FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Innovation Lab for
Collaborative Research on Grain Legumes
(Legume Innovation Lab)

FY 2014 Technical Highlights

April 1, 2013–September 30, 2014

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Acronyms

ADP ....Andean Diversity Panel

ALS................angular leaf spot

ANT ....anthracnose

AOR...............Agreement Officer's Representative, USAID

ARS ....Agricultural Research Service (USDA)

ATA ....Ethiopian Agricultural Transformation Agency

BCMNV ....Bean Common Mosaic Necrosis Virus

BCMV ....Bean Common Mosaic Virus

BEA ....biding experimental auctions

Bean-CAP .....Bean Coordinated Agricultural Project

BGYMV..........Bean Golden Yellow Mosaic Virus

BHEARD........Borlaug Higher Education Agricultural Research and Development Program

BIC.................Bean Improvement Cooperative

BMS...............Bean Stem Maggot

BNF ....Biological Nitrogen Fixation

Bt...................Bacillus thuringiensis

BTD ....Bean Technology Dissemination

BUCADEF......Buganda Cultural and Development Foundation

CARITAS–MADDO ....Masaka Diocesan Development Organization

CBB...............Common Bacterial Blight

CEC ....Cation Exchange Capacity

CEDO .... Community Enterprise Development Organization

CGIAR ....Consultative Group on International Agricultural Research

CIAT...............Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)

CIAT...............Centro International de Agricultura Tropical International/Centerfor Tropical Agriculture

CIDI................Community Initiated Development Initiatives

CRI.................Crops Research Institute (Kumasi, Ghana)

CRSP.............Collaborative Research Support Program

CSB ....Community Seed Bank

CSIR ....Council for Scientific and Industrial Research (Ghana)

DS..................Drought Stress

EAP................Escuela Agrícola Panamericana–Zamorano (Honduras)

FE ....Field Experiments

FGD ....focus group discussions

FSRP ....Food Security Research Project

FTF ....Feed the Future

GM.................geometric mean

GWAS ....genome-wide association study

HC ....Host Country

HCPI ....Host Country Principal Investigator

IAR.................Institute for Agricultural Research, Nigeria

IARC ....International Agriculture Research Center (of the CGIAR)

ICM ....Integrated Crop Management

ICRISAT ....International Crops Research Institute for the Semi-Arid Tropics

ICTA...............Instituto de Ciencia y Tecnología Agrícola

IDIAF.............Instituto Dominicano de Investigaciones Agropecuarias y Forestales

IEHA ....Presidential Initiative to End Hunger in Africa

IGA ....Income Generating Activities

IIA ....Instituto de Investigação Agronómica, Angola

IIAM ....Instituto de Investigação Agrária de Moçambique (Mozambique)

IITA.................International Institute of Tropical Agriculture

INERA............Agricultural and Environmental Research Institute (Institut de l'Environment et des Recherches Agricole)

INIAP ....Instituto Nacional Autónomo de Investigaciones Agropecuarios (Ecuador)

INRAN ....l'Institut National de la Recherche Agronomique du Niger

INTA .... Instituto Nacional de Tecnologías Agrícolas (Nicaragua)

IPM-omics ..... Integrated Pest Management-omics

ISRA .... Institut Sénégalais de Recherches Agricoles

ISSD .... Integrated Seed Sector Development

ISU .... Iowa State University

KARI .... Kenyan Agriculture Research Institute, Kenya

KREC .... Kearney Research and Extension Center

KSU .... Kansas State University

LEAP .... Leadership Enhancement in Agriculture Program

LSMS–ISA ..... Living Standards Measurement Survey—Integrated Survey on Agriculture LSMS–ISA

LUANAR .... Lilongwe University of Agriculture and Natural Resources

M&E .... Monitoring and Evaluation

MAB .... Master of Agribusiness

MAS .... marker-assisted selection

MDP .... Middle American Panel

ME .... Management Entity (for the Legume Innovation Lab, Michigan State University)

MO .... Management Office (of the Legume Innovation Lab)

MSU .... Michigan State University

NaCRRI .... National Crops Resources Research Institute

NARS .... National Agriculture Research System(s)

NDSU .... North Dakota State University

NGO .... Nongovernmental Organization

NS .... Nondrought Stress

NSS .... National Seed Service (Haiti)

PaViDIA .... Participatory Village Development in Isolated Areas

PCCMCA .... Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales

PCR .... polymerase chain reaction

PI .... Principle Investigator

PIC .... Polymorphic Information Content

PVS .... participatory variety selection

QDS .... quality declared seed

QTL .... Quantitative trait loci

RCBD .... Randomized Complete Block Design

RCT .... randomized control trial

RFP .... Request for Proposals

SABREN .... Southern African Bean Research Network

SARI .... Savanna Agricultural Research Institute

SAWBO .... Scientific Animations Without Borders

SNF .... symbiotic nitrogen fixation

SNP .... single nucleotide polymorphism

SO .... Strategic Objective

SSGA .... Shangila Seed Growers Association

SUA .... Sokoine University of Agriculture

TAT .... Tepary Adaptation Trials

TMAC .... Technical Management Advisory Committee

UCA .... Universidad Centroamericana

UCAD .... University of Dakar

UCR .... University of California, Riverside

UIUC .... University of Illinois at Urbana–Champaign

UNL .... University of Nebraska

UNZA .... University of Zambia

UPR .... University of Puerto Rico

USAID .... United States Agency for International Development

USDA .... United States Department of Agriculture

USDA–ARS ... United States Department of Agriculture–Agricultural Research Service

UWO .... University of Western Ontario

VEDCO .... Volunteer Efforts for Development Concerns

ZARI .... Zambian Agriculture Research Institute

Preface

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab)

Throughout the world today, more than 800 million people suffer from chronic hunger, with demand for food projected to increase 50 percent over the next 20 years. Additionally, malnourishment, especially among infants and childbearing women, persists at unacceptably high levels. With most chronic hunger rooted in the rural poverty of developing countries, addressing agricultural challenges lies at the heart of Feed the Future's mission to create a sustainably food secure and well-nourished world.

Grain legumes represent a diverse group of edible leguminous crop species, including common bean, cowpea, lima beans, pigeon pea, chick peas, lablab, and lentils that contribute significantly to household food and nutritional security while also improving soil health. Nutrient-dense and affordable, grain legumes are considered a staple food throughout the world as well as a cash crop for resource-poor smallholder farmers, many of whom are women, in Africa and Latin America. For these reasons, grain legumes are a research priority crop for Feed the Future in harnessing scientific innovation and technology in agriculture and nutrition; Feed the Future recognizes that advancing science research is key to reaching its core objectives of reducing global hunger, poverty, and undernutrition.

In keeping with these priorities, USAID's Office of Agriculture, Research and Policy, Bureau of Food Security awarded a $24.5 million, 4.5 year extension (April 1, 2013 through September 30, 2017) of the Legume Innovation Lab program, previously branded the *Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP)*. In alignment with Feed the Future, the Legume Innovation Lab's technical approach is built on the premise that science, technology, innovation, and collaborative partnerships can accelerate the achievement of development outcomes more quickly, more cheaply, and more sustainably. This extension confirmed USAID's recognition of the importance of grain legumes for cropping system sustainability and the enhancement of dietary quality as well as the value of its collaborative research strategy. The Legume Innovation Lab draws on top U.S. universities and developing country research institutions to access cutting-edge research capacities and expertise to address challenges and opportunities facing the grain legume sectors in Feed the Future focus countries through a program that has spanned more than 30 years.

In keeping with Feed the Future's research strategy, Legume Innovation Lab projects focus on four strategic objectives that build on earlier program achievements. The global program goal of the Legume Innovation Lab is to substantively increase grain legume productivity through sustainable intensification of smallholder farm systems to increase the availability of affordable grain in domestic markets, increase consumption of legumes by the poor, and improve nutrition and nutritional security of critical populations in developing countries. This overarching goal is broken down into four strategic objectives (SOs).

Strategic Objective 1: Advancing the Productivity Frontier for Grain Legumes

- To enhance the genetic yield potential of grain legumes by improving resistances to economically important abiotic and biotic constraints that limit yield
- To sustainably reduce the yield gap for selected grain legume crops produced by smallholder, resource-poor farmers in strategic cropping systems

Strategic Objective 2: Transforming Grain Legume Systems and Value Chains

- To transform grain legume-based cropping systems through improved soil fertility operations and better management of value chains.

Strategic Objective 3: Enhancing Nutrition

- To improve the nutritional quality of diets and enhance the nutritional and health status of the poor, especially young children and women, through increased consumption of beans and cowpeas.

Strategic Objective 4: Improving Outcomes of Research and Capacity Building

- To assess the impacts of investments in research, technology dissemination, and institutional capacity strengthening to improve program effectiveness.

The eight projects presented in the *FY 2014 Technical Highlights Report* involve collaborative research, long- and short-term training, and technology dissemination activities in 10 sub-Saharan African countries (Benin, Burkina Faso, Ghana, Malawi, Mozambique, Niger, Senegal, Tanzania, Uganda, and Zambia) and three Latin American countries (Guatemala, Haiti, and Honduras).

This report highlights the technical progress and achievements made by Legume Innovation Lab projects during FY 2014. Two additional projects—*Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies* and *Legumes, Environmental Enteropathy, the Microbiome and Child Growth in Malawi*, under SO1 and SO3, respectively, were started later under the Legume Innovation Lab and will have progress reports in 2015. Readers should be aware that the *FY 2014 Technical Highlights Report* is only a one-year snapshot; achievement of research objectives requires years of investment; even small advances within a research project represent a significant commitment of effort. Note also that most development outcomes are not realized within the early years of a research project. Additionally, these highlights are condensed versions of more comprehensive technical reports that subcontracted U.S. universities provide annually to the Management Entity and USAID.

Technical progress reports are valued and utilized for assessing Legume Innovation Lab program performance and reporting by USAID to the U.S. Congress on Title XII and Feed the Future achievements and impacts. A small selection of noteworthy achievements for this fiscal year follows.

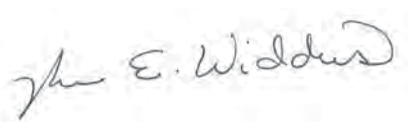
- Initial molecular genetic characterization of 25 climbing bean accessions and six breeding lines in Guatemala was completed.
- A standardized method for rating color and appearance of canned bean lots has been developed that could successfully replace the subjective, tedious, and costly visual sensory analysis at research facilities and bean canning industries.
- The tepary bean Tep-22 that combines resistance to common bacterial blight, rust, and bruchids was formally released. The development of disease-resistant tepary beans is significant because there are regions and growing seasons in Central America, Haiti, and Africa that are too hot or dry to produce common beans. The tepary bean is a potential alternative grain legume for these stressful environments.
- A multiple disease-resistant small-seeded black bean variety adapted to the humid tropics of Central America, XRAV-40-4, has been developed and released in Haiti. XRAV-40-4 combines resistance to the Bean Golden Yellow Mosaic Virus (BGYMV), Bean Common Mosaic Virus (BCMV), and Bean Common Mosaic Necrosis Virus (BCMNV). The need for resistance to these diseases has increased with expanded bean production in the Central American lowlands, which are generally warmer and more humid. Small-seeded black and red bean varieties also tend to have greater yield potential and heat tolerance than Andean beans planted in these areas.
- Red mottled bean lines PR0737-1 and PR0633-10, which combine the bgm-1 gene for resistance to BGYMV and the bc-3 genes for resistance to BCMV and BCMNV were approved for commercial production in Haiti.
- A panel of resistance sources was established and uniform test protocols designed for field and screen house aphid screening to characterize cowpea aphid biotypes. The tight genetic linkage between pinkeye and aphid resistance QTL (quantitative trait locus) has been broken so as to allow for the breeding of aphid-resistant blackeye cowpeas.
- Mechanisms to effectively deploy pest-control solutions in a cost-effective and sustainable manner are needed by smallholder cowpea farmers in West Africa. The unexpected recovery of pupae of the parasitoid *Apanteles taragamae* from *Maruca vitrata* feeding on flowers of the legume tree *Lonchocarpus sericeus* paves the way for more in-depth studies on the genetics of *Apanteles taragamae*. The goal is to release and establish natural populations of the *Apanteles taragamae* parasitoid in the natural environment near where cowpeas are grown to provide a biological control for the management of *M. vitrata*.
- An impact assessment study was completed in 2014 in Central America to examine the factors contributing to the success and sustainability of seed systems for grain legumes in different socioeconomic and agricultural systems contexts. Findings indicate that successful sustainable seed systems allow flexibility in payment methods and are closer in proximity to the communities they serve.

I encourage you to read the *FY 2014 Technical Highlights Report* in its entirety. A comprehensive view of the scope of vital outputs generated by each project and the new knowledge, management practices, and technologies resulting from the research activities provide an excellent picture of how the Legume Innovation Lab uses collaborative science research to advance food and nutrition security in developing countries. It is these outputs that will benefit stakeholders of grain legume value chains—from producers to consumers in Sub-Saharan Africa, Latin America and the United States.

For more detailed information on the Legume Innovation Lab, including its technical vision, annual workplans, technical progress reports, funding, and links to websites with additional information on grain legumes, please visit the program's web page at www.legumelab.msu.edu. We also have a Facebook page (Legume Innovation Lab) and twitter feed (Legume InnovationLab) that regularly publishes legume-related research.

As the director of the Legume Innovation Lab, I want to thank USAID for its financial support of this worthy program. USAID's investment in the Legume Innovation Lab under the Feed the Future presidential initiative is making a difference worldwide through its research and institutional strengthening activities on grain legumes. As a complement to the work of other international research programs (e.g., CG Research Program on Grain Legumes), the Legume Innovation Lab is making tangible contributions to the nutritional and food security of the rural and urban poor as well as to providing opportunities for resource-poor farmers and other value chain stakeholders to generate income and escape poverty. The host country and U.S. scientists and institutions partnering in this endeavor are to be thanked and commended for their commitment to scientific excellence, to generating new knowledge and technologies that bring the hope of a better tomorrow, and to training a new generation of scientists and professionals who will provide leadership to the agricultural development of many African and Latin American countries.

Dr. Irvin E. Widders



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Genetic Improvement of Middle-American Climbing Beans for Guatemala

(SO1.A1)

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Abstract of Research and Capacity Strengthening Achievements

This breeding project focuses on the genetic improvement of climbing beans for planting in the highlands of Guatemala. During the first year of this project, on-farm field testing and validation of nine breeding lines with near future release potential across 14 locations and extensive on-farm testing and validation of Bolonillo-Texel across 18 locations were conducted. An initial molecular characterization of 25 climbing bean accessions and six breeding lines was also conducted. Two women students were recruited for M.S. training in Plant Sciences, beginning in FY2015, at NDSU.

Two collaborations were established with other LIL projects—*Impact Assessment of Dry Grain Pulses CRSP Investments in Research, Institutional Capacity Building and Technology Dissemination for Improved Program Effectiveness* (SO4.1) and the associate award, *MASFRIJOL*, to augment the success of this project's breeding efforts.

Project Problem Statement and Justification

With approximately 11 million habitants, Guatemala is mostly a rural country, with 60 percent of the population living on farms and 50 percent of the population indigenous. Maize and beans are the main staple food in most households, with a per capita bean consumption of 9.4 kg per year. Since few other sources of protein are available, this amount is not sufficient to ensure an acceptable nutritional quality, especially within poor households. The lack of protein intake has reduced the nutritional quality in many households, significantly affecting children.

Demonstration plots of the improved climbing bean Bolonillo-Texel in a farmer's field in Huehuetenango. On the right, a plot with the farmer's local varieties of maize and beans (*milpa* system); on the left, a plot with the improved bean variety Bolonillo-Texel and the same local maize as that on the right (also using the *milpa* system). These side-by-side plots allow the farmers to easily compare the lines and see the yield improvements gained when using improved seed varieties.

Beans are grown on 31 percent of the agricultural land and mostly in the low- to mid-altitude regions (0–1500 masl [meters above sea level]) in a monoculture system. Contrastingly, intercropping (locally known as *milpa*) is the main production system in the highlands, where maize–bean is the most common crop association. Unfortunately, on-farm productivity of these climbing beans is approximately one-third of their genetic yield potential, mostly due to the lack of improved cultivars that are able to withstand biotic and abiotic stresses. Fungal and bacterial diseases and pests are the main cause of yield reductions. In addition, production is made with almost no inputs of fertilizers and/or other chemicals.

Historically, climbing beans worldwide have received less attention and breeding effort than the bush-type beans commonly grown in the lowlands, as evidenced by the significant yield gap between regions. In addition, there are genetic and environmental interactions among species (maize, bean, squash, etc.) not well understood within the intercropping system that may affect crop performance and, hence, seed yield. The Legume Innovation Lab has been involved in collaborative bean breeding research targeting lowland agroecologies in Central America, but research for the highland bean production systems is still lacking.

There is an existing collection of approximately 600 accessions of climbing beans collected from across all bean production regions in Guatemala. This collection is kept by ICTA and has been characterized morphologically, agronomically, and with a few molecular markers (six SSR primers). Initial results suggest that half of the collection consists of duplicates. In addition, some initial crosses among climbing beans and selections have been made by the ICTA group. These lines will be used intensively in this study.

Objectives

1. The development of germplasm with improved disease resistance and agronomic performance
2. An analysis of the genetic diversity of this unique group of germplasm
3. A socioeconomic study to gather detailed information about the current status of climbing bean production
4. Capacity building through training and equipment

Technical Research Progress

Objective 1: Development of germplasm with improved disease resistance and agronomic performance

1A. Field testing of 10 selected lines (ICTA)

A total of 10 climbing bean breeding lines that are at advanced breeding stages were selected to be part of field trials:

1. Bolonillo Altense
2. Bolonillo Hunapu

3. Bolonillo-Texel

4. Bolonillo Anita

5. Bolonillo LOV

6. Bolonillo Martin

7. Bolonillo ICTA Santa Lucia

8. Voluble GUATE 1120

9. Voluble GUATE 1026

10. Local check from the grower (differs among farms)

Most of these breeding lines are the product of initial crosses made five to six years ago and subsequent composite mass selection and testing by Dr. Fernando Aldana at the ICTA–Quetzaltenango station. Any superior line or lines could be released as varieties in the near future while a breeding pipeline is established.

The trials were planted in May and grown at the ICTA–Quetzaltenango station and in farmers' fields in 14 locations (Table 1).

Department	Municipality	Community	Type of Trial
Totonicapán	Paxtocá	Xecoshon	10-entry replicated trial
	Totonicapán	Chuisuc	10-entry replicated trial
	San Francisco el Alto	San Antonio Sija, Paraje Chipuerta	10-entry replicated trial
	Sta. María Chiquimula	Xesená, paraje Pachun	10-entry replicated trial
	Sta. Lucía la Reforma	Aldea Gualtux, paraje Xequelaj	10-entry replicated trial
	Paxtocá	Xecoshon	On-farm strip trials
	Paxtocá	Xecoshon	On-farm strip trials
	San Antonio Sija	Paraje Chipuerta	On-farm strip trials
	Momostenango	Pachawacán	On-farm strip trials
	Momostenango	Pancá	On-farm strip trials
	Sta. Lucía la Reforma	Gualtux	On-farm strip trials
	San Andrés Xecul	San Felipe Xejuyup, sector III	On-farm strip trials
Quetzaltenango	San Juan Ostuncalco	Las Victorias, Caserio Los Escobar	On-farm strip trials
	San Juan Ostuncalco	Caserío Los López	On-farm strip trials
	Olintepeque	La Cumbre	On-farm strip trials
	Olintepeque	La libertad	On-farm strip trials
	Cabricán	La Loma	On-farm strip trials
	Quetzaltenango	Aldea Choquí Alto, zona 6	10-entry replicated trial
	San Juan Ostuncalco		10-entry replicated trial
	Olintepeque	Barrio Pila Vieja, 3ra calle zona 1	10-entry replicated trial
Chimaltenango	Santa Apolonia	Xeabaj	10-entry replicated trial
	Tecpan	Chirijuyu	10-entry replicated trial
	San Juan Comalapa	Panabajal	10-entry replicated trial
	Sta. Cruz Balanya	Chuicapulin	10-entry replicated trial
	Zaragoza	Puerta Abajo	10-entry replicated trial
	San Miguel El Tejar	San Miguel El Tejar	10-entry replicated trial
	Tecpan	Chirijuyu	On-farm strip trials
	Parramos	Chirijuyu	On-farm strip trials
	Sta. Apolonia	Chuaparral 1	On-farm strip trials
	Zaragoza	Puerta Abajo	On-farm strip trials
	Chimaltenango	El Socobal	On-farm strip trials
	Balanya	Chuicapulin	On-farm strip trials

Table 1. List of climbing bean trials made during the 2014 growing season in the Guatemalan highlands.

Most locations were tested under the common intercropping system (*milpa*) and a few under monoculture. Depending on space and resources at each location, the 10-entry trials were planted using a Randomized Complete Block Design (RCBD) with two or three replications. Farmers' trials included the local varieties/landraces used by the farmer as the local check to make side-by-side comparisons for these growers. Harvest of these field trials should be finished by early December 2014. All this extensive testing is coordinated by the field validation unit at ICTA, which is the final step before official variety release under ICTA standards.

The following agronomic data were collected across most locations:

- Aggressiveness of growth
- Disease symptoms, if present (natural pressure)
- Days to maturity
- Seed yield
- 100-seed weight

- In-station trials also tried to collect the following information:
    - o Days to emergence
    - o Vigor
    - o Early disease symptoms
    - o Days to flowering
    - o Pod distribution
    - o Aggressiveness of growth
    - o Disease symptoms (natural pressure)
    - o Days to maturity
    - o Seed yield
    - o 100-seed weight

1B: Genetic purification of selected material (ICTA)
Because phenotypic variation has been detected within accessions, individual plant selections were made within the breeding lines during the 2013 growing season and planted again as plant-rows at Quetzaltenango. Selections were based on potential yield and quality, absence of disease symptoms, and other agronomic traits. Selection of promising genetic material will be made at the time of harvest and selected rows will be sent to the ICTA–San Jeronimo station for winter increase, if possible, which will allow for the detection of additional genetic heterogeneity while increasing seed.

1C: Field evaluation of Bolonillo-TEXEL (ICTA)
The Bolonillo-Texel line was also tested on growers' fields. Side-by-side milpa, on-farm strip trials of the local's landrace, and Bolonillo-Texel were grown, using the same maize material and agronomic practices, in the 18 locations mentioned in table 1 as on-farm strip trials. Since these trials are mostly managed by growers, data collection is mostly focused on seed yield, agronomic performance, and personal feedback from each grower. Technical assistance from ICTA agronomists and crop extension personnel from the Ministry of Agriculture has been crucial for finding these growers and locations.

Farmer field trials in Quetzaltenango with improved breeding lines of climbing beans, using the *milpa* system and a local maize variety.

Seed yield and other traits will be compared with common varieties and landraces grown in the vicinity of the testing fields. Results from these field trials will be available once all trials are harvested and data are analyzed. If Bolonillo-Texel has good acceptability it could be released sooner, which would allow for a significant impact of this project earlier than planned.

Objective 2: Characterization of the genetic diversity of this unique set of germplasm

2A: Evaluation of core collection with the 6K SNP chip (NDSU)
This activity had to be postponed because the seed available from the germplasm collection stored at ICTA–Chimaltenango was in bad condition and would not pass phytosanitary inspection for shipping to NDSU. To address this issue, a new field was planted to produce fresh seed for shipping to NDSU for DNA analysis, to be harvested December 2014. Options to address ICTA's lack of adequate long-term seed storage infrastructure are being investigated.

Tender pods of climbing beans growing around a maize plant. The future harvest of beans and maize provides a perfect cereal–legume combination for high protein.

This newly planted field presents a good opportunity for the PI to phenotypically evaluate the entire collection in the field one more time to identify genetic material with interesting traits for future use in the breeding process. Once seed is cleaned and conditioned, a sample from each accession will be prepared and sent to the Ministry of Agriculture for phytosanitary inspection and, subsequently, shipped to NDSU for DNA extraction and molecular analyses using the 5k SNP chip. Preliminary results about the organization of the genetic diversity of this collection and how it is related to other races and gene pools will be ready in 2015.

In spite of these delays, 25 superior accessions previously selected by the ICTA bean breeding program and six breeding lines from Dr. Aldana's program (part of the field testing mentioned in objective 1A), were grown in 2013 and fresh seed was sent to NDSU for initial molecular screening with some InDel markers. Figure 1 shows polymorphisms for only one of the InDel markers across all the 31 genotypes; however, more InDel markers are currently being screened to provide a better picture of the genetic variability of this subset of germplasm. McClean's lab at NDSU has a collection of approximately 500 InDel markers that could provide some initial insights into the genetic diversity at the DNA level of this germplasm. Preliminary results on this initial screening will be available in the near future and will give us a better idea of how to plan for the actual screening of the whole collection once the seed arrives.

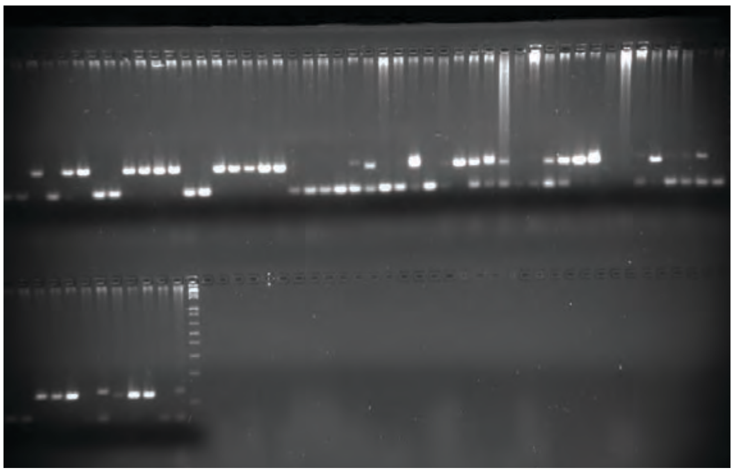


Figure 1. Example of polymorphisms among accessions as revealed by InDel marker 04-07-4908 screened in 25 germplasm accessions (upper lanes, each accession repeated twice), and six breeding lines from Dr. Aldana's initial crosses (lower lanes, each breeding line repeated twice).

2B: Assessment of the intra-accession variability (NDSU)

Because of the reasons cited in the previous section, this activity had to be postponed. A genetic assessment of variation within the 10 selected lines used in objective 1A will be made to account for the heterogeneity not only among but within accessions and, possibly, extrapolated to the rest of the accessions. Preliminary phenotypic observations in the field suggest that there is a high amount of genetic heterogeneity (heterozygosity) within accessions.

Objective 3: A better understanding of the current socioeconomic status and needs of bean production within the context of intercropping systems in the region

Growers' surveys

Previous socioeconomic information on production and consumption of beans in the Guatemalan highlands indicated that no other information than the agricultural census from 2003 was available. Nonetheless, that information has been helpful in determining which departments and municipalities should be the focus of our surveys and the sample size that may be needed to obtain reliable and useful information. Thus, the project decided to focus on the departments of Quiche, San Marcos, Huehuetenango, Totonicapán, and Quetzaltenango, which represent most of the climbing bean production areas.

A new collaboration for objective three with the Legume Innovation Lab project, *Impact Assessment of Dry Grain Pulses CRSP Investments in Research, Institutional Capacity Building and Technology Dissemination for Improved Program Effectiveness*, to design a survey instrument, discuss the questions, and arrange all the important parameters for this activity has been established. This collaboration will include help and training during the actual surveys.

The survey instrument is in the final design stage and will be submitted to the NDSU–IRB (Internal Research Board) for final approval. The plan is to conduct the surveys in early 2016, after the harvest season has been finished across the entire region. In this way, growers will not only have time to talk with the surveyors but also fresh memory of the events in the growing season. The survey will include questions about cultivation methods, preferred seed types, household consumption, and marketing of harvested beans, among other things. Results will be shared not only within the project but with other projects currently working in Guatemala (e.g., MASFRIJOL) and interested government agencies.

> ***Farmers' trials included the local varieties/landraces used by the farmer as the local check to make side-by-side comparisons for these growers.***

Objective 4: Capacity building: training the next generation of plant breeders for Guatemala and establishing a long-term breeding plan to increase the productivity of climbing bean in the region

The project PI visited Guatemala in June 2014 and interviewed potential candidates for M.S. degree training at NDSU. Two of the five potential applicants have already applied to NDSU. One has expertise in food science; we hope she will study the nutritional and cooking qualities of bean germplasm and their genetic components. The other is the daughter of an agronomist with outstanding knowledge of disease-resistant genes and molecular markers in beans. The remaining three are all interested in plant breeding, plant pathology, and/or biotechnology; they just need to improve their English before applying.

Student research topics will be directly related to our project's research objectives, focused on the analyses of genetic diversity, genetic resistance to diseases, and production systems, nutrition and cooking quality, and the like.

Farmer field trials in Quetzaltenango, with improved breeding lines of climbing beans mixed with local maize variety in the *milpa* system.

Major Achievements

1. On-farm field testing and validation across 14 locations of nine breeding lines with potential to be released in the near future
2. Extensive on-farm testing and validation of Bolonillo-Texel across 18 locations

Research Capacity Strengthening

A Legume Innovation Lab capacity strengthening grant provided a new thermal cycler this year, which will not only benefit the bean breeding program but other programs that need to run PCRs (polymerase chain reactions).

Human Resource and Institutional Capacity Development

Degree Training

Two women have been recruited to start formal training (M.S. in Plant Sciences) at NDSU during FY2015.

Achievement of Gender Equity Goals

The thermal cycler obtained through the capacity strengthening award will be mainly used by women in the biotechnology lab at ICTA. In addition, two women ICTA employees have been recruited for formal training at NDSU.

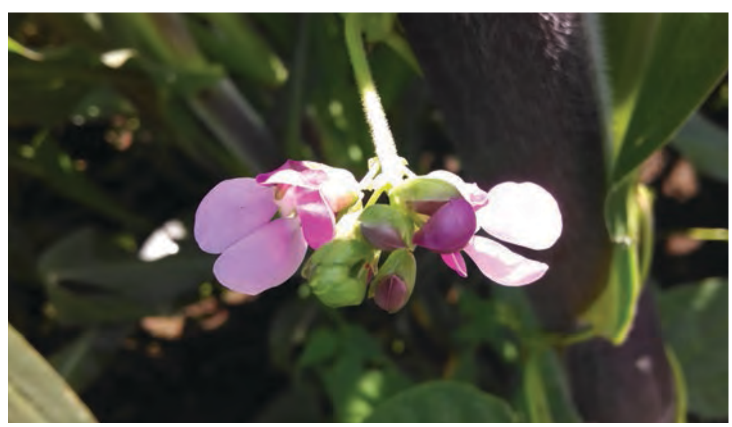
Scholarly Accomplishments

Moghaddam, S.M., S. Mamidi, Q. Song, **J.M. Osorno**, R. Lee, P. Cregan, and **P.E. McClean**. 2013. Developing marker-class specific indel markers from next generation sequence data in *Phaseolus vulgaris. Frontiers in Plant Genetics and Genomics* 5:185.

Vandemark, G.J., M.A. Brick, **J.M. Osorno, J.D. Kelly**, and C.A. Urrea. 2014. Yield gains in edible grain legumes. In J. Specht, B. Diers, B. Carver, and S. Smith (eds.) *Genetic Gains of Major U.S. Field Crops*. CSSA Press, Madison, WI.

Osorno, J.M., and P.E. McClean. 2014. Common bean genomics and its applications in breeding programs. In S. Gupta, N. Nadarajan, and D.S. Gupta. *Legumes in the Omic Era* (pp. 185–206). Springer, New York, NY.

Schmutz J, **McClean** P, Mamidi S, Wu GA, et al (2014) A reference genome for common bean and genome-wide analysis of dual domestications. *Nature Genetics* 46:707–713.



Clusters of flowers on a climbing bean plant.

Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF)

(S01.A3)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

James D. Kelly, Michigan State University

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Wayne Loescher, Michigan State University

James Steadman, University of Nebraska, Lincoln

Carlos Urrea, University of Nebraska, Scottsbluff

Karen Cichy, USDA–ARS, East Lansing, Michigan

Stanley Nkalubo–NaCRRI, Uganda

Kennedy Muimui–ZARI, Zambia

Abstract of Research and Capacity Strengthening Achievements

Common bean is the most important grain legume consumed in Uganda and Zambia. The development of improved bean varieties and germplasm with high yield potential, healthy root systems, improved biological nitrogen fixation (BNF) with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions is needed to increase profit margins and lower production costs. An improved understanding of plant traits and genotypes with resistance to multiple stresses from abiotic (drought) and biotic (root and foliar pathogens) sources will provide unique genetic materials for enhanced plant breeding methods and sources to study plant tolerance mechanisms in common bean. Improvements in current understanding of the physiology of drought and evapotranspiration and the genetics of drought tolerance in common bean are needed, as is the development of effective molecular and quantitative methods for the selection of drought tolerance. The project will use QTL analysis and SNP-based, genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, enhanced BNF, and shorter cooking time. Results of this project would contribute to improved yield, farm profitability, and human resources in the host countries and indirect benefits to participating U.S. institutions and bean producers.

Project Problem Statement and Justification

Beans, the second most important legume crop after ground nuts in Zambia, are a major source of income and cheap protein for many Zambians. Most of the bean crop (62%) is produced on 60,000 ha in the higher altitude, cooler, and high rainfall zones of the northern part of Zambia. Andean beans are predominant and landraces are the most widely grown, although a few improved cultivars are also grown as sole crops or in association with maize.

Bean production in Zambia is constrained by several abiotic and biotic stresses that include diseases, pests, low soil fertility, and drought. All the popular local landraces in Zambia are highly susceptible to pests and diseases that severely limit their productivity. This susceptibility is reflected in the very low national yields ranging from 300 to 500 kg/ha that result in an annual deficit of 5,000 MT (megaton). To avert future food shortages and feed the growing population of 13 million, there is critical need for increasing the productivity of most food crops, including beans, in Zambia, which ranks 164 out of 184 countries in the Human Poverty Index.

Beans are grown on more than 660,000 ha of land in Uganda and are consumed throughout the country. They are a major source of food and income for rural smallholder farmers, especially the women and children. The majority of bean production in Uganda depends on the use of inferior landrace varieties that are generally low yielding because of their susceptibility to major biotic and abiotic stresses, which gravely undermine the potential of the bean as a food security crop, a source of income, and as a main source of dietary protein for the majority of Ugandans. Drought affects 60 percent of global bean production and the severity of yield reduction depends on the timing, extent, and duration of the drought stress. The development of improved varieties and germplasm with high yield potential, healthy root systems, improved BNF with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions is needed to increase profit margins and lower production costs.

The project will use QTL analysis and SNP- (single nucleotide polymorphism) based, genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, enhanced BNF, and faster cooking time.

Objectives

1. Integrate traditional and marker-assisted selection (MAS) approaches to combine resistances to economically important foliar diseases and drought, improve biological nitrogen fixation (BNF), and assess acceptability of fast cooking, high mineral content in a range of large-seeded, high-yielding red mottled, white, and yellow Andean bean germplasm for the Eastern Africa highlands (Zambia and Uganda), and the United States.

2. Characterize pathogenic and genetic variability of isolates of foliar pathogens collected in Uganda and Zambia, and identify sources of resistance to angular leaf spot (ALS), anthracnose (ANT), common bacterial blight (CBB), bean common mosaic virus (BCMV), and bean rust present in Andean germplasm.

3. Use SNP-based, genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, cooking time, and BNF to identify QTLs for use in MAS to improve Andean germplasm.

4. Develop phenometric approaches to improving the efficiencies of breeding for abiotic stress tolerance, especially drought.

5. Increase institutional capacity building and training in plant breeding, genetics, and biotechnology.

Technical Research Progress

Objective 1. Integrate traditional and marker-assisted selection (MAS) approaches to combine resistances to economically important foliar diseases and drought, improve biological nitrogen fixation (BNF), and assess acceptability of fast cooking, high mineral content in a range of large-seeded, high-yielding red mottled, white, and yellow Andean bean germplasm for the Eastern Africa highlands (Zambia and Uganda) and the United States.

Assemblage of different nurseries in Uganda

Different bean nurseries were assembled through direct collection from within the country, importation from other countries, or reassembling of already existing germplasm. The nurseries are inclusive of the following:

1. A germplasm collection of 150 accessions for screening against rust
2. Anthracnose and root rot nursery comprising 56 lines pyramided with two to three anthracnose genes and one root rot resistant gene
3. Anthracnose differentials of 12 bean lines
4. Angular leaf spot differential set of 12 bean lines
5. Drought nursery comprising 51 lines obtained from CIAT
6. High iron and zinc nursery comprising 62 lines
7. The Andean diversity panel (ADP)
8. Bean stem maggot nursery with 16 tolerant lines
9. Assembled 330 root rot resistant/tolerant lines
10. Collected 318 bean accessions from different agroecologies within Uganda

Development of a drought screening protocol

A screen house-based watering regimen protocol for drought has been adopted in NaCRRI (National Crops Resources Research Institute).

Seed increase of the different nurseries

For the different nurseries acquired, field screening, characterization, and multiplication of the acquired germplasm were conducted on station at NaCRRI. The seed obtained will be utilized in further characterization and breeding activities to introgression resistance within the farmer-preferred Andean varieties.

Cross sources of resistance to different stresses made with large-seeded lines with contrasting colors in Uganda

A set of 22 crosses were made between Andean market class varieties from Uganda and drought, bruchid, and stem maggot imported germplasm.

Sensory evaluation of elite lines with superior cooking time and mineral bioavailablity in Uganda.

Twelve elite lines from the ADP are being multiplied and will undergo sensory evaluation on-farm next year (2015) using participatory variety selection trials.

Drought and Disease Screening in Nebraska

1. Two bean nurseries, the Andean Bean Coordinated Agricultural Project (Bean-CAP) and 81 Andean Diversity Panel (ADP), were grown under drought (DS) and nondrought stress (NS) in Mitchell, Nebraska, in 2013. The NS and DS plots received 453 and 248 mm of total water, respectively; a total of 63.2 mm of precipitation occurred after flowering when the stress was applied. Drought stress was moderate (DII = 0.47) in the Andean BeanCAP nursery. Yield under NS and DS ranged from 1402 to 4011 kg/ha, and from 682 to 2847 kg/ha, respectively. Wallace 773-V98 was well adapted to both NS and DS environments. Kardinal Kidney had a GM of 2787 kg ha-1 and the lowest yield reduction (8.8%). GM in Drake, K-42, UC Canario 707, Sacramento, Beluga, Red Kote, USDK-CBB-15, Silver Cloud, Charlevoix, USCR-9, CDRK, and UC Nichols had a GM range from high of 1803 to 1313 kg ha-1.

Kelvin Kamfwa, a Legume Innovation Lab graduate student at Michigan State University, conducts research on plant breeding and genetics.

2. Drought stress was less severe (DII = 0.38) in the ADP nursery. Yield under NS and DS ranged from 11,267 to 3,791 kg/ha and from 717 to 2572 kg/ha, respectively. Using GM as the major selection index, ADP-7 (Bukoba), ADP-626 (Dolly), and ADP-41 (Morondo) were well adapted to both NS and DS environments. DAP-97 (Bilfa 4) had a GM of 2,645 kg ha-1 and one of the lowest yield reductions (12.5%). The same set of lines was evaluated in North Platte, Nebraska, for reaction to common bacterial blight. ADP-97 (Bilfa 4), ADP-113 (OPS-RS4), ADP-123 (Jenny), and ADP-626 (Badillo) had the lowest score (2.3). Cardinal had the lowest CBB (4.0) followed by VA-19 (4.9), and Capri Michigan Improved Cran, Myasi, and Red Kanner with a score of 5.0, whereas

Fiero and Drake had the highest scores of 8.3 in the BeanCAP nursery.

3. Both the ADP and BeanCAP Andean Panel were screened for reaction to CBB Nebraskan strains SC-4A and LB-2 at North Platte, Nebraska, in 2014. H9659-21-1 had the lowest CBB score of 2.7 followed by Incomparable, RH No.1, and Witrood with a score of 2.9. Badillo, Kabuku, Njano-Dolea, OPS-RS4, INIAP 480, and Kisapuru had scores from 3.0 to 4.4.

Conduct sensory evaluation of elite lines with superior cooking time and mineral bioavailablity in Michigan.
Dr. Fernando Mendoza, in chemical engineering and bioprocess at MSU, began working on the project in March 2014 to 1. implement a color imaging system for calibrated color measurements of raw and processed dry bean seeds and the evaluation of their overall surface appearance and morphological characteristics and to 2. implement hyperspectral imaging and NIR techniques for the nondestructive quality characterization and evaluation of internal properties of raw and soaked beans and their relationships with physicochemical, sensorial, and nutritional properties.

Accomplishments for the period FY13–14

1. Sensory evaluations were performed on canned black beans to develop standard scales or categories for scoring color and appearance traits. The color chart represents the black bean color retention (or discoloration) from very light brown to very dark, and the overall appearance chart represents the seed shape, splits, clumps, color uniformity, and visual aspect, such as surface texture varying from *unacceptable to excellent* in appearance.

Figure 9.1. Color chart for canned black beans representing five typical categories observed in canned beans: (1) Very light brown, with 50 percent mix of seed colors very noticeable; (2) Slight dark brown or light gray, with 11–49 percent color variation somewhat noticeable; (3) Average brown black: with 5–10 percent color variation; (4) Dark brown or medium black, with less than 5 percent color variation not very noticeable; and (5) Very dark: 100 percent uniform color. (Note that the color categories were reproduced using the same bean image with different tones).

Figure 9.2. Appearance chart for canned black beans after drained and washed representing five typical quality categories observed in commercial canned beans: (1) Unacceptable: with severe split grains and grains blown apart; (2) Poor: seeds with bad splits but holding together; (3) Average: showing 60–69 percent of seeds intact; (4) Very good appearance: with 70–89 percent of seeds intact; and (5) Excellent appearance: with 90 percent of seeds intact.

2. A machine vision system was developed for the automatic inspection of color, appearance, and morphological properties (shape and size) of raw and processed dry bean seeds. Computerized image analysis techniques, multivariate statistical analysis, and pattern recognition methods were used for prediction and sorting of color and appearance traits, among others, in canned black beans. Figure 9.3 shows the implemented computer vision system. Figure 9.4 shows the model performance for predicting color and appearance rates (a) and (b), respectively, using color and texture image information.

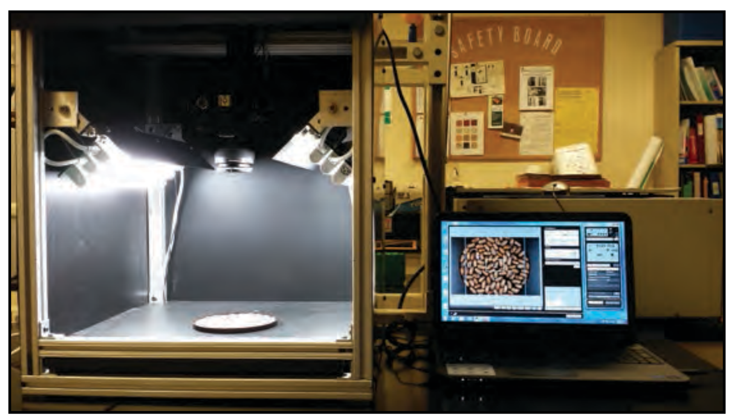


Figure 9.3. Computer vision system for visualization, acquisition, and analysis of raw and processed beans

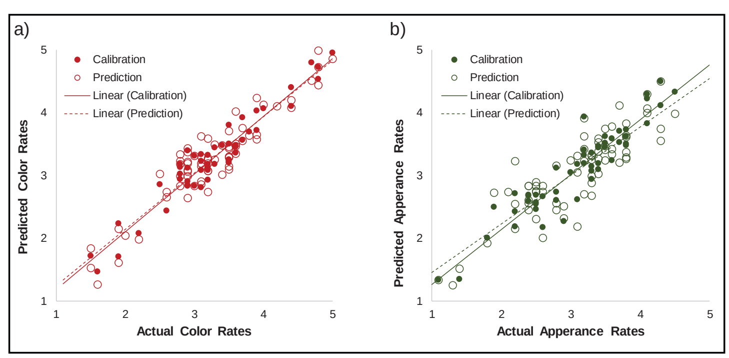


Figure 9.4. Predictions for visual color and appearance rates (a) and (b), respectively, using color (full grain + brine) and image textural features (contrast, correlation, energy, homogeneity) extracted from RGB, L*a*b*, HSV and gray intensity channels.

3. A set of 230 Andean Diversity Panel genotypes grown at the Montcalm Research Farm in 2013 were evaluated for cooking time. In addition, whole, raw seed was also scanned with NIR (Near Infrared) to try to predict genetic variability for cooking time in the ADP lines. Preliminary analysis using multiple regression models and sequential forward selection for selecting the best Vis/NIR wavelengths showed descent prediction results for cooking time when a large number of latent variables were used in the model. Large number of variables could be explained by the complexity of the bean microstructure and their interactions with the light. Figure 9.4 presents the prediction performance increasing number of latent variables (or wavelengths). Figure 9.5 depicts the relationships between the measured and predicted cooking time (min) when 40 wavelengths are used. The standard error of prediction was an average 10±1 min, and hence, improved measurements using transmittance mode instead of reflectance would be the next design to test in this study.

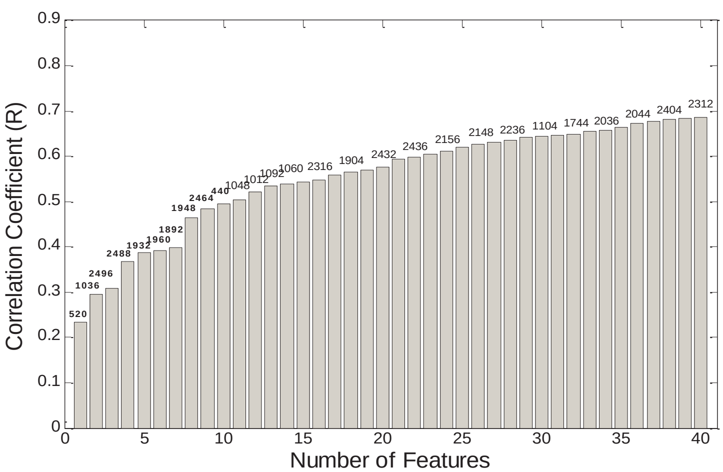


Figure 9.5. Prediction of cooking time increasing the number of latent variables in the model.

4. Currently a hyperspectral imaging technique has been used for testing different bean types (more than 500) to improve the prediction of internal traits in canned beans from raw seeds. The algorithms for image segmentation and analysis using a huge amount of spectral and spatial data are being developed.

Conduct evaluation of elite lines for cooking time in Nebraska.
In 2013, the ADP and BeanCAP Andean panel grown under normal and drought stress in Nebraska were cooked. On average, the beans grown under normal conditions cooked in 65 minutes and those grown under drought stress cooked in 106 minutes. Under both normal and drought stress environments, RH No.11, Soya, and RH No.2 had the lowest cooking time (51–61 minutes), while Musanze, UCD 0801, and Bilfa 4 were affected by the drought stress with cooking times ranging from 171 to 182 minutes, compared to the normal cooking time conditions of 58, 100, and 51 minutes, respectively.

Objective 2. Characterize pathogenic and genetic variability of isolates of foliar pathogens collected in Uganda and Zambia, and identify sources of resistance to angular leaf spot (ALS), anthracnose (ANT), common bacterial blight (CBB), bean common mosaic virus (BCMV) and bean rust present in Andean germplasm.

Initiate the collection of isolates from the different production regions of Uganda
A survey was conducted in two agroecologies, nine districts, and 18 subcounties where a total of 192 disease samples of Rust (84), ALS (52), CBB (11), Anthracnose (26), and Root Rot (19) were collected (see table 1). During this sample collection and survey, GPS positions for these locations were also taken. Samples are currently undergoing isolation and purification. This survey exercise will be continued in the next financial year to cover the other agroecologies.

A total of 140 bean accessions including 80 landraces, 19 released varieties, and 41 introduced lines were screened in the field for rust without inoculation.

Increase seed of the differentials for ANT, ALS, and rust in Uganda
For each of the collected germplasm, one two-meter line was planted for seed increase and initial characterization.

Race characterization of ANT, ALS, and Rust in Uganda
Diseased samples were collected and are undergoing isolation and purification and single spore isolation.

Utilize the mobile nursery protocol to determine the effectiveness or rust resistance genes in genotypes.
A total of 140 bean accessions including 80 landraces, 19 released varieties, and 41 introduced lines were screened in the field for rust without inoculation. Natural field inoculation was relied on by planting susceptible K123 as spreaders for rust disease. Data were taken on resistance/susceptibility, disease incidence, disease severity, size and type of pustule, and number of plants per row. The performance of the accessions is shown in table 2; from this data, it was noted that at least 20 genotypes did not show any symptoms for rust disease at NaCRRI. The table shows a whole range of variations in the genotypes reaction to rust, BCMV, and root rot disease. These results will be verified in the second screening experiment. The rust differentials have been requested from the University of Nebraska and will be arriving in the country in the near future.

Agroecology	District	Sub-county	Rust	ALS	CBB	Anth	Root rot
Central/ Lake Victoria basin	Wakiso	Wakiso	17	9	3	-	-
	Mpigi	Kamengo	9	4	2	-	-
	Luwero	Bamunanika & Zirobwe	7	3	-	-	-
	Mukono	Kasawo, Kitalo, Ndese & Nakifuma	7	1	-	-	-
	Jinja	Butagaya	14	8	-	-	-
	Kamuli	Butasi, Bugulumbwa, Kasambira & Naluwoli	14	7	-	-	-
South western	Bushenyi	Kigalama & Nyabubale	9	13	2	15	5
	Kabale	Kamuganguzi & Mwendo	2	4	3	9	4
	Mbarara	Biharwe	5	3	1	2	10
		Total	**84**	**52**	**11**	**26**	**19**

Table 1. Bean diseased sample collection in different regions of Uganda

Parameters	Rep 1	Rep 2	Rep 3	Total	Mean
No. genotypes: Symptom absent	22	37	1	60	20
No. of resistance/ tolerant genotypes (score 1–5)	85	94	92	271	90.3
No. of susceptible					
Genotypes (score 6–9)	51	25	39	115	39.3
Viral infection (BCMV)	14	9	17	40	13.3
Root rot	-	-	1	1	

Table 2. Initial field screening for identification of rust resistant genotypes in Uganda

Increase seed of these selected genotypes for inclusion in the mobile nursery.

This activity will be undertaken on acquisition of the rust differentials from Nebraska as will the choosing of the most relevant races of ANT, ALS, and rust and strains of CBB for screening breeding nurseries in Uganda after the isolates have been characterized.

Activities under way in Zambia

1. Sixty lines were evaluated for reaction to root rot and foliar diseases at Misamfu, Zambia; 31 showed root rot resistance; two showed resistance to ALS; three were resistant to CBB; two showed resistant to Rust.
2. Line PI 321094-D showed resistance to Root rot, ALS, CBB, and Anthracnose.
3. ADP 188 (G1375) showed resistance to CBB, RR, and Rust resistance; the line also showed intermediate reaction to CBB in North Platte, Nebraska.
4. NE 34-12-50 showed resistance to CBB, ALS, and Rust, and to CBB in Nebraska, and had the highest yield per plot in Zambia. These lines, materials will be used as parents in future breeding efforts at ZARI.
5. Seed for Rust differential will be received from Nebraska and will be used for rust screening in Zambia.
6. In the ALS Nursery Planted at Misamfu in a RCBD, with three reps comprising 45 lines, 15 lines showed resistance to ALS while 24 were resistant to ALS, and about 28 lines showed resistance to CBB while most of the lines did not show symptoms of rust.

Activities underway at the University of Nebraska (UNL)

For personal reasons, the project's full-time technologist was on leave for five months. Consequently, there was need to hire a half-time person to help with the bean rust project. Fortunately, the project was able to hire a head technologist with bean disease expertise, who has been increasing critical rust races needed for resistance gene identification and has initiated tests to determine rust resistance genes in new bean cultivars. These cultivars will be released if they have at least two genes for rust resistance, possibly in Zambia.

A trip to Zambia in November 2014 allowed Carlos Urrea and Jim Steadman to explain the interaction of our NIFA (National Institute of Food and Agriculture) bean root rot project with the foliar bean disease Legume Innovation Lab project. Protocols for collection of bean rust samples in the 2015 nurseries and farmer fields were explained. The use of a mobile rust nursery with 12 key bean lines was also demonstrated for use in identifying sources of resistance to rust in bean fields in 2015.

Carlos Urrea explained his breeding program, especially the drought tolerant and common blight/bean common mosaic lines we have selected for the 2015 bean nursery that will be planted in the Kasama and north of Lusaka locations. Twelve entries in these nurseries were derived from the best lines of 60 tested in fields in Zambia in 2014. Four local landraces were chosen as controls. The planting design is a split/split plot with fertilizer added or not and stem maggot control added or not and three replications.

Objective 3. Use single nucleotide polymorphism (SNP)-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, cooking time, and BNF to identify QTLs for use in MAS to improve Andean germplasm.

In Michigan a genome-wide association study (GWAS) using a global Andean diversity panel (ADP) of 237 genotypes of common bean was conducted to gain insight into the genetic architecture of several agronomic traits controlling phenology, biomass, yield components, and seed yield. The panel was evaluated for two years in field trials and genotyped with 5,398 SNP markers. After correcting for population structure and cryptic relatedness, significant SNP markers associated with several agronomic traits were identified. Positional candidate genes, including *Phvul.001G221100* on the *Phaseolus vulgaris* (Pv) chromosome 01 that is associated with days to flowering and maturity, were identified. Significant SNPs for seed yield were identified on Pv03 and Pv09, where several previous studies have also reported quantitative trait loci (QTL) for yield. These yield QTL that have been identified in several environments and genetic backgrounds are potential candidates for marker-assisted breeding.

Heat stress is similar to and shares some of the same response mechanisms with drought stress, and the two are often coincident in the field, so we investigated the bean varieties' responses to progressively increasing temperatures over the course of weeks.

Objective 4. Develop phenometric approaches to improving the efficiencies of breeding for abiotic stress tolerance, especially drought

Physiological responses to drought stress in several bean varieties were investigated at MSU to determine how the responses differed among varieties. Among the lines investigated were several varieties of common bean and a variety of tepary bean. Measurements using a new technique (e.g., MultispecQ or PhotosynQ) are continuing to evaluate the utility of phenometric instrumentation currently under development in the David Kramer laboratory and progress is quite promising.

Using more conventional gas exchange measurements, we also examined the rates of photosynthesis and conductance of plants exposed to well-watered or drought stress conditions. Known drought tolerant varieties, such as SER-16 and tepary bean, had lower rates of photosynthesis and conductance under well-watered conditions compared to elite varieties like Jaguar, which is especially drought susceptible, and Zorro. When these same varieties were exposed to progressively increasing drought stress, drought tolerant varieties perceived drought stress sooner in the dry down process and closed their stomata earlier than the elite varieties. With closed stomates, the tolerant varieties' conductance and photosynthesis rates decreased further, and they conserved more water. These results suggest that drought tolerant varieties follow a conservative strategy toward managing stress. Also, although they may not be as productive as elite varieties under ideal conditions, tolerant varieties are primed and quicker to respond to a drought event.

Because compatible solutes play a role in adjusting water potentials and protecting cellular components under stress, we investigated their concentration in plants exposed to drought stress. Although the amino acid proline accumulates in response to drought in certain plant species, in bean plants free proline levels did not differ between control and drought-treated plants. When examining other metabolites, e.g., malic acid, fructose, glucose, and sucrose, their concentration in leaf tissues was significantly greater in drought-stressed plants than in controls. The varieties tepary and Zorro accumulated more sugars and organic acids under drought stress than the varieties Jaguar and SER-16. This pool of sugars and organic acids could allow them to osmotically adjust their tissues under stress and provide them with a ready source of energy to help them recover after the passage of the stress. Consistent with their higher accumulation of sugars and organic acids, the leaf water potentials of tepary and Zorro were more negative under drought stress than the other varieties.

Heat stress is similar to and shares some of the same response mechanisms with drought stress, and the two are often coincident in the field, so we investigated the bean varieties' responses to progressively increasing temperatures over the course of weeks. Overall, the varieties tended to respond to heat stress in the same fashion as they responded to drought stress. Tepary and SER-16 followed a more conservative, adaptable strategy while Zorro and Jaguar followed a faster growing, less responsive strategy.

Abscisic acid is a major plant hormone key to drought signaling. After treating plants with increasing ABA concentrations and measuring conductance, variety SER-16 closed its stomates at lower ABA concentrations than Jaguar or Zorro. These results suggest that SER-16 is more sensitive to ABA and, more broadly, that significant differences to ABA responsiveness exist among the common bean germplasm.

Kelvin Kamfwa, a Legume Innovation Lab graduate student in Plant Breeding and Genetics at Michigan State University, works with Dr. Jim Kelly on MSU's bean fields testing new, improved bean varieties.

Major Achievements

For the first time, standard charts for rating color and appearance in canned black beans have been proposed. A machine vision system was successfully developed to automatically predict the quality ratings of color and appearance in canned black beans as a professional visual perception, with prediction accuracies of 93.7 percent for color and 87.1 percent for appearance and sorting of canned beans to "acceptable" and "unacceptable" quality groups by color and appearance simultaneously, with accuracies higher than 89 percent. The implemented machine vision technique can successfully replace the subjective, tedious, and costly visual sensory analysis at research facilities and bean canning industries.

Research Capacity Strengthening

The project will enhance scientific capacity in Uganda and Zambia through graduate student training and short-term workshops. The project has two PhD students from Africa and is training 16 staff (10 male and six female) in disease and pest identification in Uganda and Zambia.

Dr. Stanley Nkalubo, NaCRRI, Uganda, and Mr. Kennedy Muimui, ZARI, Zambia, spent two weeks at Michigan State University (August 2014) participating in a Molecular Plant Breeding class and visiting bean breeding facilities and field plots. They attended grower field days and met all MSU collaborators and students on this Legume Innovation Lab project as well as on the WorldTAP program, Management Office, and Kramer Lab.

"The project will enhance scientific capacity in Uganda and Zambia through graduate student training and short-term workshops."

Human Resource and Institutional Capacity Development

Training for Host Country PI at MSU

Training was provided for the Host Country Ugandan Principal Investigator in breeding and marker-assisted breeding in August 2014 through lectures and practical application sessions. During the first week, there were also daily practices on breeding data analyzing using R and Gen Stat statistical programs. The topics covered were:

1. introductory plant breeding and breeding methods
2. introduction to statistical terminologies of data and trial design and analysis;
3. mixed models in plant breeding
4. population genetics
5. molecular biology techniques and marker-assisted breeding
6. DNA sequencing
7. basic principles of linkage mapping and marker associated analysis
8. marker trait association analysis for qualitative vs quantitative traits
9. advances in QTL mapping and Marker trait association analysis
10. advances in linkage map construction
11. marker-assisted selection breeding applications and genomic selection

Short-Term Training

Two short training programs were conducted with assistance from Dr. Kelly during his visit to Uganda in May 2014. The first was the training of researchers, research assistants, and technicians in the field of breeding and screening for various bean diseases. He also visited the screen houses and field experiments, giving advice where appropriate. The second introduced the PIs from Uganda and Zambia to new advances in plant breeding (e.g., use of marker-assisted selection breeding techniques) to enable application during project implementation.

Three additional short training programs were conducted in Zambia to teach seed production principals and regulations to small-scale farmers to ensure their access to improved technologies (varieties) for planting. Training community seed producers helps make quality seed available within communities, which improves productivity and production among smallholder farmers.

Degree Training

Kelvin Kamfwa (Zambia), Ph.D. program in Plant Breeding, Genetics and Biotechnology, Michigan State University, *Topics Genetic Dissection of Biological Nitrogen Fixation in Common Bean Using Genome-Wide Association Analysis and Linkage Mapping*, August 2008 to September 2015 (projected).

Isaac Dramadri (Uganda), Ph.D. program in Plant Breeding, Genetics and Biotechnology, Michigan State University, *Physiological Studies on Drought Tolerance in Andean Beans*, August 2013 to September 2017 (projected).

Achievement of Gender Equity Goals

In Zambia, the project has identified NGOs that can partner with the project for outreach and technology dissemination to female farmers; they are the Kusefya pa Ngw'ena Women's Farmer Group, the Shangila Seed Growers Association (SSGA) in Mpika, and the Participatory Village Development in Isolated Areas (PaViDIA) in Mporokoso and Luwingu. PaViDIA is working toward empowering women in communities in income generating activities and seed and grain production for market sales to elevate income and reduce poverty. In Uganda, the NGOs include the Community Enterprise Development Organization (CEDO), Integrated Seed Sector Development (ISSD)–Uganda, CARE, ADRA, SHUPO, SASAKAWA Global 2000; Nyakatozi Growers Cooperative Union, Appropriate Technology (Uganda), and seed companies (Pearl, Victoria, NASECO, East African Seed, FICA seed). Many organizations have increasing women's agriculture skills and leadership roles as objectives in addition to access to credit for sustainable and profitable farming.

Scholarly Accomplishments and Awards

Articles

Cichy, K.A., A. Fernandez, A. Kilian, **J.D. Kelly**, et al. 2014. QTL analysis of canning quality and color retention in black beans (*Phaseolus vulgaris* L.). *Molecular Breeding* 33:139–154. doi: 10.1007/s11032-013-9940-y.

Kelly, J.D., G.V. Varner, **K.A. Cichy**, and E.M. Wright. 2014. Registration of "Powderhorn" great northern bean. *J. Plant Registrations* 8:1–4. doi:10.3198/jpr2013.05.0020crc.

Mendoza, F.A., **K. Cichy**, R. Lu and **J.D. Kelly.** 2014. Evaluation of canning quality traits in black beans (*Phaseolus vulgaris* L.) by visible/near-infrared spectroscopy. *Food Bioprocess Technol*. 7:2666–2678. doi: 10.1007/s11947-014-1285-y

Miklas, P.N., **J. D. Kelly, J. R. Steadman** and S. McCoy. 2014. Registration of Partial white mold resistant pinto bean germplasm line USPT-WM-12. J. *Plant Registrations* 8:183–186.

Vandemark, G.J., M.A. Brick, **J.M. Osorno, J.D. Kelly**, and C.A. Urrea. 2014. Edible Grain Legumes. p. 87–123. *In*: S. Smith, B. Diers, J. Specht, & B. Carver (eds.). *Yield Gains in Major U.S. Field Crops*. CSSA Special Pub. 33, Madison, WI.

Awards

James Kelly received a Meritorious Achievement Award from the Legume Innovation Lab–Michigan State University 2014 and the Ralph H. Smuckler Award for Advancing International Studies and Programs–Michigan State University, 2014.

Development and Implementation of Robust Molecular Markers and Genetic Improvement of Common and Tepary Beans to Increase Grain Legume Production in Central America and Haiti

(S01.A4)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

James Beaver, University of Puerto Rico

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Consuelo Estevez de Jensen, University of Puerto Rico, Mayaguez, Puerto Rico

Timothy Porch, USDA/ARS/TARS, Mayaguez, Puerto Rico

Phil Miklas, USDA/ARS, Prosser, WA

Juan Osorno and Phil McClean–North Dakota State University (NDSU), Fargo, ND

Juan Carlos Rosas, Escuela Agrícola Panamericana (Zamorano), Honduras

Julio Cesar Villatoro, Instituto de Ciencia y Tecnología Agrícola (ICTA), Guatemala

Emmanuel Prophete, National Seed Service, Ministry of Agriculture, Haiti

Abstract of Research and Capacity Strengthening Achievements

Conventional plant breeding techniques and marker-assisted selection were used to develop dry bean cultivars with enhanced levels of disease resistance and greater tolerance to abiotic stresses. The multiple disease resistant black bean cultivar *XRAV-40-4* and red mottled bean breeding lines *PR0737-1* and *PR0633-10* were formally released. White and pinto bean lines that combine resistance to Bean Golden Yellow Mosaic Virus (BGYMV), Bean Common Mosaic Necrosis Virus (BCMNV), and rust resistance, and yellow beans that have resistance to BGYMV, Bean Common Mosaic Virus (BCMV), and leafhoppers were developed. The Bean Technology Dissemination project (2010–2014), an associate award affiliated with the Dry Grain Pulses CRSP and the Legume Innovation Lab, multiplied and distributed seed of improved bean cultivars developed by S01. A4 plant breeders to thousands of farmers in Central America and Haiti.

The BGYMV and BCMNV resistant black bean line *MEN-2201-64ML* from Zamorano had superior performance under drought conditions in Nicaragua and El Salvador. Black bean breeding lines that combine resistance to BGYMV, BCMNV, and bruchids are ready for field testing. Angular leaf spot isolates from Honduras and Puerto Rico were found to have high levels of virulence. Populations are being developed to identify a molecular marker for the *Bgp-1* gene that confers resistance to pod deformation in the presence of BGYMV.

Research on improving tepary bean lines continues. The tepary bean, *Tep-22*, that combines resistance to common bacterial blight, rust, and bruchids was formally released. A potential source of resistance to BCMNV in tepary bean was identified. Populations to increase seed size and improve agronomic traits of tepary beans were developed.

Training and capacity strengthening continues throughout our project. Informal training in plant pathology and BNF research techniques was provided at Zamorano and the University of Puerto Rico. Candidates for M.S. degree training of students from Guatemala and Honduras have been identified. Several B.S. degree students have opportunities to work with the bean research program at Zamorano.

A field planted with common bean (left) and tepary bean (right.)

Project Problem Statement and Justification

Increased bean production over the past 30 years in Central America and Haiti has been due, in large part, to expanded bean production in the lowlands (lands less than 1000 masl). Bean production in Guatemala and Nicaragua has expanded into more humid lowland regions, while a significant portion of the beans in Haiti continues to be produced in the lowlands. Bean production in Africa could be expanded if lines with better lowland adaptation were developed. This project addresses several of the biotic and abiotic constraints encountered by bean producers in the tropical lowlands.

The presence of BGYMV and BCMNV in the Caribbean, Central America, and southeastern Mexico make the selection for resistance to these viruses priority breeding objectives. Greater heat tolerance combined with resistance to BGYMV increased bean seed yield and production in El Salvador. BCMNV threatens bean production in warmer bean production regions of Central America, the Caribbean, and Africa. The recent arrival of BCMNV in the Caribbean made the selection for resistance to this virus a priority breeding objective in Haiti, the Dominican Republic, and Puerto Rico.

Small red and black beans tend to have greater yield potential and heat tolerance than Andean beans. Middle American beans also tend to have greater resistance to diseases in Africa, since pathogens in this region have co-evolved with Andean beans. Increased resistance to common bacterial blight and web blight is needed for beans produced in warm and humid lowland regions, such as the Petén in Guatemala. This combination of resistances may also permit increased production of beans in Central America during the first growing season, when rainfall is generally more abundant and reliable.

The previous Dry Grain Pulse CRSP project (*Development, Testing and Dissemination of Genetically Improved Bean Cultivars for Central America, the Caribbean and Angola [UPR-1,]*) developed Middle American and Andean bean breeding lines with adaptation to the lowland tropics and different combinations of resistance to diseases (common bacterial blight, rust, angular leaf spot, web blight, and root rot) and tolerance to edaphic constraints (low N soils, high temperature). This project will use these elite breeding lines as the base for the continued improvement of beans for our target countries.

More resistance to ashy stem blight is needed to improve adaptation to hot and dry environments such as the dry corridor in Guatemala and southwestern Haiti. Greater resistance to web blight is required to increase yield and seed quality of beans produced in more humid environments, such as the Petén Department in Guatemala and eastern Nicaragua.

There are regions and/or growing seasons in Central America, Haiti, and Africa that are too hot and/or dry to produce common beans. The tepary bean is a potential alternative grain legume for these stressful environments. In fact, farmers on the Pacific coast of Central America and some countries of Africa already produce tepary beans on a limited scale. In addition to heat and drought tolerance, tepary bean lines with high levels of resistance to common bacterial blight, bruchids, and other important traits have been identified. Resistance to BCMV, BGYMV, larger seed size, and improved agronomic traits would increase the potential adoption of tepary beans. Interspecific crosses with common beans could be used to introgress these traits into tepary beans. This effort represents the first systematic attempt to genetically improve tepary beans.

Seed of unimproved tepary bean (top left) surrounded by improved tepary bean seeds

Bean breeders were early adopters of marker-assisted selection to identify lines with desired combinations of traits. These identifications resulted in increased efficiency in the development of improved breeding lines. There are, however, molecular markers available for a limited number of traits. Others, such as the SAP-6 SCAR marker, are only effective in a specific gene pool. Therefore, there is a need to develop new or more robust markers, particularly for traits of economic importance to bean breeding programs in the tropics. Recent advances by the BeanCAP project, led by North Dakota State University, in sequencing the bean genome and the development of a SNP array will facilitate the mapping and development of molecular markers for traits of economic importance, while breeder-friendly InDel markers are a broadly applicable technology. The availability of phenotypic data in appropriate populations is a major factor limiting the development of these markers.

Objectives

1. Genetic improvement of common and tepary beans for Central America and Haiti.
2. Develop and implement robust molecular markers for disease resistance genes.
3. Strengthen the capacity of bean programs in Central America and the Caribbean to conduct research and to develop, release, and disseminate improved bean cultivars.

Technical Research Progress

Objective 1. Genetic improvement of common and tepary beans for Central America and Haiti

Development, testing, and release of improved bean cultivars
XRAV-40-4, a multiple disease resistant black bean adapted to the humid tropics, was developed and released cooperatively by the University of Puerto Rico (UPR) and University of Nebraska (UNL) Agricultural Experiment Stations, the USDA–ARS, the Instituto Dominicano de Investigaciones Agropecuarias y Forestales (IDIAF), the Escuela Agrícola Panamericana, Zamorano, Honduras, and the National Seed Service of the Ministry of Agriculture of the Republic of Haiti. *XRAV-40-4* combines resistance to BGYMV, BCMV, and BCMNV. When planted at higher altitudes, XRAV-40-4 has earlier maturity than the black bean cultivar *DPC-40*. XRAV-40-4 performed well in on-farm trials conducted by the NSS with support from FAO.

Red mottled bean lines *PR0737-1* and *PR0633-10*, which combine the bgm-1 gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV, were released as improved germplasm. Seed of PR0737-1 is currently being multiplied in Haiti and is in the process of being formally released as a cultivar.

White bean lines were developed that combine the *bgm-1* gene and the SW13 *QTL* for resistance to BGYMV, the I and bc-3 genes for resistance to BCMV and BCMNV, and resistance to a wide range of rust races. Results from inoculations with specific races of rust conducted by Dr. Pastor Corrales, USDA–ARS–Beltsville, suggest that the white bean lines have a unique combination of the *Ur-4, Ur-5* and *Ur-11* rust resistance genes.

The rust resistant white bean breeding lines were used as parents to introgress high levels of rust resistance into black beans. DPC-40 and XRAV-40-4 were used as the other parents so progeny from these crosses have multiple virus resistance. F5 black bean lines with good agronomic type were selected from these populations. These lines will be screened during FY15 at Zamorano for resistance to rust. Previous research has found rust races in Honduras to have high levels of virulence. Dr. Pastor Corrales (USDA FTF project collaborator) will conduct greenhouse evaluations of lines that are rust resistant in field trials in Honduras. This effort should lead to the development of black bean lines that combine multiple virus resistance and the *Ur-4, Ur-5* and *Ur-11* rust resistance genes.

Leafhopper tolerant line PR1146-138 (left) vs. a leafhopper infested line (right)

Yellow bean lines that combine the *bgm-1* gene for resistance to BGYMV and the *I* gene for resistance to BCMV were developed and tested in Puerto Rico, Angola, and Haiti. One of the lines had tolerance to leafhoppers in a trial planted in Damien, Haiti (see image, above) and produced a seed yield of 1,884 kg/ha in seven environments. Seed of this line has been multiplied for on-farm trials that will be conducted in Haiti during FY15. $F_{5:6}$ yellow bean plants with superior agronomic traits and commercial seed types were selected in a nursery planted in Puerto Rico. They will be screened using molecular markers and greenhouse evaluation to identify lines that combine resistance to BGYMV, BCMV, and BCMNV.

Pinto beans have gained popularity in Haiti after this market class was imported as food aid. Consumers note that pinto beans have a shorter cooking time than other seed types used in Puerto Rico. During the past year, we selected $F_{5:6}$ plants that have multiple virus resistance. The *bgm-1* gene and the SW12 QTL for BGYMV resistance and the *I* gene for BCMV resistance were identified using marker-assisted selection. The bc-3 gene was identified in greenhouse inoculations using the NL-3 strain of BCMNV. All of the selections have commercial pinto seed type and many have an erect growth habit. During the upcoming year, these lines will be evaluated in trials in Haiti and Puerto Rico. These pinto lines should segregate for the *Ur-11* gene, so special attention will be given to lines that do not develop rust symptoms. Two generations will be planted in Puerto Rico during FY15 to multiply seed of the most promising lines.

Advanced generation black bean lines (F_7) from Puerto Rico that were identified as possessing the *bgm-1* gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV were tested in Haiti and Puerto Rico. Many of these lines have progenitors with heat tolerance and resistance to common bacterial blight and web blight. These lines expressed little damage from leafhoppers in Haiti, although many bean lines in neighboring trials were severely damaged.

During the winter of 2013–14, the National Seed Service in Haiti planted a seed increase of the Haitian Lima bean landrace *Beseba*, which produced the greatest seed yield in a high temperature trial in Colombia in 2014.

IICA personnel reported that the shiny black bean variety *ICTAZAM*, which has resistance to BGYMV, BCMV, and web blight, and was identified by ICTA researchers as having superior performance in more humid regions, such as the Petén, is acceptable to consumers in Guatemala.

Trial Name	Small red	Small black	Countries
VIDAC	43 entries + 2 checks	30 entries + 2 checks	GU, ES, HO, NI, CR, PR, HA
ECAR	14 entries + 2 checks	14 entries + 2 checks	ES, HO, NI, CR, GU, HA
VIROS	52 entries + 2 checks		ES,HO, NI, CR
ERMAN	24 entries + 2 checks		ES, HO, NI, CR, GU, HA
ERMUS	14 entries + 2 checks		ES, HO, NI, CR, GU
AGROSALUD	9 entries + 1 check		ES, HO, NI, GU, CR
ERCAUPI (cowpeas)	9 entries		ES, HO, NI, GU
ERTEPARI (tepary bean)	21 entries + 1 check		ES, HO, NI
ERLIMA (Lima bean)	12 entries		ES, HO, NI, CR

Table 1. Bean and other grain legume trials distributed to Central American and Caribbean Bean Research Network collaborators during 2014–2015.

Greater tolerance to abiotic stress
INTA and CENTA researchers reported that the black bean line *MEN-2201-64ML* from Zamorano had superior performance under drought conditions in Nicaragua and El Salvador. MEN-2201 was also selected for resistance to BCMV, BCMNV, and BGYMV. On-farm testing of MEN-2201-64ML in Haiti, Honduras, Guatemala, and other Central American countries where drought is a frequent constraint to bean production will be tested in 2015.

Small red and black breeding lines having greater nodulation, plant growth, seed yield, and resistance to BCMV and BGYMV were selected at Zamorano from the second cycle. The most promising lines were distributed to collaborators in Central America for field evaluation in diverse conditions. Greater nodulation in the field (0.08 % N), soil: sand benches (0.06% N), and plastic pouches (nodulation speed) was obtained with *Rhizobium tropici* (CIAT 899) and *R. etli* (CIAT 632).

Lines from past studies as well as from the ADP were evaluated for nodulation characteristics in pasteurized sand inoculated with the *Rhizobium tropici* strain. Twelve days after inoculation, lines ADP-186, ADP-225, ADP-302, 368, 390, 444, 456, 477, and 514 were selected for early and best nodulation.

Bruchid resistance
Bruchid resistant bean breeding lines developed by Dr. Kusolwa at Sokoine University of Agriculture have been used to introgress resistance to this pest into commercial seed types (black, small red, red mottled, light red kidney, and yellow) produced in the target countries. A laboratory screening technique developed at the University of Puerto Rico has been used to evaluate the resistance of bean breeding lines.

An additional breeding objective is to combine bruchid and virus (BCMV, BCMNV, and BGYMV) resistance; considerable progress has also been made. Rojo's backcross lines combine resistance to bruchids and the *I* and *bc-1*^{2} genes that confer resistance to BCMV and BCMNV. The performance of these lines is being tested in field trials in Puerto Rico and Tanzania. In 2015, these lines will be screened for disease resistance genes using molecular markers.

Black and white bean lines were developed that combine resistance to bruchids, the *bgm-1* gene for resistance to BGYMV, and the *I* and *bc-3* genes for resistance to BCMV and BCMNV. Seed of lines are being evaluated for adaptation and for resistance to local eco-types of bruchids in Honduras, Guatemala, and Haiti.

Evaluation of bean diversity panels and identification of new sources of disease resistance
The virulence patterns of *Phaeoisariopsis griseola* isolates from Honduras and Puerto Rico were studied. In collaboration with the USDA–ARS FTF project, association mapping of the response to *Macrophomina phaseolina* in the Andean Diversity Panel was conducted. Results from field screening identified a small group of lines in the ADP with resistance to ashy stem blight. Regions on Pv03, Pv09, and Pv11 were significant for charcoal rot resistance in the association mapping analysis.

Genetic Improvement of Tepary Beans
Although the tepary bean has high levels of abiotic stress tolerance, it is susceptible to viruses such as BGYMV, BCMV, and BCMNV. To expand the potential use of tepary bean in abiotic stress prone regions, a primary focus of this project will be to initiate the introgression of virus resistance from common bean into tepary bean. By project end, we expect to have tepary breeding lines with improved virus resistance available for pyramiding of virus resistance loci in future efforts. A tepary breeding program was initiated at USDA–ARS–TARS in 2008. Advanced breeding lines developed from these previous breeding efforts was increased in FY13 and FY14 and then shared with collaborators for testing in Tepary Adaptation Trials (TAT). New tepary F4 lines will be generated from crosses between promising large and round seeded genotypes from the CIAT collection and breeding lines selected for disease and abiotic stress tolerance. Superior lines will then be tested in the host countries for potential future release. Tepary bean selection Tep-22, which combines resistance to common bacterial blight, rust, and seed weevil and tolerance to heat and drought was released.


Collecting nodulation data in a Tepary heat trial in Puerto Rico

Objective 2. Develop and implement robust molecular markers for disease resistance genes

This project will leverage the results from the USDA Common Bean Agricultural Project and the USDA/DOE/JGI common bean sequencing project. The BeanCAP project developed a suite of approximately 3000 InDel markers distributed across all common bean chromosomes. These markers are codominant and designed to be functional in labs with a simple set of equipment and reagents. The release of the common bean whole genome assembled sequence allows for precise localization of each of these markers. The final key element that facilitates this project is the development, over the last fifteen years, of markers (mostly SCARS) that are linked, from 0–5 cM, to important target disease genes; however, these SCAR markers don't work across different market classes or genetic backgrounds. Contrastingly, most InDel markers developed at NDSU are market class specific, which will facilitate their use and increase their reliability.

Identify genetic materials for marker evaluation
Potential targets for improved marker development include bean golden yellow mosaic virus resistance genes and QTL, bruchid resistance genes, CMV and BCMNV, and bean rust.

Development of InDel markers
DNA will be isolated from genetic populations or collections of lines with known phenotypes. The physical locations of target genes or markers will be identified using sequence information. Once the location of the marker is determined, it will then be compared to the InDel database to discover Indel markers that straddle the physical location of the marker. Those InDel markers will be used in PCR amplification to determine which one acts as a definitive marker that is unambiguous in its predictive power.

Major Achievements

Development, testing and release of improved bean cultivars

- XRAV-40-4, a multiple disease resistant (BGYMV, BCMV, and BCMNV) black bean adapted to the humid tropics, was developed and released cooperatively (see above for greater details).
- Red mottled bean lines PR0737-1 and PR0633-10, which combine the *bgm-1* gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV, were released as improved germplasm.

Tepary adaptation trial (TAT)

Genetic Improvement of Tepary Beans

- Release of tepary bean selection Tep-22 that combines resistance to common bacterial blight, rust, and seed weevil and tolerance to heat and drought.

Research Capacity Strengthening

Legume Innovation Lab plant breeders assisted bean research programs in Guatemala and Haiti to develop the capacity to produce populations and test breeding lines that will lead to the release of improved bean cultivars. This should contribute to the long-term sustainability of bean breeding activities in the region.

The project received Institutional Strengthening funds to continue to support the bean research network in Central America and the Caribbean. These funds will permit bean researchers in the region to attend the annual meeting of the PCCMCA to share research results. Legume Innovation Lab and CIAT scientists also meet with bean researchers to plan collaborations.

A planning meeting and field day for the release of improved small red and black bean cultivars was held at Zamorano in April 2014 with NAR's and NGO's technical personnel and farmers from Honduras, El Salvador, and Nicaragua.

This Legume Innovation Lab project continues to collaborate with many CRSP alumni institutions. This collaboration extends the potential impact of Legume Innovation Lab research and generates information that is valuable to the global bean research community. A few of the collaborative research activities are:

- Bruchid resistance research with Paul Kusolwa at Sokoine Agricultural Univ. in Tanzania
- Evaluation of red mottled and black bean breeding lines by IDIAF in the Dominican Republic

- Regional performance trials (SISTEVER) in Nicaragua, El Salvador and Costa Rica
- Evaluation of Andean and pinto bean lines in Angola
- Rhizobium Inoculant production in Haiti

Human Resource and Institutional Capacity Development

Short-Term Training

Short-term training in plant pathology and BNF research techniques and angular leaf spot was conducted during 2014 in Honduras, Tanzania, and Guatemala. A total of three women and one man benefitted from these training opportunities at UPR and in Zamorano.

Degree Training

During FY14 and FY15, this project worked with eight bachelor of science students (three women and five men) from Ecuador, El Salvador, Bolivia, and Honduras, working on research projects in plant science on such subjects as molecular germplasm, multiple virus resistance, MAS for virus resistance, high iron and zinc content in beans, and a differential nursery for Rhizobium–bean interactions. All of these students successfully completed their degrees in December 2014.

Consuelo Estevez de Jensen showing biological nitrogen fixation in roots of a common bean increase of DPC-40 at the Hands Together Project in Gonaive.

Achievement of Gender Equity Goals

The development and dissemination of improved bean cultivars using conventional techniques and marker-assisted selection should produce greater or more reliable bean yields. This should contribute to economic growth and improve the lives of the families of bean producers in Central America and Haiti. The project also supports the participation of women in formal and informal training activities.

Drying of common bean for threshing at the Damien Experiment Station of the National Seed Service.

Scholarly Accomplishments

Beaver, J.S., E.H. Prophete, J.C. Rosas, G. Godoy Lutz, **J.R. Steadman and T.G. Porch**. 2014. Release of "XRAV-40-4" black bean (*Phaseolus vulgaris* L.) cultivar. *J. Agric. of the Univ. of Puerto Rico* 98:83–87.

Porch, T.G., Beaver, J.S., Abawi, G.A., **Estevez de Jensen, C.E.**, Smith, J.R. 2014. Registration of a small red dry bean germplasm, TARS-LFR1, with multiple disease resistance and superior performance in low nitrogen soils. *J. Plant Reg*. 8:177–182.

Porch, T.G., J.S. Beaver, S. Colom, A. Vargas, Y. Trukhina, and **C. Estevez de Jensen**. 2014. Development of tools for *Macrophomina phaseolina* evaluation and for genetic improvement of common bean. *Ann. Rep. Bean Improv.Coop*. 57:189–190.

Prophete, E., G. Demosthenes, G. Godoy-Lutz, **T.G. Porch**, and **J.S. Beaver**. 2014. Registration of PR0633-10 and PR0737-1 red mottled dry bean germplasm lines with resistance to BGYMV, BCMV, BCMNV, and common bacterial blight. *J. Plant Reg*. 8:49–52.

Professional Recognition

Dr. Juan Carlos Rosas received the 2014 Gamma Sigma Delta Distinguished Achievement in Agriculture Award.

Consuelo Estévez de Jensen received a Certificate of Recognition for Excellence in Research, Creativity from the University of Puerto Rico, Mayaguez, College of Agriculture, on May 9, 2014. She also received the Professional Oral Presentation Award for her paper *Inoculant Production in Haiti* at the 38th Annual Meeting of the Puerto Rican Scientific Society Annual Meeting on November 2, 2013.

Genetic Improvement of Cowpea to Overcome Biotic Stress and Drought Constraints to Grain Productivity

(SO1.A5)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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Issa Drabo and Jean-Baptiste Tignegre, Institut de l'Environment et des Recherches Agricole (INERA), Koudougou and Kamboinse, Burkina Faso

Ibrahim Atokple and Francis Kusi, Savanna Agricultural Research Institute (SARI), Tamale, Ghana

Ndiaga Cisse, Centre National Recherches Agronomie, Bambey, Institut Senegalais de Recherches Agricole (ISRA) and CERAAS, Thies, Senegal

Abstract of Research and Capacity Strengthening Achievements

A panel of resistance sources was established and uniform test protocols designed for field and screen house aphid screening to characterize cowpea aphid biotypes. Linkage between pinkeye and aphid resistance QTL was broken to breed aphid-resistant blackeye cowpeas. Two F3 populations were developed in Burkina Faso to identify QTLs for pod bug resistance. Three large white-seeded CRSP cowpea varieties were released in Senegal after 10 final on-station and on-farm trials. In Burkina Faso 18 prerelease CRSP cowpea lines were evaluated in on-farm and on-station trials in 2013; farmers' Participatory Variety Selection chose nine lines that were tested in 20 on-farm trials in 2014. The 2014 data will inform which candidate lines will be submitted for release.

Five African students engaged in degree training programs (three PhD, one MS, one TS) in the project. Five Capacity Strengthening awards from the MSU management entity supported the development of screen houses (Ghana and Burkina Faso), cowpea seed storage (Senegal), off-season field irrigation (Burkina Faso), and short-term training for a Ghana scientist at UCR. These projects are in various stages of progress. Continuous short-term training occurred through iterative data analysis and interpretation cycles using the phenotype and genotype data from each host country. A training/planning workshop in 2014 at UCR for scientists from Ghana, Senegal, Burkina Faso, Nigeria, and Mozambique utilized molecular breeding modules.

Project Problem Statement and Justification

The project is aligned with the following FTF strategic research priorities:

1. crop resistance to heat, drought, salinity, and flood
2. West African Sudano–Sahelian systems emphasizing insect-resistant cowpea
3. grain legume productivity

Strategically, our partner countries Ghana, Senegal, and Burkina Faso represent primary agroecologies for cowpea production in the Sudano–Sahel region.

Low productivity of agriculture is central to rural and urban poverty in Africa. On-farm cowpea yields in West Africa average 240 kg/ha, even though potential yields are five to 10 times greater. Most of the loss in yield potential is due to drought, poor soil fertility, and insect pests. By targeting insect tolerance with drought tolerance, cowpea productivity, food security and rural incomes can be increased. To increase marketing options, new cowpea varieties must have features desired by consumers—in grain appearance, cooking and processing characteristics. Regionally adapted cowpea varieties with large white grain and large rough brown grain with resistance to pests would increase the marketing opportunities of cowpea farmers and traders in both West Africa and the United States.

The project focus is to

1. discover insect tolerance and resistance QTL for cowpea breeding
2. increase African and U.S. cowpea productivity by improved varieties with resistance to insect stresses, drought tolerance, or disease resistance
3. expand farmer marketing opportunities with improved cowpea varieties; and
4. provide training and capacity building in modern cowpea breeding

The project employees genomics and modern breeding to improve cowpea yield by targeting insect tolerance and resistance. By leveraging genomic resources, the project applies modern breeding tools. The project targets insects that attack at every stage of cowpea development—early (aphids), mid-flowering and pod-set (flower thrips), and later pod-filling (pod-sucking bugs). Discovery research work through phenotyping, genetic mapping, and QTL identification needs to be conducted to address the vulnerabilities of these insect pests, using high throughput SNP genotyping, genetic maps, and QTL discovery. The project's breeding programs have early generation populations with target traits, providing valuable starting points for breeding cowpeas with the characteristics necessary to increase yields.

Objectives

1. Discover QTL for insect resistance and apply in molecular breeding for target regions in West Africa and the United States.
2. Complete release and validation of advanced cowpea lines developed under the Pulse CRSP in Burkina Faso, Senegal, and the United States.
3. Increase capacity of NARS in Burkina Faso, Ghana, and Senegal to serve the cowpea sector.
4. Provide training and capacity building in modern cowpea breeding.

Technical Research Progress

Objective 1. Discover QTL for insect resistance and apply in molecular breeding for target regions in West Africa and the United States.

Genotyping

We are applying the KASP SNP (Kompetitive Allele Specific PCR Single-Nucleotide Polymorphism) platform that we developed with the GCP IBP (Generation Challenge Programme Integrated Breeding Platform) and LGC KBioscience for SNP genotyping both in the QTL discovery phase and for breeding. The platform has 1,022 mapped SNPs providing excellent coverage across the cowpea genome. We will genotype all parent and control genotypes with the full set of SNPs. This approach is being used for genotyping RIL (recombinant inbred line) populations or $F_{2:3}$ families for QTL mapping purposes or for backcross populations to select the appropriate individuals (BC1F1 or BC2F1, etc.) carrying positive alleles for making the next backcross. The NARS breeders grow plants in the host country, take leaf punches at the young plant stage, place in 96 well plates, dehydrate with silica gel, and then express ship to LGC KBioscience in the UK or United States.

For the Bt-cowpea work, DNA is extracted in Africa for shipping and genotyping, instead of leaf samples. The data are returned within four weeks, analyzed and jointly interpreted for a breeding decision (which plants to cross or advance). In July 2014 the Infinium iSelect cowpea genotyping platform was developed through our complementary USAID Climate Resilient Cowpea project, with greater than 40,000 SNPs. DNA of key parents and breeding lines are being prepared for high density genotyping on the new platform.

Phenotyping and data handling

Phenotyping is being conducted under field, greenhouse, and lab conditions (insect screens) at NARS locations using standard test protocols. Phenotypic data analyses are by standard ANOVA. When drought tolerance is being selected, performance testing under water-limited conditions is conducted at NARS field sites.

> *The tight genetic linkage between the pinkeye seed trait and one of the key aphid resistance QTLs was broken in a few backcross progeny individuals, allowing the development of aphid resistant blackeye cowpea varieties for the United States.*

1.1 Aphid resistance. We are testing the genetic relatedness of five sources of cowpea aphid resistance. Field observations in Africa and California indicate differential effects of resistance sources on aphid populations from different cowpea production areas. A differential cowpea panel of aphid resistance sources and control lines was established and seed was multiplied for multilocation field screening and screen house seedling screening to facilitate the determination of cowpea aphid biotypes in West Africa and the United States.

We adopted a field–based screen using a panel of photographs representing the different infestation and plant damage ratings on a phenotyping index. This screen is being used in conjunction with a screen house-based assay developed by SARI, Ghana, in which three to five aphids are placed on a one-week-old seedling. A uniform test protocol was designed for aphid biotype screening under field conditions in California and a seedling screen house protocol was developed at SARI, Ghana, to enable direct comparisons of aphid populations from the West Africa and U.S. target cowpea breeding areas.

A set of F1s was made from aphid resistant x drought tolerant line crosses at SARI, Ghana—the first step in combining aphid resistance with drought tolerance in elite cowpea breeding lines.

The tight genetic linkage between the pinkeye seed trait and one of the key aphid resistance QTLs was broken in a few backcross progeny individuals, allowing the development of aphid resistant blackeye cowpea varieties for the United States.

Sets of 15 seeds per line were distributed to all partners for phenotyping during the 2014 main season, and each partner is increasing seed for next season trials (Table 1).

No.	Name	Quantity received	Quantity produced	Seed coat color	Source	Remarks
1	KN1	15 seed	350 g	Not white	Burkina Faso	Enough seeds for field, insectary tests and multiplication
2	B301	15 seed	200 g	Not white	IITA	Enough seeds for field, insectary tests and multiplication
3	SARC1-57-2	15 seed	400 g	White	Ghana	Enough seeds for field, insectary tests and multiplication
4	SARC1-91-1	15 seed	400 g	White	Ghana	Enough seeds for field, insectary tests and multiplication
5	CB 27	15 seed	200 g	White	UCR	Enough seeds for field, insectary tests and multiplication
6	KVX 295-2-124-99	15 seed	350 g	White	Burkina Faso	Enough seeds for field, insectary tests and multiplication
7	IT97K-556-6	15 seed	400 g	Not white	IITA	Enough seeds for field, insectary tests and multiplication
8	No, 2300	15 seed	200 g	Not white	Burkina Faso	Enough seeds for field, insectary tests and multiplication
9	Niebe sauvage farako-bo (NS Farako-bo)	15 seed	200 g	Not white	Burkina Faso	Enough seeds for field, insectary tests and multiplication
10	Niebe sauvage-1 (NS-1)	15 seed	200 g	Not white	Burkina Faso	Enough seeds for field, insectary tests and multiplication

Table 1. Details of sources of resistance to the cowpea aphid for the differential panel for determining resistance uniqueness and aphid biotype differences.

At SARI, Ghana, an insectary has been roofed with transparent roofing sheets to allow sun rays in to ensure normal plant growth (Figure 1). All the windows and door to the insectary have also been sealed with insect proof net to prevent entry of insects other than the aphids that are artificially infested at the seedling stage of the plants. Land earmarked for the field screening of the sources of resistance to cowpea aphids has also been prepared (Figure 1).


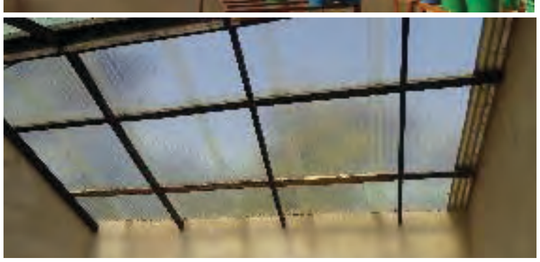


Figure 1. The clear-roof insectary and the field area at SARI being used for the aphid resistance and biotype screening.

To identify and compare new sources of aphid resistance and the differential panel, 41 cowpea lines including landraces and a resistant wild cowpea, from IITA, Burkina Faso, Ghana, and Mozambique, were field-screened for aphid resistance at Kearney in unprotected plots, in a RCBD design with three replications. Susceptible cv. Big Buff was grown on every third row (spreader rows) to attract aphids. The wild cowpea with tiny seeds did not germinate. Infestation was not uniform across the experiment, so only plots next to highly infested spreader rows were scored. Lines showing strong aphid resistance included INIA-19, INIA-3, INIA-42F, INIA-5A, INIA-5E, IT97K-556-6, SARC-1-57-2, Tvu-2845, and VAR-11D. The resistance panel will be rescreened in 2015.

Figure 2. The set up in the screen house to initiate the crosses of aphid resistant x drought tolerant lines (SARI, Ghana).

In Burkina Faso, F1, F2, and BC3F1 generations have been developed from the cross Tilgre x KVX 295-2-124-99. In late summer 2014, phenotyping was done on 150 F2 plants for aphid resistance (aphid population from Pobe), 150 F2 plants (aphid population from Kamboinse), and 150 F2 plants (aphid population from Bobo Dioulasso—Farako-Ba). The differential resistance panel was also screened and results are being analyzed. Insect samples were collected and data are being analyzed.

In California, to develop aphid-resistant blackeye cowpea, resistance alleles at both major and minor QTLs from the African donor IT97K-556-6 are being introgressed into blackeye cultivars CB27, CB46, and CB50. Strong linkage drag for pinkeye at the minor resistance QTL has now been broken in BC5 F1 and BC4-intercrossed plants. These plants are being selved at time of reporting to obtain BC4/BC5 F2 seeds for genotyping. Selected F2 plants fixed for resistance alleles at both QTLs will be selfed in the greenhouse for field trials in 2015.

At SARI, Ghana, a population of a cross of aphid resistant x drought tolerant lines has been initiated with our source of aphid resistance (SARC1-57-2) and IT89D-374-57, which is also a source of drought tolerance (See figure 2). Our target is to improve the field resistance/tolerance of the improved Zaayura with IT89D-374-57. Four other lines also being improved with SARC1-57-2 are now at the BC4F1 stage and will be crossed with IT89D-374-57. The screen house used for crosses and line advancement is shown in figure 2. A set of BC1 progenies will be generated by early 2015, using the improved Zaayura with aphid resistance as recurrent parent for which we used the SNP platform for background selection during 2014. We now have improved Zaayura, which is resistant to cowpea aphid and has also recovered 95 percent of the background of the original Zaayura.

Figure 3. The three F3 populations with the Sanzi resistance donor parent planted at SARI, Ghana, for flower thrips phenotyping during autumn 2014.

1.2 Flower thrips resistance. In recent work on QTL discovery, we identified and SNP-mapped loci for flower thrips tolerance donated by Sanzi in the cross Sanzi x Vita 7, and these loci are promising for introduction and selection in breeding progenies but require better definition through phenotyping. In Senegal, the Sanzi x Vita 7 RIL (140) population and parents were planted during the 2013 and 2014 growing seasons. In 2013, because of extreme thrips pressure, none of the lines in the trials flowered to set pods by 80 days after planting. In 2014, the RIL population Yacine x 58-57 was planted at two different dates while the Sanzi x Vita 7 RIL population was included on one planting date, all at Bambey. Data on pods number and seed weight per plant and plots are being obtained. Due to lack of seed for field testing, genotyping of these RILs at SARI, Ghana, was delayed and will be conducted in 2015.

At SARI, Ghana, three Sanzi-derived F3 populations segregating for seed color (including white) and flower thrips resistance are available for QTL discovery and breeding. The three F3 populations with Sanzi donor parent were planted and leaf samples from tagged individual plants were sent to UCR for genotyping. This was to be followed with sampling for Thrips; however, we realized that the destructive sampling of the flowers from the single plants tagged for this study would negatively affect the quantity of seeds that will be produced from each of the plants. So the Thrips sampling was suspended and the plants were allowed to produce enough seeds. The seeds have been planted, as shown in figure 3, and the phenotypic data will be recorded by early December 2014.

1.3 Pod-sucking bug resistance. The Heteropteran Coreid pod-sucking bugs are a major yield suppressor in Burkina Faso, Ghana, and neighboring countries. We have not yet identified genes or QTL for resistance to pod-sucking bugs but resistant cowpea accessions are available. We are using biparental resistant x susceptible segregating populations to map QTL and initiate their selection as a new breeding target. In Burkina Faso, F2 seed was grown and plants selfed to produce F3 families to facilitate phenotyping of the two F3 populations generated from pod-bug resistance donor IT86D-716 crossed with parents Kvx771-10 and IT98K-205-8. These populations will enable combining Striga resistance with pod-sucking bug tolerance.

Objective 2. Complete release and validation of advanced cowpea lines developed under the Pulse CRSP in Burkina Faso, Senegal, and the United States.

2.1. A first component of this objective is to use our genotyping capability with genome-wide markers to conduct background selection in backcross progenies carrying the BT-gene insertion for Maruca resistance with our SNP marker panel to track the gene in segregating progeny in breeding populations in Burkina Faso. The background selection will aid in obtaining Bt-lines with the highest recurrent parent content. In Burkina Faso, BC3 F3 plants were phenotyped at Kamboinse and leaf samples used for extraction of DNA for SNP genotyping and to confirm presence of the Bt insert using the protein dip-stick assay. The DNA was shipped to UC Riverside for SNP genotyping. The data are being used for making background selection decisions to expedite the selection of progeny with the highest recurrent parent background content.

2.2. This subobjective capitalizes on previous Pulse CRSP breeding by completing the release of several advanced breeding lines that are in the final stages of performance testing in Burkina Faso, Senegal, and California.

A successful cowpea harvest

Genotypes	Days to 1st flower	Days to 50% flowering	Days to 95% maturity	100-Seed weight	Grain yield Kg/ha
PAKAW	32.3	34.5	55.8	17.6	2456.3
ISNI2007-3217	33.0	35.0	56.0	23.2	3278.5
ISNI2007-3178	31.8	33.8	55.5	25.5	3016.0
MELAKH	32.5	34.8	55.8	17.8	2116.0
YACINE	34.8	36.8	55.0	20.5	2875.5
ISNI2007-3205	34.5	36.5	56.5	24.7	2995.3
ISNI2007-3201	32.3	34.3	55.5	24.3	2980.5
ISNI2007-3211	32.0	34.3	55.8	23.9	2853.9
Mean	32.98	35.13	55.97	22.71	2481,55
LSD	1.45	1.29	0.76	2.32	709,21

Table 2. Advanced large white-grain breeding lines performance in the main season 2013 on-station trial at Bambey, Senegal.

In Senegal, during the 2013 main season, the five new lines were tested for the last time on station and on-farm before being proposed for release. High yields were obtained with these new lines, often significantly better than the checks. These lines matured at about 60 days after planting with larger white grains (100-seed weight [Table 2]). The on-farm tests were conducted in cooperation with the farmer organizations RESOPP, UGPM, Millennium project villages, and FONGS. Yields obtained were comparable or higher than the check Melakh. Yields are given per genotype for all 10 trials (Table 3) and per collaborator organization (Table 4).

Genotypes	Mean grain yield Kg/Ha
3178	858.6
3217	823.8
3211	739.1
3205	708.7
MELAKH	698.3
3201	669.7
Mean	749.71

Table 3. Summary of advanced large white-grain breeding lines performance in the main season 2013 on-farm trials in Senegal.

Researchers examine cowpea plants for disease resistance and healthy growth.

Partner Organization	Mean grain yield Kg/Ha
RESOPP	965.2
FONGS	972.6
MILLENIUM	885.8
UGPM	175.3
Mean	749.71

Table 4. Summary by partner farmers' organization of advanced large, white-grain breeding lines' performance in the main season 2013 on-farm trials in Senegal.

In Burkina Faso, prerelease CRSP advanced lines developed by Dr. Drabo required final rounds of on-farm performance testing. Multilocation tests are needed to support the final selections for release. In the main season 2013, 18 prerelease CRSP advanced lines and two checks were evaluated in on-farm trials at Réo, Pobé, Saria, and Poa. A participatory variety selection (PVS) in the trials with local lead farmers was conducted in September 2013 (Figure 4). As a result of the PVS, nine lines were selected by farmers. The criteria for selection were earliness, biomass, pod-load, seed color (white), and seed size (Figure 5). Due to the impact of severe drought that occurred in the 2013 main season, yields were very low and could not be considered as a criterion for selection. In 2014, the 2013-selected nine prerelease CRSP lines and three checks (Yisyande, Comcallé, Tilgré) were evaluated in 20 on-farm trials at Saria (5), Poa (2), Ralo (1), Ramongo (1), Godin (1), Pobe (5) and Djouroum (5). Rainfall was very good. Farmers have started to thresh at the time of reporting and performance data will be available in the next month and reported in the next annual report. The aim is to choose a minimum of three lines for release as new varieties.

Figure 4. Farmers' participatory variety selection (PVS) of INERA white-seeded prerelease CRSP advanced lines in 2013 in Burkina Faso.

In California, field tests for release potential were made in 2013 and 2014 of advanced CRSP-developed blackeye, all white, and dry green blackeye breeding lines. The lines carry a combination of lygus bug tolerance, and root knot nematode and Fusarium wilt resistance. Two advanced blackeyes were tested in on-farm large strip trials to assess commercial yield performance. Fifteen new blackeye breeding lines, candidate line CB46Rk2, and checks CB46, and CB50 were tested at the Kearney Research and Extension Center (KREC) and UCR field stations; 2013 yield weights, 100-seed weights, and lygus damage to seed were assayed and data analyzed by ANOVA; 2014 trial data are being analyzed at time of reporting and will be included in the next annual report.

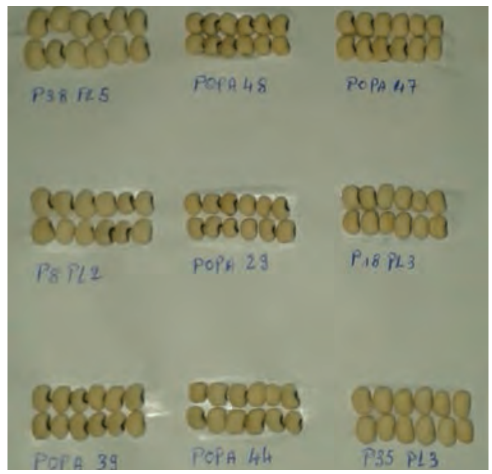

Figure 5. The nine selections of white-seeded prerelease CRSP advanced lines made in 2013 in Burkina Faso.

Table 5 lists the grain yield, 100-seed weight, and root-galling reactions to two species of root-knot nematodes garnered from these 2013 trials. Yield was generally lower than observed in 2012, possibly due in part to heat stress. Of the new selections, five lines ranked higher in yield than both CB46 and CB50 at KREC and three of these yielded higher than the checks at UCR. The best subset of these lines was retested in larger plots in 2014. In particular, line 10K-19 appears to be an outstanding yielder across years and had larger seed than CB46. Entry CB46Rk2 is a new version of CB46 with improved resistance to root-knot nematodes whose yield performance was again good in 2013, comparable to CB46 (Table 5). The smaller seed size of this line compared to CB46 has been consistent over years and locations; we think it is well-suited to canning (Table 5). The line 10K-115 was outstanding in 2011 and 2012 at KREC and similar in performance to CB46 and CB50 in a 2013 Tulare production field strip trial (Table 6) but had lower yield than CB46 at KREC in 2013. This line had consistently larger seed than CB46 across years. The lygus resistant line 07KN-74 yielded significantly lower than CB46 at KREC, Tulare, and UCR due to early cut-out (Tables 5 and 6). Some nematode-resistant lines in the N series yielded better than or comparable to CB46 and had good grain size. These lines, plus 10K-19 and 10K-115 were tested in 2014, along with CB46Rk2.

Entry	KREC Yield (kg/ha)	UC-R Yield (kg/ha)	KREC 100 seed wt (g)	UC-R 100 seed wt (g)	Galling M. incognita	Galling M. javanica	Galling M. incognita "Muller"
10K-19	3435	2384	22.6	21.7	3.9	4.4	3.7
N17	3298	2531	21.2	20.2	1.8	3.9	2.6
N20	3169	NA	21.2	NA	1.8	3.9	2.6
N5	3144	2675	20.7	20.9	1.8	3.9	2.6
N2	3112	2643	20.6	20.0	1.8	3.9	2.6
CB46	3070	2448	20.9	20.6	3.2	5.0	4.4
10K-29	2999	2546	23.4	21.9	4.2	4.7	4.0
N16	2902	2615	21.1	20.4	1.8	3.9	2.6
CB46Rk2	2872	2317	20.1	19.2	4.1	3.7	3.7
10K-77	2808	2454	23.3	22.6	3.7	3.8	4.3
10K-4	2807	2385	22.0	22.1	3.9	4.6	4.1
N4	2698	2651	20.5	19.5	1.8	3.9	2.6
CB50	2601	2002	25.1	23.9	3.5	4.9	4.3
10K-121	2550	2134	23.6	23.3	2.4	4.6	3.9
N10	2502	2489	21.4	21.3	1.8	3.9	2.6
10K-115	2419	2240	21.6	23.4	2.9	4.6	4.1
07KN-74	2271	1916	20.6	18.4	3.2	4.3	3.1
Mean	2862	2389	21.6	21.1			
CV(%)	10	10	5	3			
LSD(0.05)	369	311	1.6	1.0			

Table 5. New blackeye breeding lines and checks tested at Kearney REC and UC Riverside in 2013 with pedigree, grain yield, 100-seed weight, plus galling ratings from 2012 field screening with root-knot nematodes *M. incognita, M. javanica,* and *M. incognita Muller*. Kearney REC trial planted on June 5 and cut on October 1 (118 days). UC Riverside trial planted on July 10 and cut on November 18 (131 days).

In California, development of lygus bug resistant blackeyes continued in 2013 and 2014. From eight lines evaluated under protected and unprotected plots in 2010–2012, we retested the best four lines in comparison with an advanced breeding line 10K-4 and checks (CB46, CB50, and CB27) in 2013 at KREC under protected and unprotected conditions and at UCR under unprotected conditions. Lygus pressure was much heavier in 2013 than in 2012, resulting in grain yield loss of between 19 and 65 percent, thus discriminating between protected and unprotected conditions (Table 7). The experimental lines had similar (four lines) or significantly higher (07KN-74) protected yield than CB46, indicating they have high innate yield potential. The unprotected yields were significantly higher than CB46 for three of the five advanced lines, indicating strong yield ability under lygus pressure (Table 7). The best lines to indicate high performance under both protected and unprotected conditions were retested in 2014.

Line	Yield (kg/ha)	Seed weight (g/100 seeds)
CB46	3688	19.5
10K-115	3522	22.7
CB50	3191	23.8
07-KN-74	2362	18.9

Table 6. New blackeye lines and checks tested in a production field strip trial in Tulare Co. in 2013. [Trial planted on June 4 and cut on October 5 (123 days).]

Five F2 populations derived from intercrosses between resistant lines and blackeye CVS. CB27, CB46, and CB50 also were grown under protected and unprotected conditions in 2014. Among these, the CB27 x 09KLN1-9 population appeared segregating for lygus-resistance phenotype and 150 F2 plants are being genotyped for QTL analysis. Some F5 resistant families derived from other crosses also were field-phenotyped.

Major Achievements

The tight genetic linkage between the pinkeye seed trait and one of the key aphid resistance QTLs was broken in a few backcross progeny individuals, allowing the development of aphid resistant blackeye cowpea varieties for the United States.

The release of three large white seeded CRSP cowpea varieties was completed in Senegal following final performance testing in on-station and on-farm trials.

Research Capacity Strengthening

The Legume Innovation Lab granted approval for funding to renovate the 1960s cold room used for seed conservation at the ISRA, Senegal Bambey research station to insure adequate temperature and humidity required for cowpea germplasm conservation. It will be installed by September 2015.

The Legume Innovation Lab granted approval to fund INERA, Burkina Faso, breeding activity enhancement at Kamboinse research station by developing an irrigated field for off-season activities (crosses, advancing lines, breeder seed production). A one-ha plot will be managed by implementing a new drip irrigation system that will be completed by Spring 2015.

The Legume Innovation Lab granted approval to fund INERA, Burkina Faso, to renovate one screen house at Kamboinse Research Station and a second at Saria Research Station to prevent outcrossing during crossing and to advance breeding lines under protection from insect, rodent, and rabbit damage. The renovation will be completed by September 2015.

The Legume Innovation Lab granted approval to fund a screen house at SARI, Ghana, to enhance successful crosses and the multiplication of breeder seeds during the Harmattan period. Plans were made for a 16 m x 8 m screen house fitted with a 500-gallon politick reservoir for water, a metal frame covered with insect proof net and a polythene sheet for sealing the roof to prevent rain, and benches 80 cm to one m high for growth containers. Construction will be completed by September 2015.

The Legume Innovation Lab granted approval to fund a young scientist with an M.Sc. in plant breeding for training in molecular technology and molecular breeding at UCR. The six-month training is being planned and will be conducted March to August 2015.

Human Resource and Institution Capacity Development

Short-Term Training

Regular short-term training workshops on the molecular breeding approach were held through iterative data analysis and interpretation cycles using the phenotyping and genotyping data generated by host country partner teams; 12 African scientists/students (11 male; one female) benefitted.

Two two-day workshops on cowpea production and seed storage techniques were held in Burkina Faso in October 2014 for a total of 115 participants (45 women and 70 men).

Degree Training

Arsenio ND eve (Mozambique), Ph.D. program in Plant Pathology, University of California–Riverside, *Genome-wide selection for disease and drought tolerance in SE African cowpeas*, January 2012 to December 2016 (projected).

Sassoum Lo (Senegal), MS. program in Plant Genetics, University of California–Riverside, *MABC for Enhanced Seed Size in Cowpea*, March 2014 to June 2017 (projected).

Line	Yield (kg/ha)				100-seed weight (g)			K-REC lygus damage (%)	UCR lygus damage (%)
	Kearney-REC			UCR	Kearney-REC		UCR		
	prot'ed	unprotected	Loss (%)	unprotected	prot'ed	unprotected	unprotected		
07KN-74	2723	2099	23	1578	22.0	23.9	18.5	17	3
10K-4	2504	1201	52	1953	23.6	24.5	21.9	23	4
09KLN-2-27	2295	1294	44	1519	20.3	22.4	19.4	42	5
09KLN- 2-30	2264	1616	29	1708	19.2	21.1	19.5	21	4
09KLN- 1-9	2239	1809	19	1874	20.1	21.3	20.6	21	5
CB50	2209	1047	53	1788	25.4	27.5	23.5	23	3
CB46	2099	925	56	2062	20.6	21.8	20.1	31	5
CB27	1963	693	65	1699	22.4	24.4	20.3	28	4
Mean	2253	1285	41	1754	21.7	23.3	24.1	26	4
CV (%)	18	29	39	10	4	5	4	30	55
LSD (0.05)	476	460	19	203	1.1	1.4	1.0	9	3

Table 7. Grain yield, 100-seed weight, and lygus grain damage of five advanced blackeye lines, CB46, CB50 and CB27 when grown under insect-protected and unprotected conditions at Kearney REC and unprotected conditions at UC–Riverside in 2013.[Kearney trial planted on June 5 and hand-harvested on September 6 (93 days).] [UC Riverside trial planted on July 10 and cut on November 18 (131 days).]

Achievement of Gender Equity Goals

In Ghana, a total of 30 women farmers' groups interested in cowpea production and marketing from 15 communities were trained by the SARI team during the reporting period. With approximately 25 women per group, more than 600 women participated. Among the topics introduced to the women's groups, in collaboration with CARE international Ghana, were:

- host plant resistance
- sources of resistance to major cowpea insects and drought
- current research to develop cowpea varieties resistant to insects and drought
- integrated strategies to manage insect pests, diseases, and drought
- identification of cowpea insect pests, their damage, and management

In Senegal, training of members of the farmers' organization RESOPP on seed production and postharvest operations continued. In total, 346 and 496 producers were trained in 2013 and 2014, respectively; women numbered 49 and 108 for each year, respectively.

In Burkina Faso, 45 women farmers were trained on cowpea production and seed storage.

Scholarly Accomplishments

Huynh, B.L., **Close, T.J., Roberts**, P.A., **Cisse, N., Drabo, I., Boukar**, O., Lucas, M.R., Wanamaker, S., Pottorff, M., Ehlers, J.D. 2013. Gene pools and the genetic architecture of domesticated cowpea. *The Plant Genome* 6:1–8.

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Belko, N., **Cisse, N.**, Diop, N.N., Zombre, G., Thiaw, S., Satoru Muranaka, S., Ehlers, J.D. 2014. Selection for postflowering drought resistance in short- and medium-duration cowpeas using stress tolerance indices. *Crop Science* 54:1–9.

Pottorff, M., Li, G., Ehlers, J.D., **Close, T.J., Roberts, P.A.** 2014. Genetic mapping, synteny, and physical location of two loci for *Fusarium oxysporum* f. sp. *tracheiphilum* race 4 resistance in cowpea [*Vigna unguiculata* (L.) Walp]. *Molecular Breeding* 33:779–791.

Healthy cowpeas for sale in the local market.

IPM-omics: Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests of Cowpea in Africa

(SO1.B1)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Dr. Manuele Tamò, IITA–Benin (HC–PI)

Dr. Clémentine Dabiré-Binso, INERA–Burkina Faso (HC–PI)

Mr. Laouali Amadou, INRAN–Niger (HC–PI) (Replacement for Dr. Ibrahim Baoua with Dr. Baoua still collaborating with our team)

Dr. Ibrahim Baoua, University of Maradi (collaborator with INRAN)

Dr. Stephen Asante, SARI, Ghana (HC–PI)

Dr. Haruna Braimah, CRI–Ghana (HC–PI)

Dr. Julia Bello-Bravo, UIUC (U.S. Co-PI)

Mr. Eustache Biaou, INRAB–Benin (HC–PI)

Abstract of Research and Capacity Strengthening

Over the past 18 months, we have advanced our understanding of and solutions for the major pests of cowpeas in four West African countries: Benin, Niger, Burkina Faso, and Ghana. We have characterized pest populations through both field-level and molecular tools and explored coupling this with GIS tools. Solutions to pest problems have been developed and pushed forward, including tangible solutions from our biocontrol agent pipeline, and a neem and *Maruca*-specific viral combined spray. We have continued to develop and to investigate the use of educational tools involving animations with voice(s) overlaid into local languages as a scalable system to deploy the outcomes of our research efforts to create and deploy locally sourced pest control solutions. Our capacity building efforts have included undergraduate and graduate training in host country programs and cross-training of technicians across countries. We have continued to test our animated educational approach, including holding multiple ICT training sessions to develop networks of collaborating organizations that can, in turn, use these materials in their educational programs. We continued to collaborate with Dr. Mywish Maredia's team at Michigan State University to address social science-oriented questions related to the scaling of our technologies for pass off to other groups.

Project Problem Statement and Justification

Insect pests of cowpeas dramatically reduce yields for cowpea farmers in West Africa. Arguably, the greatest biotic constraints to cowpea production are insect pests. The major pests of cowpea in the fields in Niger, northern Nigeria, and Burkina Faso include:

- the legume pod borer (*Maruca vitrata* Fabricius)
- the coreid pod-bugs (*Clavigralla tomentosicollis* Stäl and *Anoplocnemis curvipes*)
- the groundnut aphid (*Aphis craccivora*)
- thrips (*Megalurothrips sjostedti*)

Our program is focused on a three-step approach: 1. defining the pest problems, 2. developing appropriate pest control solutions, and 3. exploring the scaling of these solutions. We have continued to develop an in-depth understanding of the pest populations through a combination of field experiments and molecular tools to characterize and compare pest populations. We have developed solutions that will allow for the development of local cottage industries that can produce biopesticides for local sale and use—thereby facilitating the potential for local value chains that result in the development and sale of ecologically friendly pest control solutions. We have continued to investigate biological control agents in our biocontrol pipeline and have promising candidates for scaling in the field along with approaches to scale their release in a cost-effective manner.

Additionally, we have 1. developed scalable educational solutions to train people in many of the pest control strategies in their own languages and for all literacy levels and 2. we are exploring pathways for passing these off to other groups that can deploy these in their educational programs.

Barry Pittendrigh and Manu Tamò, project PIs, in a cowpea field in Southern Benin checking for flower thrips damage on apical tips

Finally, in terms of capacity building, we 1. have been working with NGOs and local companies for pass off of our outcomes; 2. we have continued undergraduate and graduate training; and 3. we have developed a cross-country technician training program to facilitate capacity in biocontrol agent rearing and release, and biopesticide development, deployment, and pass-off to local commercial and noncommercial entities.

Objectives

1. Define the pest problems.
2. Develop environmentally and economically appropriate pest control solutions (the project has developed a biocontrol and biopesticide pipeline).
3. Scaling of solutions
4. Capacity building

Technical Research Progress

Over the past 18 months we have researched, developed, implemented, and performed and analyzed datasets to determine the impact potential of our strategies for cowpea farmers in West Africa. We have continued to research and to develop scalable solutions, with the potential and actualization of larger-scale impact through donor community buy-in. As part of that donor community buy-in, the Bill and Melinda Gates Foundation has funded outcomes of our past efforts on *Maruca*; the objectives of that grant do not overlap with the current USAID Legumes Innovations Lab grant.

Our objectives emerge from the vision called *IPM-omics*, which is a system to develop and to deploy scalable solutions to agricultural pest management.

First, IPM-omics is defined in the following equation:

IPM-omics = define the pest problems + appropriate solutions + scaling of solutions

Each part of this equation is a step in the overall pest management process, with the unlisted fourth set, institutional capacity building, integral to the progress and sustainability of the other three components.

A bottle of locally produced neem oil that has been packaged for sale in Benin

Objective 1. Define the pest problems

1. scouting, field experiments, light traps
2. genomic markers to define pest and biocontrol agent populations—movement patterns and sources of the outbreaks
3. computational modeling
4. understanding the biology of pest populations to drive pest control strategies

The IITA, INERA, INRAN, CRI, and SARI teams all continue to perform surveys of the pest populations during and outside the cowpea cropping cycles. Insects found on diverse alternative host plants are stored in RNAlater or 70 percent ethanol to be sent to UIUC for molecular analyses. Additionally, the INERA team has established experiments to understand the pest populations that occur in the dry season in places where an extra cycle of cowpea could occur where irrigation by some farmers is possible. All of these studies are continuing and will continue to contribute to our understanding of the cycles of pest populations on cowpeas.

In Ghana (from the SARI team), the results were as follows:

- Field studies were conducted at the Savanna Agricultural Research Institute (SARI), Nyankpala, Tolon district, northern region, Ghana, between July and September 2014 to identify the major insect pests of cowpea. The results indicated that leafhoppers, Aphis, Aphis craccivora Koch; thrips, *Megalurothrips sjostedti* T.; *Maruca vitrata* F.; Pod sucking bugs such as *Clavigralla tomentosicollis*, *Anaplocnemis curvipes*, *Riptortus dentipes* are the major pests. The thrip population was found to increase with the season and peaked with the rain in September. Incidence of *M. vitrata* and pod sucking bugs were low.
- Diagnostic survey was conducted in farmers' fields in September 2014; it was found that *M. sjostedti*, *M. vitrata*, and *C. tomentosicollis* populations were high in Krachi West and West Gonja districts, which are farther south of Nyankpala in the Tolon District.
- To date, the following have been identified as the alternative hosts of *M. sjostedti* and *M. vitrata*; *Grycine max* (L.), *Cajanus cajan* (L.), *Mucuna cochinchinensis* (Lour.), *Canavalia ensiformis*, L. and *Tephrosia* sp.


Manu Tamò, project PI, demonstrating the locally-produced slow release device for egg-parasitic trichogrammatids against the legume pod borer and maize stem borers.

1.2 Molecular Analyses of pest populations
From IITA we have received pest populations for molecular analysis for all species tested across Benin, Niger, Burkina Faso and Ghana. The specimens have been stored at $-80^{\circ}C$ and the DNA extracts have been shipped to UIUC for further molecular analyses. Similar sample collections of insects have been received from our teams in Burkina Faso, Niger, and Ghana. Molecular analyses (SNP and microsatellite analyses) are continuing at UIUC.

1.3 Computational Modeling, GIS systems and Online System
The UIUC and IITA teams have developed a flowchart system that will be used in predictive responses to when and where cowpea farmers can or should intervene in pest control strategies. The IITA team continues to use modeling approaches with the graduate students under Dr. Tamo's direction to better characterize pest populations. The IITA and UIUC teams are

continuing to explore the use of GIS systems to couple our other datasets with GIS data. The UIUC team is continuing to build a database on all of these topics for an online database that will go live in 2015.

1.4 Insect biology—Sex and aggregation pheromones for pod sucking bugs

Preliminary data from olfactometry experiments involving adult female and male of the pod bug *Clavigralla tomentosicollis* revealed that the adult female egg parasitoid *Gryon fulviventre* responded to volatiles emitted by male pod bugs only.

A subsequent experiment using different densities of adult males of *C. tomentosicollis*, both on cowpea pods and without cowpea pods, confirmed the preferences of female *G. fulviventre* for volatiles emitted by males. The nature of these pheromones needs to be further elucidated, as both sex and aggregation pheromones could be involved, as known from other coreid insect e.g. in Asia.

We have now the evidence that female egg parasitoids *G. fulviventre* use olfactic cues emitted by adult male *C. tomentosicollis* for locating egg masses in the field. This evidence could explain why, in the field, there are no parasitoids attacking eggs oviposited by the first pod bugs' generation, simply because the colonizing first generation might be female only and hence not producing sex/aggregation pheromones. It is only males issued from the first generation that will emit these pheromones and hence attract egg parasitoids. This hypothesis is substantiated by the observed parasitism rates of second-generation egg masses, which can easily reach up to 95 percent. By manipulating this system, we might be able to increase rates of parasitism right from the first generation, substantially reducing the pod bug population.

Objective 2. Appropriate solutions. We have developed a biocontrol and biopesticide pipeline in order to develop a series of environmentally and economically appropriate pest control solutions.

2.1. Novel Maruca parasitoids available for screening

Rearing colonies of the exotic parasitoids *Apanteles taragamae*, *Therophilus javanus, Phanerotoma syleptae*, and *Nemorilla maculosa* are available at IITA–Benin. As requested by USAID, Dr. Srinivasan of AVRDC conducted a thorough environmental assessment of the biological control agents prior to any trials outside the isolation rooms by and sent then to the MO. The assessment, together with comments by the MO and USAID has been returned to us for responses.

2.2 PCR techniques for detecting endophytic strains of Beauveria bassiana available

PCR primers for *Beauveria bassiana* were obtained from Inquaba Biotech in South Africa and were used to detect the presence of the entomopahtogen from pure colonies in the lab. Inoculation trials are presently ongoing as scheduled, using sprouted cowpea grains, individually inoculated with *B. bassiana* conidia, and cut into the different plantule organs (leaves, stems, roots) for further PCR detection.

2.3 Genetic improvement of cowpea to overcome biotic constraints to grain productivity (in collaboration with the UCR cowpea breeding team)

This activity has been conducte in Burkina Faso with the INERA team and in Niger with the INRAN team. Details of the activities are as follows.

1. Screening for resistance or tolerance to *Clavigralla tomentosicollis* occurred, as did screening for aphid attack.
2. Aphids were collected in three agroecological: Sahelian zone (less than 600 mm), Sudano–Sahelian zone (600–900 mm), Sudanian zone (greater than 900 mm), to screen 10 cowpea varieties from Botswana, Burkina, Ghana, Nigeria, USA.
3. Three varieties were recorded resistant or tolerant to aphid attack. F1s from the cross between susceptible plant (tiligre) x KVX 299-2-124-99 are ready to screen. The INRAN team in Niger screened more than 11 varieties of cowpeas thought to have some level of insect tolerance.

Objective 3. Scaling of solutions. When solutions have been developed we need mechanisms to effectively deploy them in a cost-effective and sustainable manner. Discovering and testing such scaling pathways is critical to determine which approaches will be most successful for scaling. Solutions for scaling fall into three categories:

1. direct release into the environment and natural establishment;
2. educational solutions; and
3. private sector and NGO involvement.

3.1 Direct Release into the Environment and Natural Establishment

3.1.1. Maruca parasitoids (IITA)

We have recovered for the first time since the last *inoculative* releases two years ago pupae of the parasitoid *Apanteles taragamae* from *M. vitrata* feeding on flowers of the legume tree *Lonchocarpus sericeus*. This is a positive and unexpected event, since previous studies revealed that M. vitrata feeding on the same substrate would not support parasitism by *A. taragamae*. This could have led to either encapsulation of the parasitoid egg inside the *M. vitrata* larva or the death of the developing parasitoid larva due to antinutritional or toxic metabolites. Discovering the establishment of the parasitoid on this host plant suggests that *A. taragamae* must have been able to adapt to these conditions and possibly developed a coping mechanisms (e.g., detoxification). This finding paves the way for more in-depth studies on the genetics of this parasitoid, comparing original populations from Taiwan with the one that has now been found adapted to *M. vitrata* feeding on *L. sericeus*. IITA is currently working with UIUC to make the molecular comparisons of the insects that were released with those that have been recovered in the field.

3.1.2. Thrips parasitoid available for scaling up (IITA, INERA, and INRAN)

Plots of *Tephrosia candida* have been established at Farakoba in Burkina Faso and Maradi in Niger as well as in Benin. As soon as we have the go ahead from the environmental assessment, IITA will send pupae from the first generation of field-collected individuals for inoculative releases on the nursery plots of *T. candida*.

3.1.3. Feasibility of storing Maruca virus both as liquid and solid substrate (IITA)

We stored viral solutions both in the deep freezer at -18°C and in a normal refridgerator at 4°C; after six months there was no significant difference of the activity between the two lab studies. Field studies with viral preparations from both cold treatments are still ongoing.

3.1.4 Scaling of the neem plus virus control strategies (IITA, INRAN, and INERA)

A detailed experiment was set up during the second season to further calibrate the dosage of emulsifiable neem oil products for aphid, thrips, and pod bugs control, and to validate an intervention threshold for viral applications against the pod borer. Different combinations of emulsifiable neem oil at dosages of 330, 660, and 1000 ml/ha with MaviMNPV sprayed at a 40 percent flower infestation level were compared to virus alone and standard insecticides (with all the necessary biological replicates for these experiments). Unusually heavy rains resulted in our first season experiments not being usable. The second season experiment is currently in the field.

Most notably, the INRAN team also tested the use of neem seed oil and virus sprays in 16 villages in the region of Maradi and Zinder. The intent of this activity is to test the effectiveness of this approach in the hands of farmers. Data collection will be completed early in FY15.

3.1.5 Portable neem oil extraction system (CRI and SARI)

The CRI and SARI teams have and are continuing to explore the development of a low-cost portable neem oil extraction system for use at the village level, working with a local company to develop a prototype.

3.1.6 Studies on the potential for use of biopesticides in the pest control market in Benin (IITA, MSU–Maredia, INRAB, and UIUC)

The INRAB and IITA teams are working closely with Dr. Maredia of MSU to perform survey studies to understand the potential for biopesticides in the pest control market in Benin. A first-round survey was conducted in FY14 and the outcomes were presented by Drs. Angela Records (USAID), Widders (MO), and Pittendrigh (UIUC) in Benin. The data are currently being assessed to determine the outcomes of this survey and what will be needed for follow-up surveys.

IITA is also continuing to work with a Benin-based company that is extracting neem oil for sale. The company purchases neem seeds from hundreds of local women, processes the neem oil, and sells the oil regionally in Benin. IITA is continuing to explore pathways to work with this company to expand their operations across Benin.

3.2 Educational Solutions

As part of our educational solutions, the project has

1. developed ICT training materials
2. developed online and in-country ICT training sessions for testing with current partners and potential new partners
3. developed FFF programs for testing of impact, leading to educational packages for scaling
4. explored potential pathways for deployment of educational videos and tested pathways to deploy videos
5. been exploring pass-off of our educational materials to NGOs and government agencies for scaling.

Because of the SAWBO program, we now have significant quantities of educational material for teaching farmers techniques to reduce problems with insect attack. We have ICT training packages and interfaces in development and ready for release to make our materials easily available to outside groups.

Packaged neem oil for sale

Training has included the following:

- An ICT training session funded by the Chancellor's office at UIUC was held in Ghana in FY13 with approximately 30 participants.
- Two ICT training sessions were held with local NGO groups (approximately 100 attendees) in Ghana online through Skype.
- The SAWBO team has conducted two ICT training sessions on campus for African librarians visiting campus (ca. 100 individuals).
- More than 2000 *Extension Systems in Your Wallet* have been created and distributed to educators, government officials, and NGOs globally (with about 500+ of these going to groups in the four main countries in the LIL program). The *Extension Systems in Your Wallet* is a credit card-style USB card containing SAWBO materials. Users can keep the USB drive in their wallet and then share our educational materials with others. Pass off has taken place with country extension programs, FARA, and other West African institutions.
- We have created two Apps for cell phones that will allow for easy distribution of the SAWBO animations (currently completing testing), which will be downloadable for free. We have also continued to collaborate with our in country teams to determine which NGO and other local groups become the logical ones to engage for deployment. We have ongoing "tagged" animation tests to determine which groups most effectively deploy the animations.

<u>3.3 Private Sector and NGO Involvement</u>
SAWBO materials are being used by NGOs and government organizations outside our target countries. SAWBO animations have also been used in documentaries on TV (e.g., in the Republic of Georgia—http://www.youtube.com/watch?v=Gh2EhCZOIV8). Within the four target counties we work in, we estimate the numbers of people that have viewed the animations in tens of thousands over the past 18 months. Additionally, biocontrol animations on the pests of cowpeas have been used in Mozambique in farmer training sessions. Finally, many outside groups have been using our materials [videos] by downloading them and placing them on small projection systems that can be used at the village level during extension sessions. This past year data analysis of an experiment performed by the MSU–Maredia, INRAN and UIUC team demonstrated that the animations were essentially as effective in promoting adoption of a new technology as traditional extension strategies.

Objective 4. Capacity Building

Our capacity building efforts fall into the following categories:

1. undergraduate and graduate student training
2. technician training
3. cross-institutional capacity building for biocontrol agents
4. systems to easily pass off our outcomes to other groups that can scale the pest control strategies

<u>4.1 Undergraduate and Graduate student training</u>
Each of our teams continues to play an active role in undergraduate and graduate training programs.

<u>4.2 Technician Training</u>
A technician from INERA spent several weeks at IITA this past year to further develop his biocontrol agent rearing and deployment skill sets. Additionally, online cross-training has occurred (via e-mail, Skype, and video exchanges based on videos made by IITA) to share skill sets between technical staff at INERA, INRAN, and IITA.

<u>4.3 Cross-Institutional Capacity Building for Biocontrol Agents</u>
IITA, INERA, and INRAN, due to ongoing collaborative efforts, are all well-positioned to rear and deploy biocontrol agents on a scale that we expect will significantly impact target pest populations in each of these countries. Additionally, all are also in a position to test, train, and scale the neem-plus-virus strategy for pest control. We have begun the process of transfer of this knowledge to our new partners in Ghana at CRI and SARI.

Varieties of cowpea for sale in a Benin market

<u>4.4 Systems to easily pass off our outcomes to other groups that can scale the pest control strategies</u>

Our team has continued to build the necessary sets of networks (e.g., NGOs, companies, FFF organizations, women's organizations, etc.) to pass off 1. educational materials 2. neem or neem and virus control strategies, 3. direct deployment of biocontrol agents and 4. FFF training approaches.

Major Achievements

1. Development of biocontrol agents useful for scaling for management of cowpea pests.
2. Experimental analyses of field data have shown that the animated educational approach is as effective as extension agent presentations in conveying information to local farmers. This strategy allows us the ability to significantly scale up our educational content.
3. SAWBO has been able to demonstrate the potential for other organizations to scale their materials. For example, a "buy in" by the Ethiopian Agricultural Transformation Agency and the ADM Institute for the Prevention of Postharvest Loss has shown that SAWBO videos can be placed on tablet computers (640 in this case) and distributed to extension agents across a given developing country for extension agents to deploy to end users (in this case an estimated 168,000 individuals) as part of their educational programs (http://news.illinois.edu/news/14/0519sawbo_BarryPittendrigh.html). SAWBO educational content has and can be scaled across borders beyond our initial target countries.

Human Resource and Institution Capacity Development

Short-Term Training

ICT training sessions of approximately 75 males and 75 females were held in Accra during summer 2013 or online in 2014 to train NGOs in the use of SAWBO materials.

Farmers throughout Burkina Faso (70 males and 50 females) and Niger (70 males and 30 females) during FY14 were trained in IPM techniques.

Training Performed by Outside Groups are in Collaboration with INRAN

Training in collaboration with a Mercy Corps NGO working in the Maradi and Zinder area is estimated to have impacted 500+ farmers (50:50 split of women and men).

One hundred-sixteen farmers were trained with Sahel Bio and HEKS.EPER, a Swiss land NGO, from July 8–10, 2014.

Achievement of Gender Equity Goals

Throughout all aspects of our efforts we attempt to meet gender equity goals, from undergraduate, graduate student, and technician training to field training of female farmers.

Scholarly Accomplishments

Publications

Agunbiade, T., Steele, L., Coates, B. S., Gassmann, A., Margam, V. M. , **Ba, M., Dabire, C.**, Baoua, I., **Bello-Bravo, J.**, Seufferheld, F., Sun, W., **Tamò, M., Pittendrigh, B.R.** IPM-omics: from genomics to extension for integrated pest management of cowpea. In: Boukar, O., Coulibaly, O., Fatokun, C., Lopez, K., Tamò M. (eds.). 2013. Enhancing cowpea value chains through research advances. *Proceedings of the 5th World Cowpea Research Conference*, 26 September–1 October 2010 Saly, Senegal, pp. 231–248.

Agunbiade, T.A., W. Sun, B. S. Coates, R. Djouaka, **M. Tamo, M. N. Ba**, C. Binso-Dabire, I. Baoua, B. P. Olds, and **B.R. Pittendrigh**. 2013. Development of reference transcriptomes for the major insect pests of cowpea: A toolbox for insect pest management approaches in West Africa. *PLoS ONE*, 8(11): e79929

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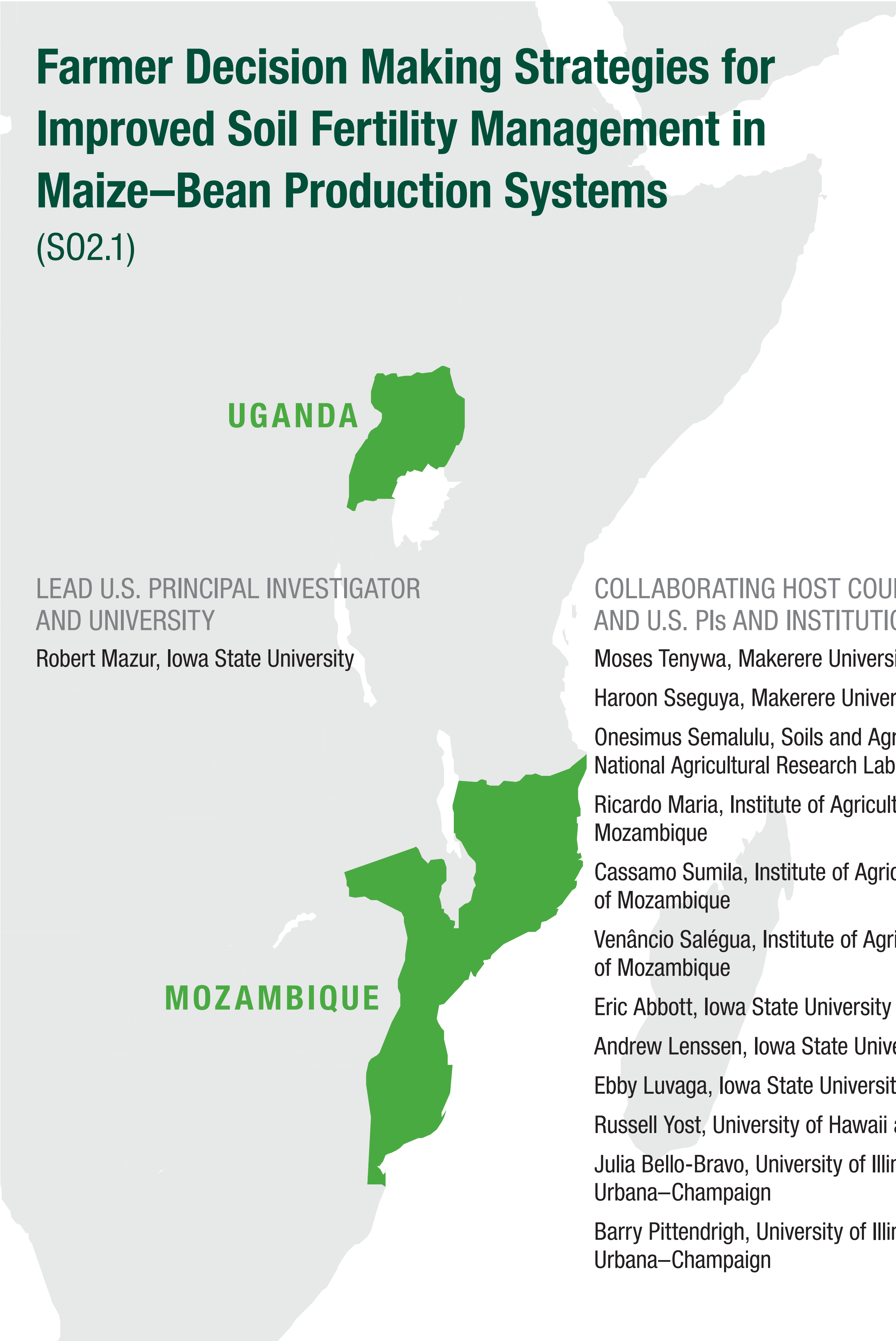
Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize–Bean Production Systems

(SO2.1)



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Abstract of Research and Capacity Strengthening Achievements

To understand limiting soil nutrients, we analyzed the physical and chemical properties of three predominant soil types used for growing common beans in study communities in Uganda's Masaka and Rakai districts and in Mozambique's Gurué district. Results guided greenhouse nutrient omission studies using soils from farmers' fields, revealing effects of specific macronutrients and micronutrients on bean plant growth and development. Complementary lime requirement studies will demonstrate soil-specific pH amelioration requirements for bean root growth. Preliminary results from initial researcher-managed field trials in Uganda indicate strong relationships for soil pH, nodulation, foliar disease, and bean yield. When initial field trials start in Mozambique in early 2015, a follow-up study in Uganda is planned. Trials will demonstrate the soil-specific nutrient and crop management practices necessary to increase bean productivity in farmers' fields.

Baseline household survey results depict smallholder farmers' practices of field selection and preparation, crop and variety selection, planting methods and spacing, input use, intercropping and rotation patterns, gender-based division of labor, problem identification and management practices, market sales and storage. Farmer research groups are being formed and supported for field experiments to test and demonstrate the impact of variations in improved management practices and technologies for bean production.

The training of three M.S. students at Iowa State University and three M.S. students at Makerere University is progressing.

Project Problem Statement and Justification

Poor soil fertility is a major factor in low bean yields in Uganda and Mozambique. Average bean yields in Uganda are 0.6–0.8 MT ha1, although yields of 1.5 MT ha-1 can be realized with improved varieties. Both countries have weak extension systems and rural social and economic institutions, limiting widespread access to information and materials that could enable smallholder bean farmers to improve crop management practices and technologies and achieve better yields.

This research project is based on two premises: 1. Sustainable intensification of agriculture production requires improved soil fertility management in which legumes are an integral part of cropping systems and 2. Effectively addressing soil-related constraints will be based on enhancing smallholder farmers' capabilities in diagnosing and finding solutions to important yield constraints and helping to remove barriers to increased access to various types of soil amendments. Analysis of the physical and chemical properties of soil combined with field trials can reveal the soil-specific effects of macro- and micronutrients on bean plant growth and development. Documentation and analysis of cropping systems, practices, and technologies utilized by farmers—and the problems they encounter—is essential for identification of strategies to address key constraints.

Working with farmer-led learning groups can effectively engage producers in field experiments that test and demonstrate the impact of variations in farmer- and scientist-recommended management practices and technologies for bean production, and help researchers learn about critical social, economic, and cultural factors and contexts that impact crop management decisions. This research approach can generate practical results, collectively transform farmers' beliefs and knowledge, encourage them to make changes, strengthen social cohesion, and stimulate interest among others in learning from trials and demonstrations.

This project is developing appropriate aids (methods and procedures) that will enable smallholder farmers with varying levels of education to better diagnose soil-related production constraints and make improved site-specific crop system management decisions that contribute to higher productivity of beans and associated crops and, over time, to improved soil fertility.

Objectives

1. Characterize smallholder farmers' practices, problem diagnoses, and solutions.
2. Develop and refine models about smallholder bean farmers' decision making.
3. Develop and validate appropriate diagnostic and decision support aids.
4. Develop and assess the effectiveness of innovative approaches for dissemination of information and decision support aids, training, and follow-up technical support

Technical Research Progress

Objective 1: Characterize smallholder farmers' practices, problem diagnoses and solutions

The research team conducted Participatory Rural Appraisals (PRAs) in Uganda in January 2014 involving two communities in the Masaka district and one community in the Rakai district. Similar research activities were conducted in Mozambique's Gurué district in June 2014. In each study area, focus group discussions (FGD) were held with local bean farmers who helped identify farmers for in-depth interviews (17 in Uganda and 25 in Mozambique). Semistructured interviews with key informants in Uganda included the District Production Coordinator, advisory service providers from Kabonera and Mukungwe subcounties in Masaka, and the extension (National Agricultural Advisory Services) coordinator in Lwankoni subcounty in Rakai. In Gurué, we met with local government officials and extension agents.

A community meeting in Mozambique

A significant range of soil types often exists within a given community, often on specific farms. Soil surveys and results from the interviews with farmers revealed that smallholder farmers recognize the impact of soil-related characteristics on their bean yield. In community focus group discussions, farmers identified and ranked the relative importance of each factor (soil color, particle size, soil texture, friability, topsoil depth, rocks, slope, water holding capacity, plant vigor, previous yield results, weeds, etc.), with soil type consistently identified as the primary criterion for planting beans. Black soils are generally considered more suitable for bean production than red soil. Farmers identified fields with soils characteristics for sampling and for participation in development and testing of diagnostic aids.

The application of nutrients by farmers typically appears to be greater in the black (*Liddugavu*) soils than in the red (*Limyufumyufu*) soils. They use indicator plants/weeds to identify good soils from poor ones. In Uganda, *Katabuteme*, *Sekoteka*, *Kafumbe* and *Lusenke* are indicative of fertile soils while black jack, Couch grass, *Kakuuku*, *Etteete* and *Muwugula omunene* grow on poor soils. Farmers have little understanding of specific nutrient requirements for bean production. Additionally, utilization of varieties with improved levels of resistance to commonly occurring foliar diseases appears limited. In Masaka, farmers are aware that bean production typically will be poor on red or gravelley soils but lack farmland with better producing black soil. Since farmers grow beans on various soil types, site specific soil management advice is needed. Many farmers understand the need to plant beans early to attain greater yields but face difficulties drying seed when rainy seasons extend beyond normal.

Competition between weeds and beans is understood by many farmers, with some initiating weeding shortly after crop emergence; however, few farmers weed beans more than twice.

Another important factor in crop production is choice of variety. Nearly all Ugandan farmers surveyed planted a single variety, which has poor resistance to common foliar diseases but is preferred for consumption. We lack data on consumer preferences for improved varieties.

Recent fertilizer recommendations indicate 15 kg N and 15 kg P per ha but ignore the organic sources that are more affordable for smallholder farmers. By linking scientific and indigenous knowledge (e.g., local indicators used to predict the onset of rain), we can better advise farmers on crop and soil management.

Farmers receive some support from government institutions and programs, such as formal extension and NGOs that operate in the project's focal districts. These agencies provide technical information about improved agronomic practices through advisory services and training, establish on-farm demonstration sites, provide planting materials (including improved bean varieties) that may be directly repaid or distributed to other farmers after harvest, and sometimes purchase farmers' produce. The support system for cash crops differs significantly between Uganda and Mozambique as well as among communities.

Farmers in Uganda and Mozambique currently use a variety of management practices and technologies to maintain or increase bean productivity, with significant variation by location regarding type and extent of use:

- Purchase of good quality seeds, where and when available
- Changing the location for planting specific bean varieties, sometimes from season to season
- Minimum tillage, with and without use of herbicides to manage weeds
- Timing of planting, from early to late, depending on rains, pests, market
- Planting patterns and spacing—some in rows, others broadcast
- Intercropping, with a variety of partner crops and precise timing of bean planting
- High plant density (makes weeding difficult and high risk of rapid pest or disease propagation)

- Crop Rotation—various patterns
- Chemical Fertilizers (uncommon, due to availability and cost)
- Foliar sprays (purported to be fertilizers, often lacking nutrient value)
- Pesticides (commonly used in Masaka, rarely available or used in Gurué)
- Weeding, from one to three times per season
- Incorporating (burying) crop residues in soil, rather than burning
- Mounding ridges where beans and other crops are planted
- Farmyard manure (very rare, given low density of livestock)
- Mulching—various materials and methods
- Fallowing (very rare, given perceived shortage of land)

We met with key staff of a nongovernmental development organization that focuses on production of certified bean seed. In Uganda's Rakai district, adjacent to the Masaka district, the Community Enterprises Development Organization (CEDO) works with 80 farmers' groups in five adjacent districts, including Masaka. CEDO has been active in the Lwankoni subcounty in Rakai since 2005, and almost all farmers interviewed reported getting their bean seed through CEDO. CEDO may be an important source of high quality bean seed for project farmers as our research, demonstrations, and dissemination progresses.

Objective 2: Develop and refine models about smallholder bean farmers' decision making

In each country, we conducted in-depth interviews with a cross section of 300 farming households. Topics covered:

- land ownership
- field selection and preparation
- crop and variety selection
- planting methods and spacing
- input use
- storage practices
- intercropping and rotation patterns
- gender-based division of labor
- problem identification and management practices
- market sales
- food consumption patterns
- uses of income earned through farming and other activities
- connections in social and economic networks
- diet and food security

Preliminary analysis of the survey data in the Masaka and Rakai districts provides valuable perspectives on farming conditions, practices, challenges, and strategies. The average landholding is 4.9 acres, with a few larger than 50 acres. The average amount cultivated is 3.3 acres, with some seasonal variation. Nearly half do not cultivate all their available land, holding some land in fallow or lacking sufficient resources for inputs or labor. One-fourth expressed concerns about security of land ownership or use rights for bean and other crop production.

Beans are an integral part all households' complex farming systems for both food security and income. The most widely grown food security crops are cassava (85%), beans (81%), maize (69%), sweet potatoes (53%), and *matooke* [cooking banana] (41%). The crops grown to earn income are beans (72%), maize (64%), coffee (42%), cassava (26%), and groundnuts (22%). They intercrop beans with maize (87%), maize and cassava together (39%), cassava (8%), and coffee (2%). The average amount of land devoted to beans is 0.85 acres (median = 0.50). Approximately 1.75 acres is devoted to other crops. The most widely grown bean variety is K132 [mottled, dark red/white], with 12 other varieties cited. More than half of farmers grow just one bean variety in a given season; 26 percent grow two varieties; 12 percent grow three bean varieties. More than half of the seeds planted are traditional, farmer-saved (59%), followed by purchased certified (27%), and purchased quality declared (13%); some borrow or exchange bean seeds with other farmers. Major bean seed problems cited were high cost (35%) and fake seed on the market (31%); in addition, purchased seed often contains mixed varieties that they must sort by hand prior to planting. Some (31%) purchase bean seeds treated with fungicide for planting; very few use *Rhizobium* (three percent).

Bean production constraints cited covered an array of issues: pests, heavy rains, low soil fertility, inadequate labor, diseases, and lack of improved seed. More than half of farmers had changed bean varieties over the last three years to improve yields, generally using improved varieties. Some have stopped growing a specific bean variety due to lack of good market (33%), low yields (30%), and low tolerance to rain. Primary constraints for producing other crops cited by farmers were similar—pests, low soil fertility, diseases, and inadequate labor. Overall, just under half of the farmers interviewed hired labor to assist in their farming. Two-thirds indicated at least small losses of their beans to storage pests, but nine percent lost nearly half.

Farmers are engaged in a variety of actions to maintain soil fertility. Nearly all practice crop rotation in fields where beans are grown, mainly with maize groundnuts, sweet potato, and cassava. Half reported making specific changes in the last three years to improve soil fertility, with manure the most common amendment, followed by inorganic fertilizers and compost. They carry out soil fertility related experiments, most compare yields between seasons, but some also compare experimental and control (untreated) plots in the same season. When their experiments indicate success, they put the results into practice, and some demonstrate their methods to other farmers. Soil erosion problems were also widely cited, with digging trenches, making terraces, and/or mulching used to address it.

Farmers' strategies to address potential disasters include crop diversification, intercropping, livestock rearing, and nonagricultural activities. Most raise livestock.

In social terms and information, half of the farmers are members of a farmer or development group and report gaining information about agricultural practices in the preceding year through extension workshops and on-farm demonstrations. Nearly all own a radio or cell phone.

The topics about which they gained information were line planting and spacing, application of fertilizers and manure, pest management, and drying on tarpaulin. Other topics included grain-seed storage and preservation; collective marketing; field preparation; disease management; timing of weeding; cleaning, sorting, grading; and airtight storage. They expressed interest in more information about fertilizers, quality seeds, pesticides and herbicides, and farm tools. Opportunities for farmer-to-farmer information sharing through exchange visits are widely appreciated.

Nearly all farmers reported selling beans as individuals rather than as a group. Most cited problems of low market prices and faulty weighing scales; a few noted price fluctuations and the lack of collective marketing. They obtain most of their market price information from traders.

Farming is the main income source for most, followed by livestock sales. Nearly half earn income from various types of employment. Income earned from bean and other crop sales is used to pay for domestic needs, school fees, health care, and investments in agriculture.

Most households are involved in a variety of financial transactions involving money or items with monetary value. Food security is often considered the most fundamental indicator of well-being. Half reported that their seasonal bean harvest had been consumed before the next season's harvest. One-third of the households indicated that their family did not have enough food to meet their annual needs; 13 percent reported that there was no food to eat in the past four weeks.

From this profile, the following information emerges. The quantity and quality of land available for farming beans and other crops varies among households. Beans are an important crop for food security and income. Farmer practices that contribute to soil fertility include crop rotation, intercropping, and application of manure and fertilizer. Principal problems are pests, rainfall, soil fertility and erosion, and labor. They belong to farmer and development groups, yet few sell collectively. While they have radios and cell phones, most depend on traders to learn market prices. With one-third experiencing inadequate food supply during the previous year and the harvest lasting no longer than three months for more than half, there is a food insecurity problem in the area.

Bean field and soil sampling

Objective 3: Develop and validate appropriate diagnostic and decision support aids

The purpose of assessing the nutrient content of soils is to determine if current nutrient levels are adequate for optimal plant growth or if growth limiting factors such as Al and Mn toxicity are limiting bean yields. Our working hypothesis has been that all soils may have some nutrient limitations.

We collected and analyzed representative soil samples from selected farmers' fields in Uganda and Mozambique at two depths (0–15 cm and 15–30 cm) from 32 bean fields managed by 17 community-selected farmers in the Masaka and Rakai districts, Uganda, in January 2014. We're also collecting biweekly data on farmers' agronomic practices and problems, including bean variety, planting date, weeding, and type of fertilizer or other amendments. In Mozambique's Gurué district, 46 soil samples were collected from the fields of 25 community-selected farmers. GPS coordinates for soil types and sites were captured to develop site-specific soil maps.

Parameter	pH	P	K	Al	Silt	Clay	Sand	Stand	Ht	Yield	Nodules	Red nodules	Leaf diseases	Weeds
Soil		———mgkg^{-1}———			———g kg^{-1}———			no. m^{-2}	cm	kg ha^{-1}	——no. plant^{-1}——		% of leaf area	no. m^{-2}
Liddugavu	6.4 a†	49 a	177 a	0.02	132	292	584 a	9.7	38 b	426 a	54 a	31 a	9 c	28.1
Limyufumyufu	5.4 b	4 b	67 b	0.52	106	390	504 b	10.2	27 c	177 b	48 b	24 c	36 a	21.1
Luyinjayinja	5.7 b	38 a	194 a	0.50	136	292	583 a	10.7	54 a	36 c	48 b	28 b	14 b	14.3
Depth (cm)														
0-15	5.9	32	175	0.32	130	309	562							
15-30	5.8	28	117	0.38	120	340	552							
Significance								*P* value						
Soil	***	***	***	**	ns	***	**	ns	***	*	**	***	***	ns
Depth	ns‡	ns	ns	ns	ns	ns	ns	-	-	-	-	-	-	-
Soil × Depth	ns	ns	ns	ns	ns	ns	ns	-	-	-	-	-	-	-

Table 1. Soil pH, available phosphorus, potassium, and aluminum, silt, sand, and clay concentration, and bean stand, height, seed yield, and root nodules for three soil types, Masaka District, Uganda.

Soils were prepared and sent to Crop Nutrition Laboratory Services (CropNuts) in Nairobi, Kenya, for analysis. An array of 19 chemical and physical parameters was determined for the samples. Analysis revealed the presence of low pH and consequent high levels of available aluminum in many fields (Table 1). Concentrations of K and P were low in Limyufumyufu and Luyinjayinja soils (Table 2). Additionally, concentrations of Ca and Mg were lower than generally recommended in other locations for bean production. The nutrient levels in black soil (Liddugavu) appeared adequate for bean production in a number of sampled fields. Results from the nutrient omission study conducted at Makerere University documented reduced bean growth in Limyufumyufu and Luyinjayinja soil when P, K, limestone, or N was not added. Nodulation of bean plants was nonexistent in treatments that had limestone omitted from these soils.

Soil	Depth	pH	P	K
Liddugavu (n=13)	0-15	6.4 (0.1)	53 (16)	192 (36)
	15-30	6.3 (0.1)	44 (14)	162 (28)
Limyufumyufu (n=4)	0-15	5.5 (0.2)	5 (1)	79 (18)
	15-30	5.3 (0.2)	3 (1)	55 (19)
Luyinjayinja (n=6)	0-15	5.9 (0.2)	38 (19)	253 (87)
	15-30	5.6 (0.2)	37 (22)	134 (20)

Table 2. Mean (SE) Mehlich 3 - Available Phosphorus, Potassium and pH – Farmers Fields, Uganda

In Gurué, four communities were selected for project work: Lioma, Ruace, Tetete, and Mepuagiua. The physical properties of these communities' soils are coarse, with sand content 45 percent. Silt contents ranged from 25 to 40 percent and clay was usually less than 15 percent. Specific textures included clay loams, sandy loams, and sandy clay loams. None of the soils was grouped as clay. The quantity of silt suggested the soils could hold substantial amounts of plant available water.

Nutrient levels varied greatly among the project communities, suggesting that a range of bean production conditions are represented. Mepuagiua, for instance, is characterized by lower levels of nutrients than the other three. Soil pH tends to be lower in that village and other measures such as the ECEC also point to more highly weathered soil conditions. Given the generally higher levels of clay in soils of farmers, these soils are of the low activity group and should be managed with those limitations in mind. Of the nutrients studied, phosphorus (P) varies the most among the communities. That there is such a high variability suggests the need for diagnostic tools to discern which of the fields have sufficient quantities of P. The overall levels of P are surprisingly high, with averages exceeding 90 mg kg^{-1} in three of the four communities. Typical critical levels for this nutrient with Mehlich-3 range from 10 to 30 depending on the crop and soil conditions. Among the nutrient cations of K, Ca, and Mg, all are present in surprisingly high levels. The community of Mepuaguia, as in the case with nutrient P, is also characterized by the lowest levels of these nutrients. While the levels of these cations are medium to high, they also are highly variable. With the relatively low levels of these nutrients and the highly variability, it is likely that there are some fields where the acidity is limiting or would be limiting to bean production.

Several tentative conclusions can be drawn from this initial sampling of soils in Gurué. The high levels of nutrients in fields need to be confirmed. It is possible that farmers selected some of their best fields to show to the project team. Subsequent samples should be carefully selected to ensure representativeness.

A nutrient omission experiment to diagnose nutrient deficiencies in selected soils for bean production was conducted in a greenhouse at Makerere University Agricultural Research Institute (MUARIK) with 11 treatments (see table 3) using a Completely Randomized Design. Each nutrient treatment was randomly assigned to three different soils (Liddugavu, Limyufumyufu, and Luyinjayinja) and replicated three times (total of 99 experimental units). Experimental factors were three soil types and 11 nutrient treatments. Four seeds were sown in each pot at planting and later thinned to two uniform plants per pot five days after emergence. Pots were watered with distilled water to keep moisture at field capacity. From 11 days onwards, regular observations were made to detect visual nutrient deficiency symptoms on foliar parts of plants. Stem height (cm) of plants and above ground biomass production (grams) were measured. Stem height was measured from plant base to apex and used as a growth parameter to measure plant size. Weights of plants were recorded after oven drying at 70°C. Composite samples of aboveground biomass per treatment per soil were ground and analyzed for macro and micro nutrients. Yield of plants growing in a soil to which all nutrients had been added was the reference point for comparison to those in a series of treatments in which each of the nutrient elements had been omitted. Differences in growth between plants grown on a deficient and a complete treatment were assumed to be caused by deficiency of the omitted nutrient.

Taking measurements in a greenhouse in Uganda as part of the nutrient omission study.

Aboveground biomass mean dry weight for the three soils are summarized in figure 1. Preliminary greenhouse results from the nutrient omission study showed that the most limiting nutrient in *Liddugavu* (black) soil was Ca followed by P. Mean bean dry matter yield was 1.5 g and 1.9 g for soil without Ca and P, respectively, compared to the control treatment where the dry matter yield was 1.6 g. Omission of K triggered the highest aboveground biomass followed by omission of micronutrients treatments. The most limiting nutrients in *Limyufumyufu* (red) soil were P followed by N. Mean bean dry matter yield was 0.8 g and 1.0 g for soil without P and N, respectively, compared to the control treatment where the dry

Table 3. NOS Treatments

Nutrient treatment	Code	Nutrients added
Control	1	Natural condition of soil
Complete nutrient treatment	2	N,P, K, Mg, Ca, S, Micronutrients
Complete nutrient treatment + Rhizobia	3	N,P, K, Mg, Ca, S, Micronutrients & Rhizobia inoculation
N omitted + Rhizobia	4	P, K, Mg, Ca, S, Micronutrients& Rhizobia inoculation
N omitted	5	P, K, Mg, Ca, S and Micronutrients
P omitted	6	N, K, Mg, Ca, S, Micronutrients
K omitted	7	N, P, Mg, Ca, S, Micronutrients
Mg omitted	8	N, P, K, Ca, S, Micronutrients
S omitted	9	N, P, K, Mg, Ca, Micronutrients
Ca omitted	10	N, P, K, Mg, S, Micronutrients
Micronutrients omitted	11	N, P, K, Mg, Ca, S

matter yield was 0.8 g. Omission of Ca triggered the highest above ground biomass followed by omission of Mg. The most limiting nutrients in *Luyinjayinja* (gravelly) soil were P and N. Mean bean dry matter yield was 0.8 g and 1.2 g for soil without P and N, respectively, compared to control treatment where dry matter yield was 0.6 g. Omission of K and S triggered the highest aboveground biomass in this soil type. These results require further field verification. In Uganda, this will involve collecting two soil types from four farmers based on their low soil pH and Ca levels. 300 g of soil will be amended with reagent grade $CaCO_3$ (Calcium Carbonate) and eight levels of lime will be used. The 32 treatments will be replicated three times.

Analysis of soils from Gurué indicates that some soils fall in strongly acidic or acidic categories. These soils are likely to have an aluminum toxicity problem or low base saturation. To assess the problem, liming curves will be developed for predicting the amount of soil amendment needed to raise soil pH up to adequate levels for bean and maize growth followed with field testing of the estimated liming requirement using an incubation study and the concentration of available Al in soils.

Identifying and understanding important interactions of soil chemical and physical parameters with bean production is a necessary component for developing improved management solutions for bean farmers. Bean growth, development, and yield were monitored every two weeks on 15 farms during the March–June 2014 rainy season in Masaka and Rakai. Several potentially important relationships previously not identified in Uganda include interactions among soil pH, bean nodulation, foliar disease level, plant density, weed density, and bean seed yield. Significant correlations were observed: red nodule number per plant with plant disease ($r = -0.620$). Further analysis of this relationship provided the regression, red nodule number/plant, $Y = 31.8–0.186x$, $r^2 = 0.385$, $P=0.0137$, where x is the percentage of leaf area diseased. The leaf area with foliar disease, often present as Angular leaf spot and anthracnose diseases, explains nearly 40 percent of the variation in effective nodule number on bean. Nodule number on a per plant basis explains nearly 40 percent of the variation in bean yield (bean yield, kg ha^{-1}, $Y = -1803 +41.5x$, $r^2 = 0.397$, $P=0.0209$ where x is the nodule number per plant).

Another important relationship determined from soil analysis and biweekly bean monitoring was for weed density and soil pH at the 15–30 cm depth. Forty-five percent of variation in average weed density was explained by soil pH (total weed density, # m^2, $Y = -99 + 21.4x$, $r^2 = 0.450$; $P=0.0121$, where x is pH at 15–30 cm depth). This relationship allows us to determine that at higher soil pH values within our set of bean fields, the influence of weed management is more important to bean production than in soils with low, or very low, subsoil pH. Edaphic constraints are more important in some soil types than others.

To confirm the importance of these relationships, a study is underway at two locations in the Masaka District. Treatments are three bean management systems, each with four different varieties of bean. Management systems vary for the level of edaphic or biologic constraints managed by specific input levels or management factors. The bean varieties include the old standard, *Nambale Omumpi*, with another older variety and two newly released varieties with greater levels of resistance to Angular leaf spot and anthracnose.

Field studies to validate soil fertility management options for beans by testing combined or sole application of inorganic (N, P) fertilizers with organic (poultry manure) were initiated in the Masaka district. A parallel study to test the added benefit of adding micronutrients (in addition to N, P) to beans was included, building on preliminary results of the nutrient omission study. Collection of data on leaf area, leaf area index, nodulation, grain yield, and soil chemical characteristics is ongoing.

Objective 4: Develop and assess the effectiveness of innovative approaches for dissemination of information and decision support aids, training, and follow-up technical support

To realize our goals, we will be working with existing institutions and organizations to identify and develop messages that can provide farmers with reliable information to make critical decisions about beans and soil fertility, and pathways that can provide relevant information in an effective, efficient, and sustainable manner.

A bean field trial in Uganda

Extension, radio, and fellow/model farmers are highly valued information sources for Ugandan farmers. While radio is easily available, extension visits and training occur less frequently. While mobile phones have made it possible for farmers to

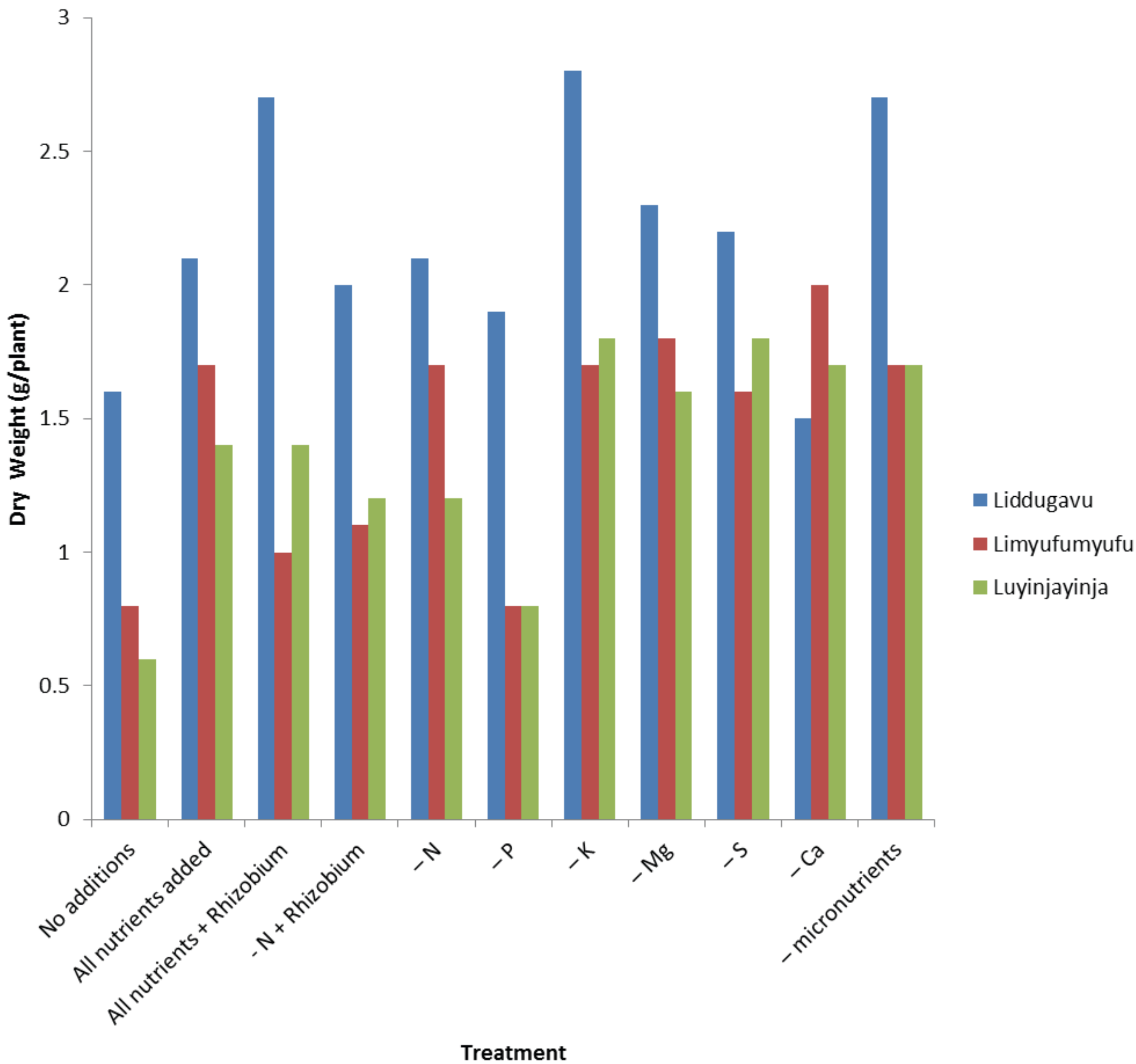


Figure 1. Nutrient Omission Study Dry Weight at Harvest in Three Soils, Uganda

contact extension directly, actual training and field visits by extension agents are not common for bean production. Mobile phones also are used to check market prices. Fellow farmers, on-farm demonstrations, and exchange visits are considered important and available information sources. Grameen's mobile phone community knowledge workers are an additional new source. In Rakai, the NGO CEDO, in cooperation with extension, is a trusted source for bean seed and technical assistance. Farm chemicals and information are now provided by the private sector, but many farmers do not trust private sector products/information.

Farmer associations (20–25 annual, dues-paying members) are an important but not universal information source in Gurué. These associations tend to be linked to specific crops, such as soybeans, but do provide technical support and sometimes access to markets. Extension is spread thinly in the area. NGOs such as World Vision, CLUSA, IITA (for nutrition linked to soybeans), and TechnoServe have been working in selected villages but not directly with common bean production. Mobile phones are being adopted, and are used to check market prices and coordinate activities.

The perceived accuracy and value of each source varies among study communities. We have developed an initial list of available and potential information channels and associated organizations. Initial discussions with providers are enabling us to assess their capacity and willingness to develop and deliver messages concerning beans and soil fertility.

To work with local information providers and dissemination systems, we are starting with existing training materials regarding anaerobic bean grain and seed storage using jerry cans and the triple bag system that were developed during the Pulses CRSP project in Uganda's Kamuli District. This will enable us to test the information system and providers so that subsequent messages regarding crop and soil management practices and technologies can be launched effectively and efficiently. The Masaka District Agricultural Officer recently used those materials to learn about and evaluate the effectiveness of these anaerobic storage methods during a three-month period. He is very enthusiastic about the results of this effective, chemical-free method. A second trial will take place following the second season harvest in late 2014.

In Mozambique, IIAM and SAWBO are working on animated videos for use in Gurué. During PRA activities in June, a short workshop was organized to show an animated video in Portuguese to more than 50 women and men farmers. It was well received and generated considerable discussion. They are identifying other topics for which collaborative work may be initiated in the coming year.

Following soil nutrient and crop analysis and community communication assessment, we will work with project staff and extension to develop an initial message that can test the communication system with a small number of farmer groups/ associations.

Major Achievements

1. Lesson learned through the IIAM social scientist's visit to Uganda to work with the team there contributed to improved baseline household survey design and implementation in Mozambique.
2. We have documented considerable variation in soil types and cropping patterns as well as in social capital and market patterns among communities. This variability underscores the need for and potential value to farmers of the types of decision support aids that we will be developing.

Research Capacity Strengthening

Two Institutional Capacity Strengthening grants have been received. The first involves collaboration among Makerere University, Uganda's National Agricultural Research Laboratories, and the University of Hawaii to combine indigenous and scientific knowledge of soils. The second, for the Institute of Agriculture Research of Mozambique, focuses on recording, analyzing, and interpreting GIS associated data with biophysical, economic, and social data.

Human Resource and Institutional Capacity Development

Short-Term Training

Four short-term training workshops on such varied topics as soil identification, characterization and classification; soil testing; innovation platform formation; and household baseline survey design and implementation were held over the course of 2014. Thirteen African scientists/students (nine males; four females) from Makerere University, the National Agricultural Research Laboratory, the Institute of Agricultural Research of Mozambique, Makerere University, and the Masaka District Agriculture Office benefitted.

Community meeting in Mozambique

Achievement of Gender Equity Goals

The project team has actively sought input from women farmers during focus group discussions and in-depth individual interviews (approximately one-half) and the baseline household survey (approximately two-thirds). In the baseline survey, we explicitly inquire about women's roles in making decisions regarding 16 activities in bean production, storage, marketing, and income use. Four women have benefitted from short-term training and one woman is benefitting from long-term training.

Scholarly Accomplishments

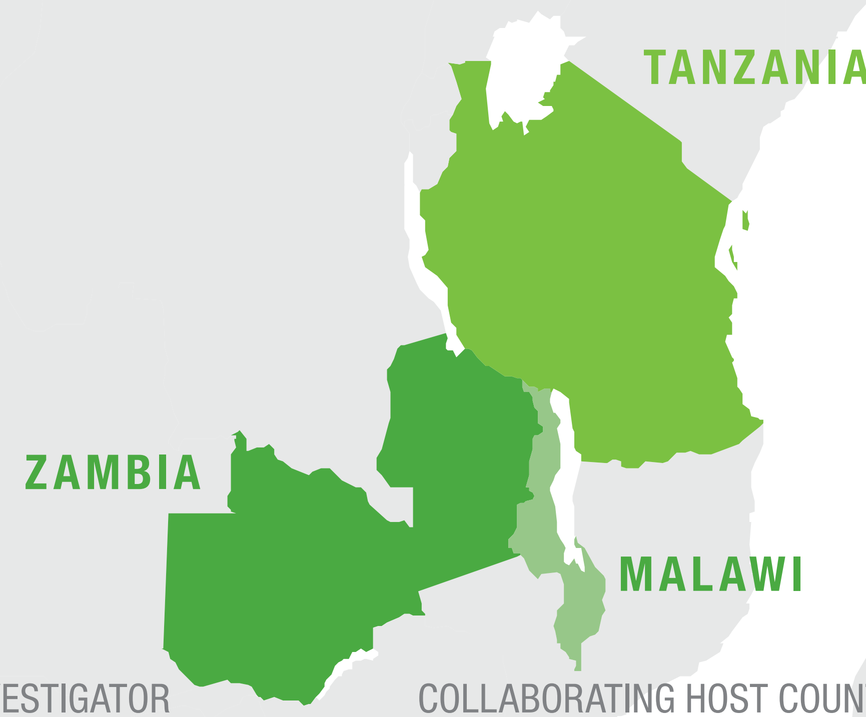
Goettsch, L. & A. Lenssen. 2014. U.S. Borlaug Fellows in Global Food Security graduate research grant. "Practical methods to alleviate constraints to common bean (*Phaseolus vulgaris*) production in Masaka, Uganda."

Goettsch, L. 2013–2015. Louis Thompson Endowment Graduate Fellowship. Agronomy Department (its premier fellowship). Iowa State University.

Goettsch, L. 2014. Global Programs Travel Grant. Iowa State University. $2,000 support for travel to Uganda for M.S. research.

Enhancing Value-Chain Performance through Improved Understanding of Consumer Behavior and Decision Making

(SO2.2)



LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Gelson Tembo, University of Zambia

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Allen Featherstone, Kansas State University

Kara Ross, Kansas State University

Abstract of Research and Capacity Strengthening Achievements

During FY2013–2014, the research team designed and developed an electronic discrete choice experiment for all three target countries: Zambia, Malawi, and Tanzania. The team conducted interviews, a focus group session, and a pretest of the survey instrument to ensure inclusion of all relevant questions that correspond with our research objectives and to ensure the phrasing of the questions would lead to unbiased and informative responses. The survey instrument was revised based on the feedback received from the interviews, focus group sessions, and the pretest. We have facilitated a discreet choice experiment training session in Zambia for our research team, collaborators, and other interested parties, such as researchers at the University of Zambia. Four students (out of six students) have been recruited by the Malawian and Tanzanian PIs to participate in this research project. Two students from Zambia are expected to be recruited into this research project by the end of 2014. One student from Zambia is enrolled in the Masters of Agribusiness program at Kansas State University. The recruited students have started the situational analyses, and drafts of these reports are expected to be completed by the end of 2014.

Project Problem Statement and Justification

Despite their significant nutritional benefits, grain legumes are not traditional staple foods in Zambia, Malawi, and Tanzania. Consequently, increased consumption to support the economic well-being of smallholder producers must be based on a clear appreciation of how consumer characteristics and the attribute level of food combinations shape consumers' decisions and choices. The fundamental objective of this project, therefore, is to develop a new understanding of the forces and factors shaping and influencing consumers' food choice decisions in eastern and southern Africa and then use this understanding to facilitate improvements in legume value chains.

The project has three integrated dimensions. First, to develop an empirical foundation for understanding the factors and the extent that these factors influence food choices. This empirical evaluation of the complex factors influencing consumer choice regarding grain legumes in eastern and southern Africa is the first of its kind. Second, from this evaluation, industry stakeholders and public institutions will explore opportunities for value creation and expansion as well as solutions to challenges preventing value chain effectiveness. The third dimension involves using the information collected on industry capacity gaps to carefully develop and deliver training and outreach programs aimed at enhancing strategy development, management, and decision-making. In the end, the project will provides innovative and unique pathways that bring smallholder producers and other stakeholders into specific value chain alliances to help smallholder producers improve their economic well-being.

The research's geographic scope covers Zambia, Malawi, and Tanzania, all Feed the Future focus countries. These countries represent the different changes occurring in eastern and southern Africa that are increasing urbanization; economic growth; and unequally distributed incomes, the latter despite increasing incomes; and changing demographics, including in agricultural production. The findings from this research will provide insight into how and where these changes are affecting legume consumption as well as how to overcome domestic consumption barriers and build stronger value chains to seize new markets.

Objectives

1. Identify and analyze the principal factors shaping bean/cowpea consumption and their relative positions in consumers' food rankings in the selected countries.
2. Conduct situation analyses for bean/cowpea production

and marketing/distribution systems with a view to identifying the nature and extent of the gaps in their value chains.

3. Implement formal and informal capacity building initiatives to address identified gaps and support value chain management capacity across the legume industry in the focus countries.

Technical Research Progress

Objective 1: Identify and analyze the principal factors shaping bean/cowpea consumption and their relative positions in consumers' food rankings in the selected countries.

Approaches and Methods

A discrete choice experiment method will be used to complete objective one. Additionally, statistical methods are employed to conduct the ranking of beans/cowpeas in consumers' food baskets in Zambia.

Two groups of variables are included in the experiment:

1. The different product attributes (availability, accessibility, perceived nutritional characteristics [fiber, protein, etc.], preparation time and preparation options, color, storage characteristics, taste, size, and cost/prices)
2. Consumer characteristics, including frequency of consumption, quantities consumed, and expenditure shares, and preference influencers—cultural and biologic ecologic variables.

Because there is a random component in random utility theory, preferences are inherently stochastic. Therefore, the foregoing analytical approach facilitates only the prediction of the probability that an individual *i* will choose beans/cowpeas. The approach, thus, leads to the development of a family of probabilistic discreet choice models that describe how probabilities respond to changes in the choice options (attributes) and/or the covariates representing differences in individual consumers. Therefore, the probability (ϱ) that individual *i* chooses option *j* from her set of competing options, C_i, equals the probability that systematic (V) and random (ε) components of option *j* are larger than the systematic and random components of all other options competing with *j*. That is:

$$(j | C_i) = [(V_{ji} + {}_{ji}) > \max(V_{ki} + {}_{ki})] \quad j,k \quad \{C_i\} \qquad (1)$$

The systematic components include attributes explaining differences in the choice alternatives and covariates explaining differences across individuals. The random components, a fundamental aspect of the model's authenticity, capture all the unidentified factors that influence choices. Together, they define the latent utility, u_{ji} that individuals associate with each alternative, as follows:

$$u_{ji} = V_{ji} + {}_{ji} \qquad (2)$$

Results, Achievements and Outputs of Research

- Designed and developed an electronic discrete choice survey instrument for all three focus countries: Zambia, Malawi, and Tanzania.
- In Zambia, interviews with the target population and a focus group session were conducted to ensure that the survey questions were clear and logical, and the language and context used for the questions were appropriate to elicit unbiased and informative responses.

- A pretest involving experienced enumerators was conducted in January 2014 in Zambia. Feedback and suggestions for improving the survey were received and incorporated into the final survey.
- A day long training session regarding the survey and the discrete choice experiment was delivered to the Zambian enumerators in late January 2014. Although these enumerators are experienced with the traditional survey approach, it is important that they be introduced and become familiar with the discrete choice approach since they will be administering the survey. By having an understanding of how the discrete choice experiment is designed, the enumerators will accurately administer the survey to guarantee valid and unbiased responses.

"Studies will investigate consumer preferences for different food types, develop the food hierarchy, and identify the socioeconomic and demographic characteristics that influence the consumption of beans."

- U.S. PIs facilitated a multiple day training session on discrete choice experiment, specially designed for the host country PIs, collaborating partners, and other interested parties. The discrete choice experiment method has not been used by host country PIs before, although they are all well versed in econometrics. A strong understanding of discrete choice experiments is needed for all members of the research team to ensure that objective 1 is completed successfully.

- The programming code for the discrete choice experiment has been developed and tested with some of the results from the pretest.
- Background research and literature reviews are being conducted to provide support for the research methods and survey design and to develop the framework for the research reports and policy briefs that will be generated from the findings of these discrete choice experiments. The recruited students in Malawi, Tanzania, and Zambia are working on the following research projects, respectively:

    - o Consumer Choice and Preferences for Beans in Lilongwe: A Discrete Choice Modeling Approach
    - o Bean Production and Marketing in Tanzania
    - o Consumer Preferences for Beans in Zambia

- All three studies will investigate consumer preferences for different food types, develop the food hierarchy, and identify the socioeconomic and demographic characteristics that influence the consumption of beans.

Objective 2: Conduct situation analyses for bean/cowpea production and marketing/distribution systems with a view to identifying the nature and extent of the gaps in their value chains.

Approaches and Methods

Objective 2 employs econometric analyses on secondary data collected by various institutions in the partner countries to develop a deeper appreciation of the grain legume production environment, including the gender issues underscoring the environment. The World Bank's nationally representative *Living Standards Measurement Survey—Integrated Survey on Agriculture (LSMS–ISA) data for Malawi and Tanzania* and the *Food Security Research Project (FSRP) dataset for Zambia* will be used to conduct the situation analyses. Primary data will also be collected and used in the situational analyses.

Results, Achievements and Outputs of Research

- The recruited students in Malawi and Tanzania are working on the following research projects, respectively:
    - o Situation analysis of production and consumption of common bean in Malawi
    - o Market Participation Among Smallholder Bean Farmers In Tanzania
    - o The market participation study in Tanzania will use primary data to examine the level of commercialization among smallholder bean farmers in southern Tanzania and to identify the factors that influence marketing participation.
- Similar studies are being conducted in Zambia.
- To help facilitate these analyses, computers, with analytical software installed on them, were sent to all the students and the host country PIs.
- Drafts of these final reports are expected to be completed by the end of December 2014.
- These reports are also expected to be a part of the students MS theses, which is a requirement for completing their degrees.

Objective 3: Implement formal and informal capacity building initiatives to address identified gaps and support value chain management capacity across the legume industry in the focus countries.

Approaches and Methods

Research partners in the three countries will begin to recruit MS students for their projects in-line with the workplan. Each host country PI is planning to have two MS students recruited by the beginning of the 2013/2014 academic session. At the same time, information about the Master of Agribusiness (MAB) program at Kansas State University will be provided to the food and agribusiness communities in Zambia, Malawi, and Tanzania to begin the search for potential qualified participants in these countries for the first round of recruitment. The research partners will be primarily responsible for the process of searching for qualified candidates and work with the U.S. PIs to facilitate their recruiting.

Results, Achievements and Outputs of Research

- Each of the focus countries, except for Zambia, has recruited one male and one female student.
- Zambia has recruited one student for the Master of Agribusiness program.

- The Malawian PI and his department (Department of Agricultural and Applied Economics) are actively recruiting students for the Master of Agribusiness program.
- The Malawian PI and his department (Department of Agricultural and Applied Economics) have partnered with the Department of Agribusiness to train agrodealers, including members of the Association of Agribusiness Women.
    - o As part of the training program, a Needs Assessment questionnaire is being developed to identify the knowledge and skills gaps and the resources and training needed to fill those gaps.
    - o Training is expected to start in January 2015.
    - o The U.S. PIs and other host country PIs are providing guidance and support toward this training initiative, and the research team plans on developing similar needs assessment and training sessions in Tanzania and Zambia.

Major Achievements

One of this project's major achievements this year has been the design and development of the electronic discrete choice survey instrument for all three focus countries. The results from the discrete choice experiment will provide empirical information for breeders to determine the characteristics and attribute sets of existing technologies that can be brought to market or information on what needs to be developed for specific markets and consumer profiles.

Research Capacity Strengthening

Discrete Choice Experiment Training

Required for host country PIs to perform their responsibilities under Objective 1, this training session was specifically developed for host country PIs to enhance their capacity in discrete choice experiments and to increase their analytical skills; researchers from the University of Zambia also attended, for a total of 11 attendees—seven males and four females. The session was led by Kansas State University PIs and held in Lusaka, Zambia, January 27 to 31, 2014.

Training the Enumerators

Training the Enumerators was a required part of the research team's training on discrete choice experiments.

Human Resource and Institution Capacity Development

Short-term Training

Short-term training in the discreet choice approach was conducted on January 31, 2014, for Zambian researchers. A total of 18 women and 14 men benefitted from these training opportunities provided by Kansas State University.

Scholarly Accomplishments

Ross, K.L., A. Shanoyan, **V. Amanor-Boadu**, **Y. A. Zereyesus**, and **G. Tembo.** From Subsistence to Commercial Production: Factors Affecting Smallholder Bean and Cowpea Producers Market Participation in Zambia. Selected paper prepared for presentation at the Annual World Symposium of the International Food and Agribusiness Association, Cape Town, South Africa, June 16–17, 2014.

Chishimba, E., **G. Tembo**, **V. Amanor-Boadu** and M. Mwiinga. Factors Affecting Bean Profitability among Bean Traders in Zambia. Department of Agricultural Economics and Extension Education, the University of Zambia, Lusaka, Zambia. 2014.

Despite their significant nutritional benefits, grain legumes are not traditional staple foods in Zambia, Malawi and Tanzania. The fundamental objective of this project, therefore, is to develop a new understanding of the forces and factors shaping and influencing consumers' food choice decisions in eastern and southern Africa and then use this understanding to facilitate improvements in legume value chains.

Impact Assessment of Dry Grain Pulses CRSP Investments in Research, Institutional Capacity Building and Technology Dissemination for Improved Program Effectiveness

(SO4.1)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

Mywish Maredia, Michigan State University

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Eric Crawford, Michigan State University

Byron Reyes, Michigan State University

U.S. and HC PIs/collaborators of other Legume Innovation Lab Projects

Abstract of Research and Capacity Strengthening Achievements

In FY 2013–14, this project worked toward completing or initiating several activities under its three objectives: 1) provide technical leadership in the design, collection, and analysis of data for strategic input and impact evaluation; 2) conduct ex ante and ex post impact assessment; and 3) build research capacity in the area of impact assessment. The project has worked with other Legume Innovation Lab projects to plan and to initiate a baseline survey in Guatemala to better understand the current status of the climbing bean/maize intercropping production system, and in Benin to assess the market potential for biopesticides. The project completed an assessment study in Central America examining the factors contributing to the success and sustainability of seed systems for grain legumes in the context of different socioeconomic and agricultural systems and initiated the planning for implementing a study on the willingness to pay for different types of seeds, with a focus on northern Tanzania. An analysis of the randomized field experiment conducted in Burkina Faso to assess the effectiveness of animated videos shown on cell phones to farmers on two postharvest cowpea storage technologies are presented. Two short-term training courses on the theory and methodology of conducting impact evaluation were completed in collaboration with CIAT and other national partners in the LAC region.

Project Problem Statement and Justification

Impact assessment is essential for evaluating publicly-funded research programs and planning future research. Organizations that implement these programs should be accountable for showing results, demonstrating impacts, and assessing the cost-effectiveness of their implementation strategies. It is therefore essential to document outputs, outcomes, and impacts of public investments in research for development activities. Anecdotal data and qualitative information are important in communicating impact to policy makers and the public but must be augmented with empirical data and sound and rigorous analysis.

Building on the momentum and experience gained over the last three years, the proposed research will contribute towards evidence-based, rigorous ex ante and ex post assessments of outputs, outcomes, and impacts with the goal of assisting the Legume Innovation Lab program and its Management Office (MO) achieve two important goals—accountability and learning. Greater accountability (and strategic validation) is a prerequisite for continued financial support from USAID, and better learning is crucial for improving the effectiveness of development projects and ensuring that the lessons from experience—both positive and negative—are heeded. Integrating this culture of impact assessment in publicly funded programs such as the Legume Innovation Lab will ultimately help increase the overall impact of such investments.

Objectives

1. Provide technical leadership in the design, collection, and analysis of data for strategic input and impact evaluation.
2. Conduct ex ante and ex post impact assessments.
3. Build research capacity in the area of impact assessment.

Technical Research Progress

Objective 1. Provide technical leadership in the design, collection, and analysis of data for strategic input and impact evaluation.

During this past fiscal year, our PIs worked with other project Legume Innovation Lab PIs to assess the feasibility of integrating data collection and impact evaluation strategies into their project design. The project team either participated in the planning meetings or had follow-up discussions to identify opportunities for collecting baseline data and integrating impact evaluation research into part of the project design.


Mywish Maredia, PI

After consulting with the PIs of each of the funded projects, several opportunities were identified for baseline assessments and/or impact studies; these are grouped into three types:

1. activities for which there is agreement and resources to do the study,
2. activities for which there is a need to explore resources, and
3. activities that are not ready for impact assessment. This project has collaborated on the following baseline data collection efforts:

1. A socioeconomic baseline study on the constraints and opportunities for research to contribute to increased productivity of climbing beans in Guatemala. This is a joint activity with the project team for *Genetic Improvement of Guatemalan Climbing Beans for Efficient Production in the Highlands* under their objective "Genetic improvement of climbing black beans for the highlands of Central America." Led by ICTA, this study is designed to establish a baseline about the production of climbing beans in the highlands of

Guatemala and to better understand the current status of the climbing bean/maize intercropping production system. Currently, the survey instrument is being developed (a draft version is under revision) in collaboration with SO1.A1 and the local partner in Guatemala, ICTA. Additionally, ICTA is assembling data on bean production in the five selected departments (Chimaltenango, Huehuetenango, Quetzaltenango, Quiche, and San Marcos) and the list of municipalities and villages in them to use during the sampling of villages. The survey instrument will be finalized in November 2014.

2. Study on the market potential for biopesticides in Benin. This is a collaborative activity with the *IPM-omics: Scalable and Sustainable Solutions for Pest Management of Insect Pests of Cowpea in Africa* project team, specifically with Dr. Leonard Hinnou from INRAB–Benin, under their objective 3 "Scaling of solutions." This study is designed to assess the potential groups that can develop, market, and sell biopesticides, and serve as the logical pass-off groups in host countries for scaling up these technologies. This study will serve as a baseline to assess the market potential for biopesticides (e.g., what farmers are willing to pay, what the costs will be to enter the marketplace for small industries, what skill sets need to be developed for women's groups to make and profit from selling such materials, etc.) and will determine the networks of NGOs and other organizations where the project can pass-off educational approaches (e.g., animations) for scaling. A draft of one of the instruments that will be used for data collection was developed in French by INRAB–Benin partners and revised by SO4.1 collaborators. However, given the language limitations, only general suggestions were provided by this team. The survey was implemented in late summer 2014.

3. Other activities implemented under this objective in FY13 and FY14:
   a. This project worked with the IPM-omics project team to plan survey instruments and to collect baseline data in the project pilot sites in FY2014
   b. For the *IPM-omics* project team, this project finalized the report of the biocontrol agent baseline assessment study conducted in Burkina Faso in 2012 designed to collect information about the 2011 production season. This report was published as an MSU Staff paper in December 2013. This study was designed to collect baseline data (and eventually end line data in year four of this extension phase) to evaluate the long-term impacts of biocontrol research.

Objective 2. Conduct ex ante and ex post impact assessments

2a. The economics of supply and demand for the sustainable development of legume grain seed systems

This project conducted the following field research to address the following research question.

Collaborating agronomist Gelio Cuellar assessing the health of the bean seed ICTA Ligero and ICTA Peten.

What factors contribute to the sustainability of seed systems?
A research study focused on identifying "elements of sustainability of the bean seed system" was jointly planned with the Monitoring and Evaluation (M&E) component of the BTD project and included the following: a) Three surveys in Nicaragua (completed in 2012): i) A survey of 153 Community Seed Banks (CSBs), ii) a survey of 480 Nicaraguan farmers who received bean seed in 2011, and iii) the cost of production record keeping by 158 CSBs during the 2011–12 bean seed growing season; b) Assessments in Honduras and Guatemala to evaluate the effectiveness of different models of bean seed dissemination used in the two countries and to assess the constraints, challenges, and factors contributing to the success (or failure) of different models, and to evaluate the benefits of improved seed distributed by the BTD project from the perspective of the beneficiaries.

Field work to address the objectives of the assessment studies in Honduras and Guatemala involved:

1. Conducting interviews (using semistructured questionnaires) with representatives of organizations/entities along the seed value chain and collecting data/information that would help us assess the constraints, challenges, and factors contributing to the success (or failure) of different seed distributions systems.

2. Conducting surveys of beneficiaries of the seed distribution efforts. The sample of farmers surveyed (about 500 in each country) was selected using a two-stage cluster sampling method. The survey focused on farmers' perception of the efficiency and effectiveness of the methods used to

distribute the seeds, the quality of seed received through the BTD project, and the economic gains experienced from planting improved variety seeds.

Using these datasets, two reports were generated:

a. Effectiveness of the bean seed dissemination models implemented under the Bean Technology Dissemination (BTD) Project: *Results of key informant interviews in Guatemala, Honduras, and Nicaragua*

b. Farmer perspective on the use of and demand for seeds of improved bean varieties: *Results of Beneficiary Surveys in Guatemala, Honduras and Nicaragua*.

Main Results of this Study

The models used for bean seed disseminations, which varied across the three countries, were analyzed based on the following principles of sustainability.

- Cost-recovery: can the system recover the cost of producing, multiplying, and distributing seeds?
- Quality: can the system supply quality seeds to farmers?
- Quantity: can the system supply enough quantity of quality seeds to meet farmers' needs?
- Diversity: can the system supply adequate quantity and quality of diverse varieties of seeds to meet farmers' needs?
- Service/accessibility: can the system deliver these seeds in a timely manner in locations that are accessible to farmers?
- Price: can the system supply these seeds at an affordable price?

The experience and evidence from the three countries suggest:

- Organized farmers can produce high quality seed in desired quantities. Between 46 percent (GUA) to 65 percent (NIC) of beneficiary HH reported the quality was superior to other seeds planted in that season. All key informants indicated that farmers were satisfied with the quality of the seed they received and that the good quality of the seed was a strength of the project. Overall the system developed to achieve the goals of the BTD project was able to supply quality seeds, but there is room for improvement.
- The demand for seed was more than what the project was able to satisfy. Fourteen percent of farmers in Honduras, 23 percent in Guatemala, and 44 percent in Nicaragua wanted more seed from the project
- The community-based seed system may not have adequate capacity to meet the seed needs of the community in terms of diversity of varieties demanded. For example, this was identified as a disadvantage of CSBs by 28 percent of respondents in Nicaragua and 19 percent of farmers in Honduras.
- Willingness exists to pay for seed with a premium over the grain price. However, in some communities meeting the seed needs based on a 100 percent cost-recovery principle may not be possible.
- Flexibility in payment method and proximity/presence of seed production/distribution closer to the community are identified as strengths of the models used.
- Despite favorable quality ratings, the average yield and seed to grain ratio reported by farmers was not very impressive. Integrating seed distribution efforts with technical support (or vice versa) may be a better strategy to realize the full potential of the quality seeds in farmers' fields.

Potential work beyond Central America

Assessment of factors important for the sustainability of bean seed systems is also a high priority area for PABRA. Our interactions with the PABRA Theme Leader and CIAT socioeconomist indicate some ongoing research by PABRA/CIAT to understand the complexity of legume seed availability and accessibility.

The scope of activities addressing these research questions in FY 2014 and beyond was contingent upon availability of resources. We decided to implement research in one country (Tanzania) to address the question of willingness to pay for quality seed over grain. To date, we have identified collaborators from the Sokoine University of Agriculture (SUA) and CIAT–Tanzania for this study to be conducted in northern Tanzania.

2b. Systematic analysis of existing datasets to assess the role of grain legumes in smallholder farming systems

In FY13–14, as part of objective 2, we initiated the exploration of available secondary data (i.e., the Living Standards and Measurement Survey/Integrated Agricultural Surveys—LSMS/ISA) to develop profiles of potential clients and beneficiaries of grain legume research and to understand the constraints and potential impact of the adoption of new technologies by grain legume growers. With the assistance of a graduate student supported through a departmental fellowship, datasets based on the most recently available nationally representative LSMS–ISA surveys were put together for the following six countries: Niger, Nigeria, Ethiopia, Tanzania, Uganda, and Malawi. This dataset includes area, production, and farming practices data for major grain legume crops across more than 25,000 plots and more than 20,000 households. The plan over the next fiscal year is to continue to explore these datasets and to apply descriptive and statistical/econometric analysis techniques to generate information that can help us understand the role of grain legumes in farmers' livelihood and food security strategies and the factors influencing the adoption of productivity enhancing technologies in grain legumes by resource poor farmers

2c. Field Experiment on the Dissemination of Postharvest Technologies in Burkina Faso

This is a joint activity with the UIUC and INERA research team (under the former CRSP IPM-omics research project) that were concluded in January 2013 with data submitted to MSU in late spring 2013.

Problem statement and study objectives

Cowpea bruchids can cause damage to cowpea seeds in storage, resulting in postharvest losses. To address these problems, researchers have tested several nonchemical, low-cost and simple approaches:

- exposing the grain to solar heat to kill the insects and eggs
- triple bagging the grain in plastic sacks

Spreading grain in the sun to kill insect pests and eggs

These techniques are well respected by the science community. Recently, SAWBO developed animated videos of these two technologies to increase the accessibility of this knowledge to low-literate farmers around the world. The success of this approach depends on two critical ingredients:

1. the effectiveness of animated educational materials in inducing learning among low-literate farmers
2. the development of innovative (i.e., cost-effective) strategies to deploy these educational materials to a large number of farmers

This study uses a randomized control trial field experiment conducted in Burkina Faso in 2012–13 to address the first issue; however, one of the indicators of learning is the adoption of the technology being conveyed; often, however, the constraint to technology adoption is availability and economic accessibility. Thus, a second research question addressed by the field experiment is whether the technology adoption outcome (after learning takes place) is a function of the availability/accessibility of inputs to farmers or the nature of technology itself.

Methodology and Data

The experiment consisted of two treatments to address research question one (i.e., effectiveness of the animated videos in inducing learning), and two treatments to address research question two (i.e., does learning induce adoption, if input availability is not a constraint?). For research question two, the focus was only on the triple bagging technology. In treatment one, extension agents used the animated videos to deliver the information on the two postharvest technologies. In contrast, in treatment two, they used the traditional extension method (i.e. live demonstration) to deliver the same information. In treatment A, extension agents left in the village (i.e. made available) a number of sets of plastic bags that farmers could buy and use for triple bagging. In contrast, in treatment B they did not leave plastic bags in the village; instead, they only provided information on where to buy these plastic bags to the participants.


Two women watch a video on their cell phone

	Average across all observations	Treatment groups: 2. Farmers trained using traditional method	Treatment groups: 1. Farmers trained using video-based method	
Number of observations (farmers) Triple bag technology related outcomes	569	283	286	T-test
Percentage of HHs that used triple bag technology post training	40%	42%	39%	
Change in adoption of triple bag from 2011 to 2012	23%	26%	20%	*
Percentage of HHs reporting using the triple bag method first time posttraining (as % of adopters)	9%	11%	6%	**
Percentage of adopters who reported correct knowledge of using triple bag technology posttraining	99%	99%	99%	
Average number of triple bags HH purchased in 2012, posttraining	0.95	0.96	0.93	
quantity of cowpea grain stored using triple bag method in 2012	102.00	104.00	99.40	
Percentage of HHs reporting not using any storage technology in 2012	28%	27%	30%	
Percentage of HHs that did not use triple bag technology posttraining	60%	59%	62%	
Percentage of farmers not adopting triple bag method because the grain was already stored pretraining or was sold soon after harvest	41%	39%	43%	
Percentage of farmers not adopting triple bag method because they didn't know how to use this method	3.5%	4.6%	2.5%	
Solar technology related outcomes				
Percentage of HHs that used solar technology posttraining	0.122	0.144	0.0986	
Change in adoption of solar method from 2011 to 2012	0.0947	0.119	0.069	**
Percentage of HHs reporting using the solar method first time posttraining (as % of adopters)	0.103	0.127	0.0801	*
Percentage of HHs that did not use solar technology posttraining	0.878	0.856	0.9014	
Percentage of farmers not adopting solarization method because the grain was already stored pretraining	0.406	0.4185	0.3944	
Percentage of farmers not adopting solar method because they didn't know how to use this method	0.17	0.169	0.171	

Table 1. Mean outcomes of adoption related variables for the two treatment groups included in the randomized field experiment, Burkina Faso, 2012–2013

T-test: * indicates significant difference at 10% level, ** at 5%, and *** at 1%. If not noted, the differences in the mean value between treatment one and two are not statistically significant.

	Three types of adoption outcomes		
	Adopted a given technology posttraining	Change in Adoption from 2011 to 2012	First Time Adoption
Triple Bag Technology Adoption Outcome			
Treatment 1 (Video-based method=1)	0.001	-0.02	-0.078
Std. Error	(0.079)	(0.106)	(0.174)
R-square	0.554	0.5324	0.752
N	320	238	108
Solar Technology Adoption Outcome			
Treatment 1 (Video-based method=1)	-0.222	-0.273	0.265
Std. Error	(0.065) ***	(0.059) ***	(0.075) ***
R-square	0.516	0.505	0.481
N	325	316	308

Table 2. Average treatment effect of the animated videos on cell phone compared with the traditional extension method of training farmers on the two postharvest technologies in Burkina Faso: Results of the Linear Probability Model Regressions

T-test: * indicates significant difference at 10% level, ** at 5%, and *** at 1%. If not noted, the differences in the mean value between treatment one and two are not statistically significant.

The combination of these two sets of treatments resulted in four groups of treatment villages labeled 1A, 1B, 2A, and 2B. Twelve villages across two provinces were randomly assigned to each of these four treatment groups (using randomized cluster experiment design). The experiment was divided into two phases. In the first phase, extension agents implemented the treatments after the cowpea crop was harvested (November 2012). Within each village, farmers were invited to attend a training session where the two postharvest technologies were disseminated as per the treatment group a village was randomly assigned. Prior to the session, 20 attendees were randomly selected to collect baseline data on their prior knowledge about the storage techniques and exposure to the two technologies. In the second phase, a follow-up impact evaluation survey was conducted six to eight weeks after the training for a subset of 12 farmers per village (total sample size = 576 farmers). These farmers were randomly selected from the list of 20 farmers who attended the training session and had completed the pretreatment knowledge module.

The high level of understanding and comprehension reported by the farmers who saw the videos and the low cost of using this method indicate that integrating this method of transferring scientific information to farmers with the traditional extension method can be a cost-effective method of scaling out new technologies

Preliminary Results

Table 1 provides the mean outcomes of the two treatments and comparison of these groups. A comparison of the mean outcome data indicates that the extension method was significantly more effective in inducing adoption of the two postharvest technologies; however, after taking into account the confounding factors that can potentially influence the adoption of these technologies by farmers (e.g., their age, education, gender, distance to market, roads and extension office, area and production of cowpea, price of cowpea grain, amount of cowpea grain available to store, whether they own a cell phone with video capability, prior training on postharvest technologies, prior awareness of these methods, etc.), and the effectiveness of the training they received (e.g., which trainer provided the training, number of participants in the training program, time spent by the trainer per trainee, etc.), the difference between the advantage of the traditional extension method was diminished at least for the triple bag technology (Table 2). However, in the case of solar technology, the traditional method was effective in inducing 22–27 percent more adoption than the video-based method (Table 2).

The overall mixed results do indicate the potential role of cell phone-based videos in promoting agricultural technologies. The high level of understanding and comprehension reported by the farmers who saw the videos and the low cost of using this method indicate that integrating this method of transferring scientific information to farmers with the traditional extension method can be a cost-effective method of scaling out new technologies based on farmers' own knowledge sharing networks.

Major Achievements

The main messages from the seed system assessments that have important implications for the Legume Innovation Lab research and dissemination strategy are:

1. Despite favorable quality ratings, the average yield and seed to grain ratio reported by farmers was not very impressive. Integrating seed distribution efforts with technical support (or vice versa) may be a better strategy to realize the full potential of the quality seeds in farmers' fields.
2. Scaling up efforts must be based on a two- (or multi) pronged approach of subsidies and cost recovery (where possible).

The main messages emerging from the effectiveness study in Burkina Faso on using animated videos for disseminating postharvest technologies:

1. The effectiveness of using the ICT-based method (video and cellphone) in inducing adoption may be context and technology specific; previous farmer exposure also appears to play a role in adoption rates.
   a. Using video technology to reintroduce a technology already familiar to or adopted by many farmers—and for which they had received prior training, such as triple bagging—the video-based method proved as effective as the traditional method in inducing re-adoption or first-time adoption of the new technology.
   b. Introducing a technology to which farmers had less exposure appears to have been less successful using cell phone videos versus traditional methods, as evidenced in introducing the solar method for reducing postharvest losses. Basically, the traditional method of live demonstration was significantly more effective in inducing behavior change (i.e., adoption of the solar method) among farmers than identical training using cell phone videos.
2. The high level of understanding and comprehension reported by farmers who saw the videos and the low cost of using this method indicate that integrating this method of transferring scientific information with the traditional extension method can be a cost-effective method of scaling out new technologies by using farmers' own knowledge sharing networks.

Research Capacity Strengthening

In FY 13–14, the following activities were implemented toward the broader goal of capacity strengthening in monitoring and impact evaluation:

1. **Presentations and interactions with other Legume Innovation Lab research project teams.** We conducted educational sessions at project planning meetings during summer 2013 to build capacity across the Legume Innovation Lab in developing and using impact pathways, understanding the concepts related to theories of change, and in systematically collecting credible data for reporting on FTF performance indicators. The discussion and exchange of information/ideas during this process has helped increase awareness among Legume Innovation Lab researchers on the importance of doing research with the goal of achieving developmental outcomes.
2. **Collaborations related to objectives one and two**, through which we have been able to expose HC researchers to the methodologies of data collection in a scientific and rigorous manner: design of instruments, sampling methods, data entry, and data analysis.

Short-Term Training

Educational sessions on constructing impact pathways and collecting/reporting performance indicator data were held in all Legume Innovation Lab host countries during project planning meetings. The training included an introduction to the concepts, tools, and methods related to impact pathway and FTF performance indicators. Sixty people (15 women and 45 men) benefitted.

Two four-day workshops introducing novel methods to assess the impact of agricultural projects and practical applications were held in Colombia and Honduras (Zamorano) in April and September 2014, respectively. In Columbia, 22 economists and researchers from National Research Centers, Universities, and International Research Centers (15 men and 7 women) benefitted; in Honduras, 16 participants (13 men and 3 women), all from LIL host countries in Central America, benefitted.

Achievement of Gender Equity Goals

This project is designed to assess how the technologies and knowledge generated by the Legume Innovation Lab (and its predecessor CRSP) benefit both men and women farmers, entrepreneurs, and consumers. Thus, where applicable, gender equity is used as one of the metrics in evaluating the impact of Legume Innovation Lab research. Survey instruments are designed to collect gender disaggregated data on beneficiaries. Where applicable, results of analyses based on primary data are reported by gender to assess the impact on women farmers and other potential beneficiaries of legume research.

Scholarly Accomplishments

Publications and Manuscripts

Maredia, Mywish, Shankar, Bhavani, Kelley, Timothy, Stevenson, James. 2014. Impact Assessment of Agricultural Research, Institutional Innovation, and Technology Adoption: Introduction to the Special Section. *Food Policy* 44 214–217.

Reyes, Byron A., Maredia, Mywish, Ba, Malick, Clementine, Dabire, Pittendrigh, Barry. 2013. Economic Impacts of Biocontrol Research to Manage Field Insect Pests of Cowpea in Burkina Faso: Baseline Survey Report. Department of Agricultural, Food and Resource Economics Staff Paper 13-04. East Lansing, Michigan: December.

Reyes, Byron A., Maredia, Mywish, **Bernsten, Richard H.**, **Rosas, Juan Carlos**. 2014. Have investments in bean breeding research generated economic benefits to farmers? The case of five Latin American countries. *Agricultural Economics* (Submitted)

Impact Briefs

Magen, Benjamin, **Crawford, Eric W., Maredia, Mywish**. 2013. Impact Economique des investissements du CRSP sur le développement et la diffusion des variétés améliorées de niébé: Nouvelle évidence du Sénégal. *Impact Assessment Research Brief 4*. Michigan State University: Dry Grain Pulses CRSP (French translation).

Legume Innovation Lab Human and Institutional Capacity Development FY 2014 Summary Report

Training

The Legume Innovation Lab invests in the development of human resources through short-term training and graduate degree support in strategic areas. These investments strengthen the capacity of national agriculture research institutions in areas related to grain legumes, from breeding and productivity research to consumption and market demand.

Short-term

Twenty short-term training programs were conducted through Legume Innovation Lab projects during FY 14, as outlined in table 1. These training programs were designed to meet local needs identified by Legume Innovation Lab researchers. In some cases, advanced scientific research methods were addressed, including genetic screening methods. In other cases, farmers and farmer organizations were engaged in the research process and training developed from the research, as with the seed production and biological control trainings.

Long-term

Long-term training, in which degree candidates learn the practice and application of science and to apply it to their respective country's needs, is a hallmark of Legume Innovation Lab research projects. Each student is mentored by an internationally recognized legume researcher, which helps establish a long-term professional relationship with their advisor as well as a larger community of legume researchers.

Number (by gender)

In FY 14, Legume Innovation Lab projects funded, fully or partially, 46 students. Table 2 shows the breakdown of students according to degree program and gender

Long-term Training Students by Degree Program				
	PhD	MS	BS	Total
Men	9	11	7	27
Women	5	7	7	19
Total	14	18	14	46

Table 2. LIL Funded Students by Degree and Gender

Purpose

As shown in table 2, the majority of students were either in doctoral or master's programs. Some regional training is provided in local universities for bachelor's degrees, helping to ensure a pool of candidates for advanced degree studies in the future. Encouraging students in the agricultural sciences at all levels proves to be important for host country institutions.

Field/Discipline

The degree training programs span the agricultural disciplines, including agronomy and soil science, entomology, plant breeding and genetics, crop production, agricultural economics and agribusiness, and the life sciences.

Home Institution

A range of home institutions are also represented among Legume Innovation Lab-affiliated students, from the national agricultural research institutes (e.g., ZARI, IIAM, ICTA, and INERA) to educational institutions (Sokoine and Makerere). A few trainees come from NGOs or the private sector, where there is a clear need for greater human capacity for legume sector development. Table 3 indicates the countries of origin for the Legume Innovation Lab long-term trainees for FY 2014, with a total of 17 trainees from Feed the Future countries and 25 from elsewhere.

Training Institution

Degree training takes place in both the United States and in developing countries. Degree training will be initiated at regional institutions that have high quality training and a recognized mentor. Such institutions include Sokoine University, Makerere University, University of Benin, University of Ougadougou, LUANAR (Malawi), University of Maradi, and the Zamorano Institute. In the United States, there are students at the University of Hawaii, Manoa, Iowa State University, Michigan State University, the University of Puerto Rico, and Kansas State University. The majority of students are training in African institutions (18 students) or international centers (10). Seven of the students are training at U.S. institutions with the remainder in Latin America (eight students).

Title	Country	Home Institution	Training Institution	Men Trainees	Women Trainees
Drought and disease screening methods	Uganda	NaCCRI	NACRRI/Namulonge	11	4
Drought and disease screening methods	Uganda, Zambia	ZARI/NaCCRI	MSU	2	0
Seed production methods for farmers	Zambia	ZARI, Farmer Orgs	ZARI	19	10
Seed production methods for farmers	Zambia	ZARI, Farmer Orgs	ZARI	16	14
Seed production methods for farmers	Zambia	ZARI, Farmer Orgs	ZARI	20	8
Plant pathology techniques	Honduras, Tanzania	Zamorano, Sokoine Univ.	UPR	1	2
Angular leaf spot	Guatemala	ICTA, Guatemala	Zamorano Institute	0	1
Molecular breeding (12 participants)	Burkina Faso, Ghana, Senegal, Moz.,Nigeria	INERA, SARI, ISRA, IIAM, Ahmadu Bello Univ.	UCR	11	1
Cowpea seed production/storage	Burkina Faso	INERA	INERA	70	45
ICT training on SAWBO (NGOs) (in person and then online training)	Burkina Faso	INERA, NGOS	INERA, INRAN	75	75
IPM with ICT and biocontrol (various trainings)	Niger	INRAN, NGOS	INERA, INRAN	70	50
IPM with ICT and biocontrol (various trainings)	Burkina Faso	INERA, NGOs	INERA	70	30
Soil identification, characterization, and classification	Uganda	Makerere, NARL	Makerere, NARL, Univ. Hawaii	2	2
Soil testing	Mozambique	IIAM	IIAM	3	2
Innovation platform formation	Uganda	Makerere University and Masaka District Agriculture Office	Makerere	3	0
Survey design and implementation	Mozambique	IIAM	Makerere	1	0
Discrete choice experiments	Zambia	ZARI, Students	KSU	14	18
Impacts pathway training at project planning meetings	All LIL countries	All LIL collaborating institutions	MSU	45	15
Impact assessment training: Colombia	Colombia, Peru	CIAT, national partners in South America	MSU	15	7
Impact assessment training: Honduras	Honduras, Guatemala, Nicaragua	Zamorano and other Central American institutions	MSU	13	3
			Total numbers	461	287

Table 1. The 20 short-term training programs conducted through Legume Innovation Lab projects

Long-term Training Students by Country	Men	Women
Feed the Future Countries		
Ghana	1	1
Honduras	2	0
Malawi	1	1
Mozambique	1	0
Senegal	0	1
Tanzania	1	1
Uganda	4	1
Zambia	1	1
subtotal	11	6
Other		
Benin	6	4
Bolivia	0	1
Burkina Faso	1	3
Ecuador	0	2
El Salvador	1	2
Nigeria	0	2
USA	4	0
subtotal	12	14
Total	**23**	**20**

Table 3. LIL long-term trainees by country and gender

Host Country Partners

Project No.	Project	HC	Institution	Awad Letter Amount
1	S01.A1	Guatemala	ICTA	$11,000
2	S01.A3	Zambia	ZARI	$18,000
3	S0.1A4	Haiti	Nat. Seed Service	$5,000
4	S0.1A4	Guatemala	ICTA	$11,520
5	S0.1A4	Honduras & CA region	EAP–Zamorano	$13,640
6	S01.A5	Burkina Faso	INERA	$6,000
7	S0.1A5	Burkina Faso	INERA	$8,125
8	S01.A5	Ghana	SARI	$7,500
9	S01.A5	Ghana	SARI	$15,000
10	S01.A5	Senegal	ISRA	$29,500
11	S01.B1	Niger	INRAN	$22,550
12	S01.B1	Ghana	CSIR	$25,700
13	S02.1	Uganda	NARO & Makerere	$26,000
14	S02.1	Mozambique	IIAM	$26,015
15	S04.1	Honduras & CA region	EAP– Zamorano	$14,136
			Total	$239,686

Table 4. Host Country Partners Benefitting from LIL FY 2014 Institutional Strengthening Awards

Institutional Development

Description

The Legume Innovation Lab invited proposals from Principal Investigators for activities that contribute to enhancing the capacity of Host Country institutions. A total of $300,000 had been budgeted in the Cost Application for Institutional Strengthening Awards during FY 2013 and FY 2014. The Legume Innovation Lab recognized that National Agriculture Research Systems (NARS) and agricultural universities in developing countries need to build and maintain capacities in strategic areas of research, training, and outreach to effectively and sustainably address the challenges facing the grain legume sectors and to contribute to economic growth and food and nutritional security within their respective countries. These needs require investments in human resource development, scientific equipment, laboratory and field facilities, computer technology, and infrastructure, complementing the investments being made by the institutions themselves. The intent of these Institutional Capacity Strengthening Awards was therefore to address critical needs of Host Country collaborators that exceed the budgetary limits of the current Legume Innovation Lab projects and to respond to identified grain legume program needs of agricultural research institutions in USAID priority countries.

In response to the solicitation in FY 2014, the Management Office received a total of 17 proposals from partner host country institutions. Based on the TMAC's evaluations and recommendations, MSU obligated a total of $239,686 to 14 partner institutions in 10 host countries in support of institutional strengthening activities associated with seven subcontracted projects. The list of institutions and host countries benefitting is presented in the spread sheet presented below. The institutional capacity strengthening funds were added to FY 2014 and FY 2015 modifications to subcontracts to the lead U.S. universities for the respective projects.