets in the roots

- Increase/maintain malate availability to bacteroids
- Maintain ureide export from non-infected cells (beans)
- Stabilizing nodule permeability to O_2

Gordon et al. (1997)



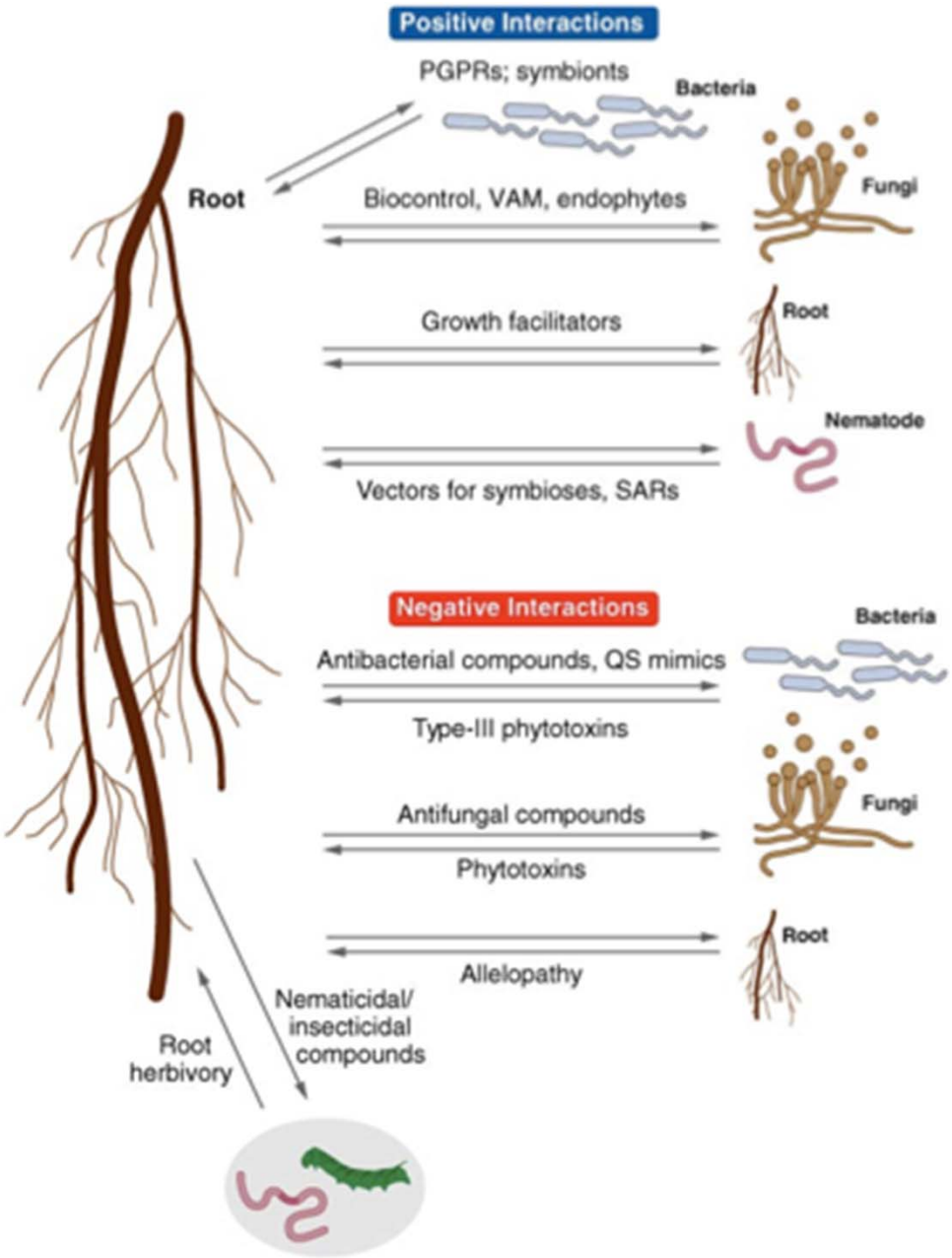


Buchanan et al 2000

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



Bais HP, et al. 2006.
Annu. Rev. Plant Biol. 57:233–66

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.