

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes



TECHNICAL HIGHLIGHTS 2014





Legume Innovation Lab

**Feed the Future Innovation Lab for
Collaborative Research on Grain Legumes**

FY 2014

Technical Highlights

April 1, 2013–September 30, 2014



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for Collaborative Research on Grain Legumes
(Legume Innovation Lab)**



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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* and the associate award, *MAFRIJOL*, 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.

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 for 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 efforts 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 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-Textel | 7. Bolonillo ICTA Santa Lucia |
| 4. Bolonillo Anita | 8. Voluble GUATE 1120 |
| 5. Bolonillo LOV | 9. Voluble GUATE 1026 |
| 6. Bolonillo Martin | 10. Local check from the grower
(different 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).

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

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, Caserío Los Escobar
San Juan Ostuncalco		Caserío Los	On-farm strip

Department	Municipality	Community	Type of Trial
Chimaltenango		López	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
	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

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, 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:
 - Days to emergence
 - Vigor
 - Early disease symptoms
 - Days to flowering
 - Pod distribution
 - Aggressiveness of growth
 - Disease symptoms (natural pressure)
 - Days to maturity
 - Seed yield
 - 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.

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-Textel 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.

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 on 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, 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.

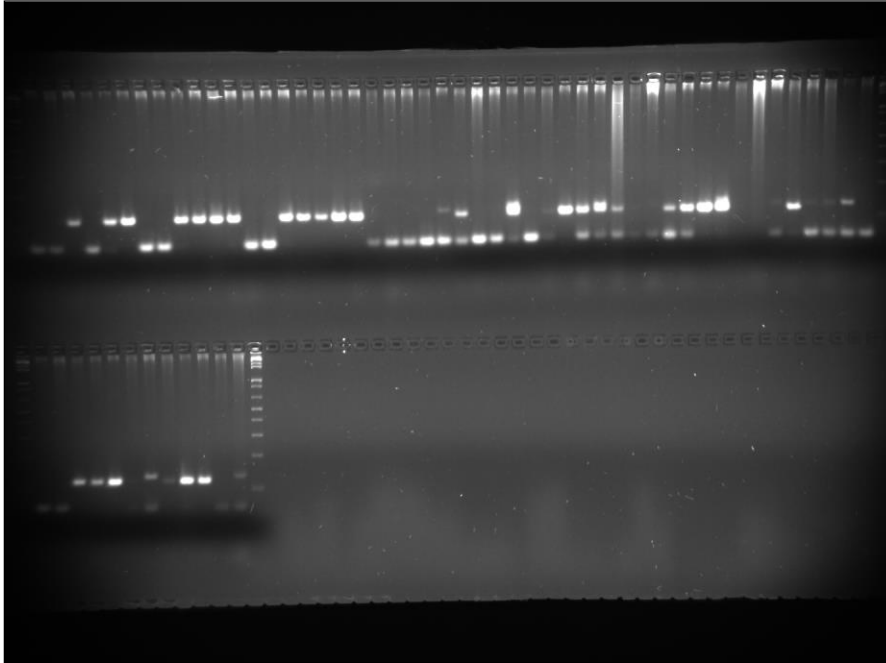


Figure 1. Example of polymorphisms among accessions as revealed by InDel marker 04-07-4908 screened in 25 germplasm accessions (upper lanes, each accession repeated twice), and six breeding lines from Dr. Aldana's initial crosses (lower lanes, each breeding line repeated twice).

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

Because of the reasons shown 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 Quiché, 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 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.

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, nutritional and cooking quality, and the like.

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-Textel across 18 locations
3. Recruitment of two female students for formal training (M.S. in Plant Sciences) at NDSU

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 PCR (polymerase chain reaction) reactions.

Human Resource and Institutional Capacity Development

Short-Term Training

Nothing to report for FY2014.

Degree Training

Nothing to report for FY2014; however, 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.

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Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF) (S01.A3)

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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 and the development of effective molecular and quantitative methods for the selection of drought tolerance are needed. 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 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), Ecuador, and the United States.
2. Characterize pathogenic and genetic variability of isolates of foliar pathogens collected in Uganda, Zambia, and Ecuador 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), Ecuador, 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 of 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 NaCRRRI (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 NaCRRRI. 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 bioavailability 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 trails.

Drought and Disease Screening in Nebraska

1. Two bean nurseries, 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.

2. Drought stress was less severe (DII = 0.38) in the ADP nursery. Yield under NS and DS ranged from 11267 to 3791 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 2645 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 bioavailability 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.

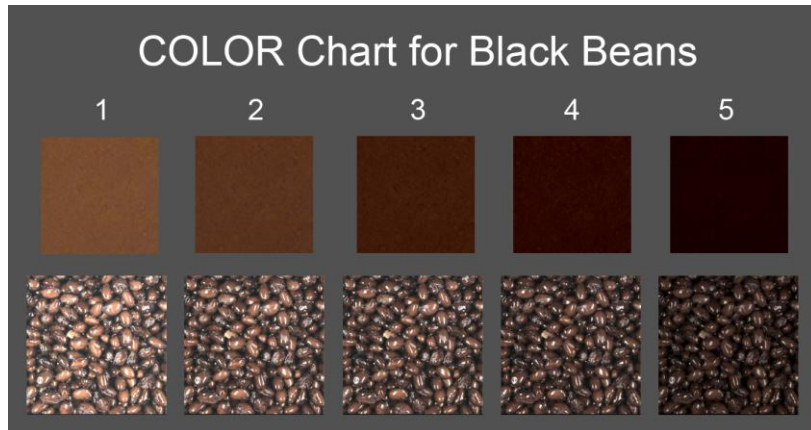


Figure 9.1. Color chart for canned black beans representing five typical categories observed in canned beans: (1) Very light brown, with 50 percent mix of seed colors very noticeable; (2) Slight dark brown or light gray, with 11 percent–49 percent color variation somewhat noticeable; (3) Average brown 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: with seeds bad split but holding together; (3) Average: showing 60 percent–69 percent of seeds intact; (4) Very good appearance: with grains moderately intact 70 percent–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.

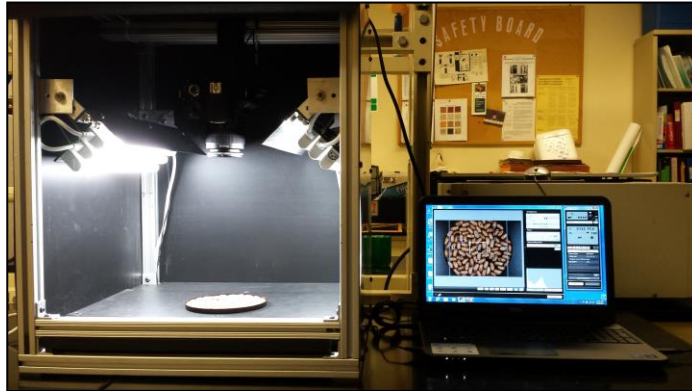


Figure 9.3. Computer vision system for visualization, acquisition and analysis of raw and processed beans

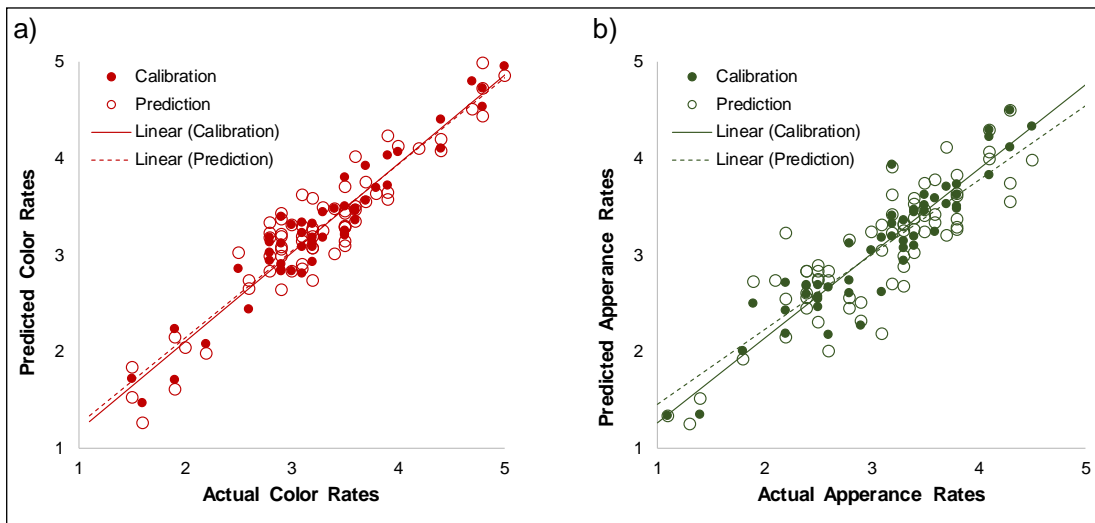


Figure 9.4. Predictions for visual color and appearance rates (a) and b), respectively) using color (full grain + brine) and image textural features (contrast, correlation, energy, homogeneity) extracted from *RGB*, *L*a*b**, *HSV* and gray intensity channels.

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 9.5 presents the prediction performance increasing number of latent variables (or wavelengths). Figure 9.6 depicts the relationships between the measured and predicted cooking time (min) when 40 wavelengths are used. The standard error of prediction was in average 10 ± 1 min, and hence, improved measurements using transmittance mode instead of reflectance would be the next design to test in this study.

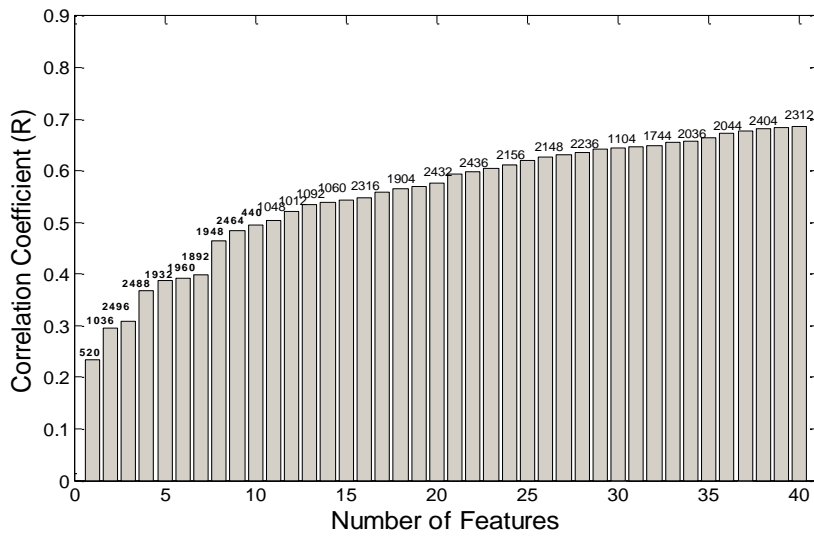
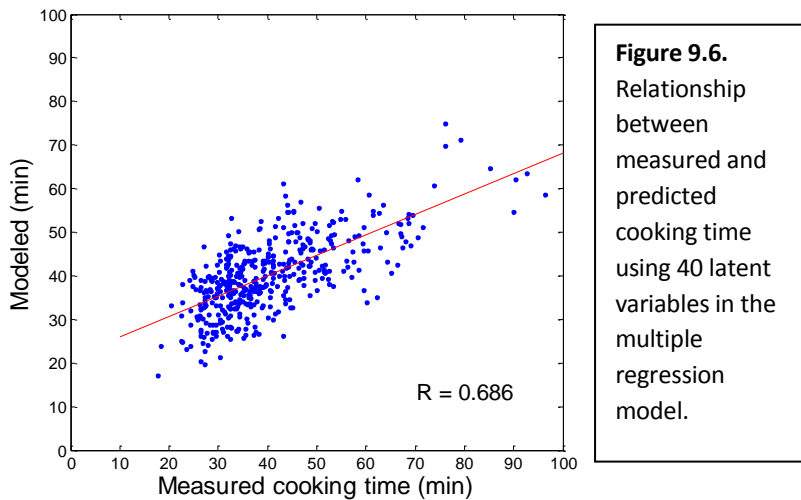


Figure 9.5. Prediction of cooking time increasing the number of latent variables in the model.



- 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, Zambia, and Ecuador 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 exercises will be continued next financial year to cover the other agroecologies.

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

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 & Ziobwe	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

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 NaCRRRI. 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.

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

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 underway 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.

From these findings, the following actions will follow:

1. The above lines materials will be used as parents in future breeding efforts at ZARI.
2. Seed for Rust differential will be received from Nebraska and will be used for rust screening in Zambia.
3. 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)

At UNL a technician was hired to help with the greenhouse identification of rust races. A visit to Zambia was done in November 2014 to explain how to collect and send samples of rust for our analysis and to explain our plan for identifying and incorporating resistance and interaction of the FTF and NIFA projects as well as to address other foliar diseases such as CBB, BCMV, and abiotic problems such as drought as a contribution of germplasm for the local bean breeding activities.

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 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.

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 (i.e., 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 (for details on current experiments, see <http://photosynq.org/>).

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.

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, NaCRRRI, 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 the WorldTAP program, Management Office, and Kramer Lab.

Human Resource and Institution 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. 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 for 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 Meritorious Achievement Award from 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

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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 *PRO737-1* and *PRO633-10* 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 Honduras, Guatemala, and Honduras have been identified. Several B.S. degree students have opportunities to work with the bean research program at Zamorano.

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.



Bean breeders were early adopters of marker-assisted selection to identify lines with desired combinations of traits. This 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



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

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.

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 on p. xx) 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 (F₇) 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 2013–2014, 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 to have superior performance in more humid regions, such as the Petén, is acceptable to consumers in Guatemala.

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

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

Trial Name	Small red	Small black	Countries
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 (teparty bean)	21 entries + 1 check		ES, HO, NI,
ERLIMA (Lima bean)	12 entries		ES, HO, NI, CR

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-1²* 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 (FY17) we expect to have tepary breeding lines with improved virus resistance that will be 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.

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.

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 (Porch et al. 2013. *J. Plant Reg.* 7:358–364).

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 NARs and NGOs 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 Institution 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 benefited 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.

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.

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 was 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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Ndiaga Cisse, Centre National Recherches Agronomie, Bambey, Institut Senegalais de Recherches Agricoles (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 employs 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 platform that we developed with the GCP IBP and LGC KBioscience for SNP genotyping both in the QTL discovery phase and for breeding. The platform has 1022 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 populations or F2:3 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 USA.

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.

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	15seed	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	15seed	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	15seed	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)	15seed	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 the insectary 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 other 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 SRAI 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 K VX 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 selfed 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 3. 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 which 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 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.



(Table 4).

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.

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

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.

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.

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 <i>M. incognita</i>	Galling <i>M. javanica</i>	Galling <i>M. incognita</i> "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.

Table 6. New blackeye lines and checks tested in a production field strip trial in Tulare Co. in 2013.

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

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 U.S.

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

Approval through the LIL was granted to fund renovation of 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.

Approval through the LIL was granted 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.

Approval through the LIL was granted 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.

Approval through the LIL was granted 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 polistick 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.

Approval through the LIL was granted to fund a young scientist with 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).

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 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.

Huynh, B.L., Ehlers, J.D., **Close, T.J., Cisse, N., Drabo, I., Boukar, O., Lucas, M.R., Wanamaker, S., Pottorff, M., Roberts, P.A.** 2013. Enabling tools for modern breeding of cowpea for biotic stress resistance. Pp. 183–200 in: *Translational genomics for crop breeding, Volume I: Biotic stress*. Editors: R. Varshney, R. Tuberosa. Wiley-Blackwell. USA.

Mahamat-Hissene, H., Belko, N., **Cisse, N., Sine, B., Ndoye, I.** 2014. Amélioration de l'adaptation à la sécheresse chez le niébé (*Vigna unguiculata* L. Walpers). *Journal of Applied Biosciences* 77:6550–6563.

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.

Line	Yield (kg/ha)			100-seed weight (g)			K-REC lygus damage (%)	UCR lygus damage (%)	
	Kearney-REC		UCR	Kearney-REC		UCR			
	prot'ed	unprot- ected	Loss (%)	Unpro- tected	prot'ed	Unpro- tected			Unpro- tected
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).

IPM-omics: Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests of Cowpea in Africa (SO1.B1)

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

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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 efforts 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 on 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* Stål 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 indepth 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.

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.



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 controls strategies

Scouting and field experiments

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 Tolon District.
- To date, the following have been identified as the alternative hosts of *M. sjostedti* and *M. vitrata*; *Glycine max* (L.), *Cajanus cajan* (L.), *Mucuna cochinchinensis* (Lour.), *Canavalia ensiformis*, L. and *Tephrosia* sp.

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°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 olfactory 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.

2.3 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 entomopathogen 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 conducted 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 K VX 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 genetic 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 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 refrigerator at 4°C; after six months there was no significant difference of the activity in 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 dosage of 330, 660, and 1000 ml/ha with MaviMNPV sprayed at 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 useable. 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.

3.1.5 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.

Due to the SAWBO program, we now have significant educational materials for educating farmers on techniques they can perform 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.



Training includes 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 occurred to 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 for deployment. We have an ongoing "tagged" animation tests to determine which groups most effectively deploy the animations.

3.3 Private Sector and NGO Involvement

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 viewed the animations in tens of thousands over this 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 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 tradition 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, and
4. systems to easily pass off our outcomes to other groups that can scale the pest control strategies

4.1 Undergraduate and Graduate student training

Each of our teams continues to play active role in undergraduate and graduate training programs.

4.2 Technician Training

A technician from INERA spend several weeks at IITA this past year to further develop biocontrol agent rearing and deployment skill sets. Additionally, online cross-training has occurred (via e-mail, Skype and videos made between INRAN, and



video exchanges based on by IITA) to share skill sets technical staff at INERA, IITA.

4.3 Cross-Building for

IITA, INERA, collaborative positioned to agents on a significantly populations Additionally,

Institutional Capacity Biocontrol Agents

and INRAN, due to ongoing efforts are all well-rear and deploy biocontrol scale that we expect will impact target pest in each of these countries. 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.

4.4 Systems to easily pass of our outcomes to other groups that can scale the pest control strategies

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 animated educational approach to be as effective as use of extension agent presentations. This strategy allows us the ability to significantly scale 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 given out to extension agents across a given developing nation 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 as a Collaboration with INRAN

Training in collaboration with a Mercy Corps NGO working in the Maradi and Zinder area is estimated to have impact 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 July 8–10, 2014.

Degree Training

Checking with Cynthia.

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
- Bello, J.**, Seufferheld, F., Steele, L. D., Agunbiade, T., Guillot, D., Cutz, G., **Pittendrigh, B.R.** Scientific Animations without Borders: an international collaborative approach for building applicable scientific educational materials for use on cell phones, and the Internet in developing nations. 2013. In: **Boukar, O.**, Coulibaly, O., Fatokun, C., Lopez, K., **Tamò, M.** (eds.). Enhancing cowpea value chains through research advances. *Proceedings of the 5th World Cowpea Research Conference*, 26 September–1 October 2010 Saly, Senegal, pp. 369–380.
- Bello-Bravo, J.**, and **B.R. Pittendrigh**. 2014. Scientific Animations Without Borders: Entomological origins and cross-discipline impact. *Entomology Society of Canada Bulletin*, 46(1): 31–36.
- Bello-Bravo, J.**, T. Agunbiade, E. Dannon, **M. Tamo**, and **B.R. Pittendrigh**. 2013. The prospect of animated videos in agriculture and health: A case study in Benin. *International Journal of Education and Development using ICT*, 9(3): 4–16.

Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize–bean Production Systems (SO2.1)

Lead U.S. Principal Investigator and University

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Ebby Luvaga, Iowa State University

Russell Yost, University of Hawaii at Manoa

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Barry Pittendrigh, University of Illinois at Urbana–Champaign

Abstract of Research and Capacity Strengthening Achievements

To understand limiting soil nutrients, we analyzed physical and chemical properties of three predominant soil types 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, follow-up study in Uganda is planned. Trials will demonstrate soil-specific nutrient and crop management practices necessary to increase bean productivity in farmer 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. 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 (Folmer *et al.* 1998), important Feed the Future focus countries. Average bean yields in Uganda are 0.6–0.8 MT ha⁻¹, although yields of 1.5 MT ha⁻¹ can be realized with improved varieties (Sibiko 2012). Both countries have weak extension systems and rural social and economic institutions (Anonymous 2013; Tomo *et al.* 2013), limiting widespread access to information and materials that could enable smallholder bean farmers to improve crop management practices and technologies—and achieve better yields (Athanasie *et al.* 2013). 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 (Bezner-Kerr *et al.* 2007; Kumwenda *et al.* 1996; Snapp *et al.* 2010); and (2) effectively addressing soil-related constraints will be based on enhancing smallholder farmers' capabilities in diagnosing and finding solutions to important yield constraints (Bursch *et al.* 1996), as well as helping to remove barriers to increased access to various types of soil amendments (Miruka *et al.* 2012). Analysis of soil physical and chemical properties, combined with field trials, can reveal 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 one another to make changes, strengthen social cohesion, and stimulate interest among others in learning from trials and demonstrations (Bartlett 2008; Critchley 2002; McCown 2005; Morton 2008, 2011; Sseguya *et al.* 2009, 2013).

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 to make improved site-specific crop system management decisions which contribute to higher productivity of beans and associated crops and, over time, to improved soil fertility. It will assess the effectiveness of innovative communication approaches and technologies to engage farmers with diverse characteristics and other key stakeholders in widespread dissemination and adoption of diagnostic and decision support aids (Bello-Bravo and Pittendrigh 2012; Martin and Abbott 2011; Sseguya *et al.* 2012; Tenywa 2013).

Objectives

1. The climbing bean production
2. building equipment

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 Masaka district and one community in Rakai district. Similar research activities were conducted in Mozambique's Gurué district in June 2014 (Photo 1). In each study area, focus group discussions (FGD) were held with local bean farmers who helped the research team to identify farmers recognized as innovative with whom individual in-depth interviews were later conducted (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 extension (National Agricultural Advisory Services) coordinator in Lwankoni subcounty in Rakai. The District Agricultural Officer in Masaka is a very enthusiastic supporter and facilitator for our community and field research. In Gurué, we met with local government officials and extension agents.

A significant range of soil types often exists within a given community, often on specific farms—providing both challenges and opportunities. Results from the team's discussions and interviews with productive and innovative farmers and our soil surveys revealed that smallholder farmers recognize the role and impact of a variety of soil-related characteristics on bean yield in their production systems: soil color (black soils are generally considered more suitable for bean production than red soils), particle size, soil texture, friability, topsoil depth, rocks, slope, water holding capacity, plant vigor, previous yield results, weeds, etc. In community focus group discussions, farmers identified and ranked the relative importance of each factor, with soil type consistently the primary criterion for planting beans. Farmers identified fields with predominant soils characteristics for extraction of samples for analysis, and for participation in development and testing of diagnostic aids. In Masaka and Rakai, these are referred to as black soils (*Liddugavu*) are preferred for bean production, while black, gravelley soils (*Luyinjayinja*) and reddish (*Limyufumyufu*) are known by farmers to be of poorer quality for bean production. Sandy soils (*Lusenyusenyu*) are more susceptible to water stress compared to clayey soils (*Lubumbabumba*). In northern Mozambique, they are *Tirokwe* (black), *Ekochoke* (red), *Nicante* (paddy), and *Ehava* (sandy).

Application of nutrients by farmers typically appears to be greater to the Liddugavu soils than to the red Limyufumyufu soils. Farmers have little understanding of specific nutrient requirements for bean production, and rarely mentioned the need for any specific nutrient necessary for bean production. Soil pH *per se*, or the many well-known ramifications of low pH and soluble aluminum on bean growth, development, water use, nitrogen fixation, and yield were never mentioned. Additionally, although the concept of host plant resistance to insect pests and diseases may be understood by some farmers, utilization of varieties with improved levels of resistance to commonly occurring foliar diseases appears limited. In Masaka, farmers are aware well that bean production typically will be poor on red or gravelley soils, but due to lack of available farmland with better producing black soil, some farmers continue to plant beans on these soils. Many farmers also clearly understand the need to plant beans early to attain greater yields, and they also face the great difficulties drying seed for sale or storage when rainy seasons extend beyond typical length. Ugandan farmers have several

months between two rainy seasons, while in Mozambique cultivation of beans and other crops in the dry season almost immediately follows harvest of crops grown during the rainy season.

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 two times, due to labor constraints and greater importance put on production of higher value cash crops. Farmers also 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. Similarly, certain perennial crops (e.g., banana) do well on good soils while a few (e.g., mango) can tolerate poor soils. Many farmers are convinced that sticker-spreader adjuvants should be applied to bean to improve yield, despite these not having any yield enhancing value in many replicated studies published in refereed journals in developed countries.

Another important factor in crop production is choice of variety. Our biweekly crop monitoring in Uganda showed that nearly all farmers surveyed planted a single variety, one that was released nearly 20 years ago and has poor levels of host plant resistance to commonly encountered foliar diseases. Farmers plant this variety because it is preferred for consumption; however, at this time we have no data on preference for any of the newer released varieties that have higher levels of resistance to these foliar diseases.

Recently revised fertilizer recommendations for beans (Kaizzi *et al.* 2012) give optimal fertilizer requirements for beans as 15 kg N and 15 kg P per ha, but consider only inorganic fertilizer sources, ignoring organic sources which are more available and affordable for smallholder farmers. There is inadequate information on fertilizer requirements for beans involving combined application of organic and inorganic fertilizers at farm level. In a maize-bean intercrop, for example, farmers in Masaka indicated that they apply fertilizer to maize rather than beans (Tenywa *et al.* 2014), and even in pure stand, most farmers rarely apply fertilizer on beans. Since farmers grow beans on various soil types, site specific soil management advice is needed (Mansour 1975). 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 are also developing adaptation measures to address emerging challenges (e.g., early planting and weeding).

Farmers receive some support from government institutions and programs, such as formal extension at district and local levels, 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 other inputs, and sometimes purchase farmers' produce. The support system for cash crops differs significantly between Uganda and Mozambique, as well as among communities. Support involves training, provision of seed and other inputs, and marketing; overall, such support is more directly available in Mozambique, provided by private sector foreign investors, NGOs and international research organizations. In Mozambique, an array of cash crops have been introduced or efforts intensified in the past decade; soybean, pigeon pea, sunflower, pineapple, cotton,

tobacco; in contrast, common bean production and sales appear to be almost exclusively driven by domestic market actors. If/when support is reduced or eliminated, or market prices for those crops decline significantly, common bean production is viewed in more lucrative terms. In Uganda, the two major cash crops are currently affected by disease—banana bacterial wilt and coffee rust; pineapple production is also widespread. Storage after harvest is rare in both countries because of income needs at (or before) harvest time and farmers’ inability to store bean grain and seed safely; in Uganda, farmers try to avoid bruchid damage by using strong chemicals (unsafe for human consumption), while most farmers in Mozambique use nothing.

In Uganda, organizations operating in the project districts include CEDO (Community Enterprises Development Organization), which focuses on replication of improved seed for beans and other crops; CIDI (Community Initiated Development Initiatives); CARITAS–MADDO (Masaka Diocesan Development Organization); BUCADEF (Buganda Cultural and Development Foundation); and Grameen Foundation, which assesses farm production and provides useful production and market information through smartphones. Farmers also rely on the private sector (e.g., traders, stockists, processors) to access agricultural inputs (seeds, farm tools and implements), purchase, add value and process farm produce. In Uganda, we have held discussions with district officials, extension service providers, private sector input dealers, and NGOs. As we foster the development of a bean sector innovation platform, we view the private sector in a central role for effectiveness and sustainability. In Gurué, an array of agricultural organizations operate: Government agriculture organizations (IIAM–Zonal Research Center, Direcção Distrital de Actividades Económicas [SDAE]), NGOs (TecnoServe, CLUSA/PROMAC), private companies (Quifel, AgroMoz, Murrimo Macadamia, Alif Quimica, and Rei do Agro, Inovagro), and international research (IITA, CIP).

To date, we have learned that the existence and strength of farmers’ groups varies significantly in both countries. In Uganda, some farmer groups formed for projects often don’t persist after project support ends (e.g., government extension); others have consolidated and grown into cooperatives. In Mozambique, farmers groups (associations) are relatively common, being the principal mechanism to access training and other support. A forum is comprised of several associations, and several forums constitute the apex organization, a federation; some associations are able to effectively engage in collective marketing, while others are not. This has significant implications for farmers’ decisions to prioritize cultivation of specific crops, including beans, as they take into account the potential for earning needed income.

Farmers in Uganda and Mozambique currently use a variety of management practices and technologies (MPT) to maintain or increase bean productivity, with significant variation by location regarding type and extent of use—reflecting awareness, availability, access and affordability. Current MPT that farmers highlighted include:

- 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—ranging from early to late, depending on rains, pests, market opportunities
- Planting patterns and spacing—some in rows, others broadcast
- Intercropping, with an array of different 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 (relatively uncommon, constrained by availability but also price)
- Foliar sprays (purported to be fertilizers, often lacking nutrient value)
- Pesticides (commonly used in Masaka, rarely available and 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 Masaka district, Community Enterprises Development Organization (CEDO) works with 80 farmers groups in five adjacent districts, including Masaka. CEDO has been active in 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 progress.

Objective 2: Develop and Refine Models about Smallholder Bean Farmers’ Decision Making

In each country, we conducted in-depth interviews with a representative cross-section of 300 farming households in the study communities to provide insights and to establish a baseline for monitoring changes associated with project activities. Topics covered land ownership, 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, storage practices, food consumption patterns, and uses of income earned through farming and other activities, connections in social and economic networks, diet and food security.

Preliminary analysis of the Uganda baseline household survey data in Masaka and Rakai districts provides valuable perspectives on farming conditions, practices, challenges, and strategies; analysis of the Mozambican baseline household survey data will begin once data cleaning is completed. The average landholding is 4.9 acres (median 3.0), with a few larger than 50 acres. The average amount

cultivated is 3.3 acres (median 2.0), with some seasonal variation. Nearly half do not cultivate all their available land, holding some land in fallow, but also due to insufficient labor or money for inputs and hire labor. One-fourth (25%) 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 (median) is devoted to other crops. The most widely grown bean variety is K132 [mottled, dark red/white] (53%), with 12 other varieties cited. More than half (62%) of farmers grown just one variety of beans in a given season; 26 percent grow two varieties, and 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 (57%), heavy rains (57%), low soil fertility (43%), inadequate labor (33%), diseases (22%), and lack of improved seed (19%). More than half (53%) 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 (18%). Primary constraints for producing other crops cited by farmers were similar—pests (63%), low soil fertility (51%), diseases (46%), and inadequate labor (35%). Overall, just under half (45%) of the farmers interviewed hired labor to assist in their farming. The majority (66%) 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 (90%) practice crop rotation in fields where beans are grown, mainly with maize (31%), groundnuts (25%), sweet potato (14%), and cassava (13%). 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 commonly cited the need for more manure and fertilizers, and capital or credit to improve further. 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 (70%), and efforts made to address this involve making or digging trenches, making terraces, and/or mulching.

Given the challenges of farming anywhere, especially under these conditions, it is noteworthy that more than half of farmers discussed how they have prepared themselves for any disaster that might

result in crop losses or failure. Their strategies involve crop diversification (54%), intercropping (22%), livestock rearing (12%), and nonagricultural income earning activities (9%). Most (93%) raise livestock—the principal types are chickens (83%), pigs (62%), goats (42%), cattle (33%), and ducks (13%).

In social terms and information, the farmers interviewed seem to be relatively well connected. Half are members of a farmer or development group. Nearly all own a radio (88%) or cell phone (89%). More than half reported gaining information about agricultural practices in the preceding year. The principal sources were workshop trainings and on-farm demonstrations by extensionists from the government (28%) and NGOs (16%), their own experience (21%), fellow farmers (14%), parents or elders (12%); only seven percent cited public media (radio, television, or newspaper—e.g., weekly “Harvest Money” series in the *New Vision* daily newspaper) and only two percent cited group or cooperative.

The most frequent topics about which they gained information were line planting and spacing (47%), application of fertilizers (57%) and manure (46%), pest management (51%), and drying on tarpaulin (40%). Other topics included grain-seed storage and preservation; collective marketing (34%); field preparation (33%); disease management (33%); timing of weeding (31%); cleaning, sorting, grading (28%); and airtight storage (8%). Farmers also generate useful information through their own experience; most important are early field preparation and timely planting; the timing of weeding; cleaning, sorting, and grading; collective marketing; and grain-seed storage and preservation. They share information on beans with a few other farmers, close neighbors, and group members. They expressed interest in obtaining more information about fertilizers (65%), quality seeds (48%), pesticides and herbicides (39%) (adulterated agricultural chemicals are common problems), farm tools—especially pump sprayers (27%), and manure (20%). Opportunities for farmer-to-farmer information sharing through exchange visits are widely appreciated.

Despite learning about and trying to obtain more information about collective marketing, nearly all (97%) reported selling beans as individuals rather than as a group. Most cited problems of low market prices (82%) and faulty weighing scales (52%), and a few noted price fluctuations and the lack of collective marketing. They obtain most of their market price information from traders (75%); a few get this from fellow farmers (19%) or the radio (14%). Prices of beans in local markets are being monitored on a periodic basis. We expect that prices are very low just after harvest when most farmers sell, and much higher later. We did note that in Gurué beans produced during the dry season—in low land or with irrigation—are generally of higher quality and obtain higher prices.

Farming is the main income source for most, followed by livestock sales. Nearly half earn income from various types of employment, primarily petty trade, casual wage employment, handicrafts, and small businesses (e.g., retail shops, hair dressing). Income earned from bean and other crop sales is used to pay for domestic needs (85%), school fees (74%), health care (23%), and investments in agriculture (16%). Half of the households owned a bicycle and one-fourth owned a motorcycle.

Most households are involved in a variety of financial transactions involving money or items with monetary value. Most (73%) reported giving or sending money, food, or goods in the past year, and

63 percent reported receiving such from outside the household. Just over half were credit and savings group members, and two thirds had cash savings. Nearly half borrowed in past year, primarily from a savings group, but also from friends and a few from a commercial bank. Purposes of loans were for school expenses, to invest in farming, and to have capital to start or expand a business. Most (75%) indicated that they could get credit or a loan if needed.

Food security is often considered as the most fundamental bottom line indicator of well-being. Half reported that all of their bean harvest from previous season (second season of 2013) had been consumed before the next season's harvest. We inquired about how long their bean harvest from the 2014 first season would provide food; their responses (in months) varied significantly—one (22%), two (18%), three (19%), four (15%), five (10%), six (7%). One-third of the households indicated that there were times in the past year when their family did not have enough food to meet their needs; 13 percent reported that there was no food to eat in the past four weeks.

From this profile, some important aspects emerge. The quantity and quality of land available for farming beans and other crops varies among households and communities. In their diverse cropping systems, beans are an important crop for both food security and income. Their practices that contribute to maintaining soil fertility include crop rotation, intercropping, and application of manure and fertilizer. Some are actively engaged in conducting their own experiments. Principal problems are pests, rainfall, soil fertility and erosion, and labor requirements. They also try to engage in additional activities that produce income. 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 that for more than one-half their harvest lasts no more than three months, there is food insecurity problem in the area. Interventions that could help farmers increase food production will make a great contribution to community well-being.

Objective 3: Develop and Validate Appropriate Diagnostic and Decision Support Aids

The purpose of assessing nutrient contents of soils of the selected communities is to determine if current levels of nutrients are adequate for optimal plant growth, or if growth limiting factors typical of soils of the tropics such as Al and possibly Mn toxicity were present and 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 (Photo 2). Soil samples were collected at two depths (0–15 and 15–30 cm) from 32 bean fields managed by 17 community-selected innovative farmers in Masaka and Rakai districts, Uganda, in January 2014. In-depth interviews were conducted with all of these farmers. In addition, we have also been 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 in June from the fields of 25 community-selected innovative farmers. GPS coordinates for soil types and sites were captured for development of site specific soil maps.

Soils were prepared and sent to Crop Nutrition Laboratory (soil and plant tissue) Services (CropNuts) in Nairobi, Kenya for analysis. This laboratory was selected so that analyses of soils between the two project sites, Masaka and Rakai districts in Uganda and Gurué district in Mozambique, will have used the same laboratory and same methods of analysis. The specific methods and procedures used by CropNuts have been developed for soils of the tropics, for example the measurement of P and K using the Mehlich-3 procedure for acid soils of low activity clays. The calculation of effective cation exchange capacity is required in soils of variable charge since the classic cation exchange capacity (CEC) is determined at pH 7 which is well above the usual pH of weathered soils.

An array of 19 chemical and physical parameters was determined for the samples at CropNuts, with some determinations of the Uganda samples completed at Makerere University. Data were analyzed by combinations of ANOVA, correlation, and regression. Analysis of these samples 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 also were lower than generally recommended in other locations for bean production. Nutrient levels in black soil (Liddugavu) appear 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 (Table 3).

In Gurué, four communities (*postos administrativos*) were selected for project work: Lioma, Ruace, Tetete, and Mepuaguia. The physical properties of soils of all four communities are coarse, with sand contents mostly above 45 percent. Silt contents ranged from about 25 to 40 percent whereas clay was usually less than 15 percent. Specific textures included clay loams, sandy loams, and sandy clay loams. None of the soils was grouped in the soil texture grouping of clay. These quantities of silt suggest the soils are capable of holding substantial amounts of plant available water.

Regarding soil chemical properties, nutrient levels varied greatly among the project communities suggesting that a range of bean production conditions are represented by the selected project sites (Figure 1). Mepuaguia, 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 (Figure 2) 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 thus should be managed with those limitations in mind. Of the nutrients studied, phosphorus (P) varies the most among the communities (see Figure 1). That there is such a high variability (represented by the standard error bars) 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, generally at or above critical levels recognized by IIAM Mozambique. 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. Here again, it is clear that there is a need for diagnostic methods to identify fields that may be responsive to additional nutrients and other soil amendments.

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. As indicated above, there is substantial variability in soil nutrient levels among the selected communities and techniques of diagnosing nutrient status in the field will be quite useful.

A nutrient omission experiment to diagnose nutrient deficiencies in selected soils for bean production (Deenik and Yost 2006) was conducted in a greenhouse at Makerere University Agricultural Research Institute (MUARIK) with 11 treatments (see Table 4) 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 (Photo 3). 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 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.

Above ground biomass mean dry weight for the three soils are summarized in Figure 3. 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 (Prossy Kyomuhendo, unpublished results, 2014). 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 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. Complementing the nutrient omission study and on-farm field experiments, we plan to conduct lime requirement studies (Manjula *et al.* 2005). 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 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 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. This experiment will be followed with field testing of estimated liming requirement using both 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 highly 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, $\# \text{ m}^2$, $Y = -99 + 21.4x$, $r^2 = 0.450$; $P=0.0121$, 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 likely 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 currently is underway at two locations in Masaka District. Treatments are three bean management systems, each with four different varieties of bean. Management systems vary for 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. Lance Goettsch is the graduate student leading this study.

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 Masaka district, Uganda (Photo 4). 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 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. During focus group discussions and in-depth interviews, farmers characterized strengths and weaknesses of current information providers and existing agricultural information dissemination systems in Uganda and Mozambique.

Extension, radio and fellow/model farmers are highly valued information sources for Ugandan farmers. However, while radio is easily available, extension visits and training occur less frequently. While mobile phones have made it possible for farmers to 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, and although it is a trusted source, a number of farmers have had no contact with extension. NGOs such as World Vision, CLUSA, IITA (for nutrition linked to soybeans) and TechnoServe have been working in selected villages, but for the most part not directly with common bean production. Community radio exists in the area, but some visited communities had poor or no reception of programs. Mobile phones are being adopted, and are used to check market prices and coordinate activities. The emphasis in some areas on soybean production through World Vision has provided full value-chain access for that crop, while reducing local emphasis on bean production.

The perceived accuracy and value of each type of sources varies among study communities. Some information received through training sessions seems to conflict with information previously disseminated; in addition, some information broadcast on the radio by private sector businesses is viewed as misleading or inaccurate. 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; this process will be continued and expanded.

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 previous 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: “Thank you so much and I strongly believe it is technology we need to recommend to our farming community.” He has already recommended it to local stockists. A second trial will take place following the second season harvest in late 2014. This will involve participating farmers and local agricultural officials. Training materials will be refined, pretested and distributed for this trial on a controlled basis to a sample of farmers. Results will be evaluated in late March 2015. If successful, a full-scale trial will be scheduled following the first season of 2015 (June and July) including participating farmers plus all target farmers in the area. Target farmers produce enough beans and can save them for at least three months before marketing. Extensive publicity would be given to this trial, including radio, extension, and local NGOs plus farmer groups. Message targets are those who can store beans for at least three months to benefit from increases in market prices later. Assessments will track channel and message effectiveness, and guide other dissemination activities developed later after soil tests and on-farm trials have been completed.

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 during the session. They are working on a composting animation that should be available in early FY15, and identifying other topics for which collaborative work may be initiated in the coming year. Local language audio will be a key feature in future work, and SAWBO and IIAM will begin translating the composting animation into local languages during late 2014 and early 2015.

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. Given the relatively high—but uneven—level of membership in farmers and other development groups, this strategy should be effective, especially since horizontal farmer-to-farmer learning is highly valued in many communities. We will then evaluate the effectiveness of the dissemination system and provide additional training and/or revise methods to prepare for subsequent participatory dissemination activities. Dissemination, training and support will target priority decision-making points for individuals and groups.

Objective 5: Enhance Institutional Research Capacity Relative to Grain Legumes

Our project team is making a significant effort graduate student education and through mentored research activities in partner countries. Specific research foci and affiliations follow:

- Naboth Bwambale — Ugandan M.S. student in Sustainable Agriculture and Sociology at Iowa State University. His research is focused on “Farmers’ Perceptions, Knowledge and Socioeconomic Factors Influencing Decision Making for Integrated Soil Fertility Management.”

- Lance Goettsch — American M.S. student in Agronomy at Iowa State University. His research is focused on “Practical Methods to Alleviate Constraints Limiting Common Bean (*Phaseolus vulgaris* L.) Production in Masaka, Uganda.”
- Prossy Kyomuhendo — Ugandan M.S. student in Soil Science at Makerere University. Her research is focused on “Limiting Nutrients and Lime Requirements for Bean Production.”
- Stewart Kyebogola — Ugandan M.S. student in Soil Science at Makerere University. His research is focused on “Evaluation of Soil Fertility Management Options for Beans in Masaka.”
- Jafali Matege — Ugandan M.S. student in Extension and Innovation Studies at Makerere University. His research is focused on “Gender Dimensions of Bean Farmers’ Decision Making for Soil Fertility Management in Masaka and Rakai Districts, Uganda.”
- Sostino Mocumbe — Mozambican M.S. student in Journalism and Mass Communication at Iowa State University. His research is focused on “Sociotechnical Approaches for Dissemination of Information and Decision Support Aids.”
- António Rocha — Mozambican Ph.D. student in Soil Science at the University of Hawaii. His research will be focused on “Alternative Management Practices for Improving Bean Production.”

Major Achievements

1. Challenges and opportunities to bean production in all project districts have been identified, which is an important step for developing specific research hypotheses.
2. 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.
3. Interdisciplinary researchers from U.S. universities are helping young IIAM social and soil scientists to gain experience in data collection (PRA, baseline survey, soil samples) and analyses.
4. 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.
5. The bean value chain in Masaka and Rakai had an informal platform which collapsed. Our interactions with extension, NGOs and the private sector reveal that this project will contribute to rejuvenation of the platform, contributing to increased yields, food security and income.

Research Capacity Strengthening

The breadth of our team which spans soil and crop sciences, sociology, economics, extension and communications contributes significantly to conceptualizing our research objectives, methods, data collection, analysis and interpretation. In addition, members from various institutions and disciplines

contribute significantly to mentoring the research of graduate students (described under Objective 5 and Degree Training). In addition, two Institutional Capacity Strengthening grants have been awarded. One involves close collaboration among Makerere University, Uganda's National Agricultural Research Laboratories, and the University of Hawaii. It will focus on combining 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. Work with the funds from both supplemental grants is scheduled to begin early in 2015.

Human Resource and Institution Capacity Development

Short-Term Training

Soil Classification

1. **Purpose of Training:** soil identification, characterization and classification
2. **Type of Training:** participatory and scientific methods
3. **Country Benefiting:** Uganda
4. **Location and Dates of Training:** Masaka and Rakai; January and June, 2014
5. **Number Receiving Training (by Gender):** 2 female, 2 male
6. **Home Institution(s):** Makerere University and National Agricultural Research Laboratory
7. **Institution Providing Training or Mechanism:** University of Hawaii, Makerere, NARL

Soil Testing

1. **Purpose of Training:** soil testing
2. **Type of Training:** field and laboratory
3. **Country Benefiting:** Mozambique
4. **Location and Dates of Training:** Maputo; September, 2014
5. **Number Receiving Training (by Gender):** 2 female, 3 male
6. **Home Institution(s) (if applicable):** Institute of Agricultural Research of Mozambique
7. **Institution Providing Training:** Institute of Agricultural Research of Mozambique

Innovation Platform

1. **Purpose of Training:** innovation platform formation
2. **Type of Training:** participatory methods
3. **Country Benefiting:** Uganda
4. **Location and Dates of Training:** Masaka; June, 2014
5. **Number Receiving Training (by Gender):** 3 male
6. **Home Institution(s):** Makerere University and Masaka District Agriculture Office
7. **Institution providing training or mechanism:** Makerere University

Baseline Survey

1. **Purpose of Training:** household baseline survey design and implementation

2. **Type of Training:** participatory methods
3. **Country Benefiting:** Mozambique
4. **Location and Dates of Training:** Masaka, Uganda; August, 2014
5. **Number Receiving Training (by Gender):** 1 male
6. **Home Institution(s) (if applicable):** Institute of Agricultural Research of Mozambique
7. **Institution Providing Training or Mechanism:** Makerere University

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.

Explanation for Changes

1. Nutrient Omission Study for soils from Gurué will soon be conducted following receipt of data from laboratory profiles of soil samples collected in late June. Adequate funds exist for this.
2. Information Practitioner Workshops . Our statistical analyses of these data from household baseline surveys in Uganda and Mozambique will help identify the content and participants for the information practitioner workshop, which is scheduled for mid-2015. Adequate funds exist for this.
3. We exceeded short-term training planned (five people) by an additional eight people (total 13).

Self-Evaluation and Lessons Learned

We have made a significant investment in developing a collegial multidisciplinary multicountry team. This brings multiple perspectives to bear in understanding dimensions of the central problems and in determining methodological approaches—everyone's input is highly valued. We are responsive in multiway communications and collaborate well in discussing, planning and implementing all project activities. Considerable organizational and logistical effort and costs have been involved in bringing the team together for field research activities in Uganda and Mozambique. Researchers from all institutions are actively involved in mentoring all of our graduate students in their research. This generates high quality scientific data, engages diverse teams in analysis and making critical decisions, and following through. We continue to build on our diverse experiences and expertise to make wise decisions with limited resources and achieve meaningful outputs and impacts.

In both countries, we are operating within complex systems that directly and indirectly influence key elements of farming systems. In Mozambique, the creation of large-scale agricultural enterprises

that emphasize certain crops (e.g., soybeans) affects bean growing and soil fertility efforts. In Uganda, government initiatives favoring larger commercial farmers over smallholder farmers have myriad impacts. Our project strategy and activities have to adapt to these dynamics to achieve our key goals.

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* L.) production in Masaka, Uganda." Funded \$14,996.

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.

Five M.S. student research proposals at Makerere University and Iowa State University.

Farmer Decision Making Project Team. 2014. *Farmer Focus Group Discussions—Masaka and Rakai Districts, Uganda*. January (unpublished report).

Farmer Decision Making Project Team. 2014. *Farmer Interviews — Masaka and Rakai Districts, Uganda*. January (Unpublished report).

Farmer Decision Making Project Team. 2014. *Farmer Focus Group Discussions — Gurué District, Mozambique*. June (Unpublished report).

Farmer Decision Making Project Team. 2014. *Farmer Interviews — Gurué District, Mozambique*. June (Unpublished report).

Progress in Implementing Impact Pathway Action Plan

The project team is making measured progress in implementing the action plan:

1. Project activities are on track to enable the team to develop and refine appropriate models of farmer decision making strategies that reflect influences of social, cultural, economic, institutional and contextual factors;
2. We are beginning to consider materials that will be useful for development of diagnostic aids using observable characteristics that enable farmers to make site-specific management decisions; and
3. We are beginning to understand the appropriateness of existing methods and media for information dissemination to intermediate and end users.

Annexes

Annex 1. Tables, Figures, and Photos Cited in the Report

Tables

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.

Parameter	pH	P	K	Al	Silt	Clay	Sand	Stand	Ht	Yield	Nodules	Red nodules	Leaf diseases	Weeds
Soil		mg kg ⁻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								<i>P</i> value						
Soil	***	***	***	**	ns	***	**	ns	***	*	**	***	***	ns
Depth	ns‡	ns	ns	ns	ns	ns	ns	-	-	-	-	-	-	-
Soil × Depth	ns	ns	ns	ns	ns	ns	ns	-	-	-	-	-	-	-

*Significant at P= 0.05; **Significant at P=0.01; ***Significant at P=0.001. †Means followed by different lowercase letter within a column and parameter are significantly different at P≤0.05; ‡Not significant.

Significant correlations and regression functions:

Yield vs nodules/plant=.630, 0.0006; Yield = -1803 +41.5x, r2 = 0.397, P=0.0209

Plant height vs %leaf disease=-0.52977; Height = 42 – 0.378x, r2 = 0.281, P=0.0626 (not very good, NS, but only n=13 points) NOT PRESENTED

ABOVE

Red nodules number/plant vs %leaf disease= -.6201; Red nodules/plant = 31.8 – 0.186x, r2 = 0.385, P = 0.0137

0-15 cm depth follow:

Total weeds (#/m2) vs pH, 0-15 cm depth = 0.622; Total weed density = -97 + 20.7x, r2 = 0.387, P = 0.0176

15-30 cm depth:

Total weeds (#/m2) vs pH, 15-30 cm depth = 0.617; Total weed density = -99 + 21.4x, r2 = 0.450; P = 0.012

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

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 3a - Mean (SD)* Results for 11 Treatments in a Nutrient Omission Study, Run 1, Liddugavu Soil - Uganda

Parameter	Treatment	FW	DW	DM	Total nodules	Red nodules	Height	Leaf
		g plant ⁻¹		g kg ⁻¹	no.	%	cm	no. plant ⁻¹
No additions	1	12.1 (0.90)	1.6 (0.18)	132 (5)	30.2 (24.7)	95 (8)	76 (14)	5.5 (1.0)
All nutrients added	2	16.5 (1.98)	2.1 (0.41)	126 (13)	2.5 (1.3)	31 (27)	81 (8)	7.0 (0.8)
All nutrients + Rhizobium	3	19.3 (2.31)	2.7 (0.19)	138 (8)	13.8 (13.5)	74 (44)	95 (11)	7.5 (1.3)
- N + Rhizobium	4	13.9 (2.02)	2.0 (0.41)	140 (9)	32.8 (5.1)	99 (1)	64 (14)	5.7 (1.0)
- N	5	15.2 (0.38)	2.1 (0.10)	141 (10)	25.8 (7.3)	82 (21)	77 (30)	7.2 (1.0)
- P	6	13.9 (5.56)	1.9 (0.80)	135 (19)	7.2 (12.0)	62 (54)	66 (22)	6.2 (1.5)
- K	7	19.0 (1.46)	2.8 (0.25)	150 (8)	17.2 (14.2)	90 (13)	67 (12)	7.7 (0.3)
- Mg	8	13.8 (2.94)	2.3 (0.91)	164 (7)	8.2 (7.3)	22 (20)	73 (22)	7.0 (1.3)
- S	9	15.2 (0.80)	2.2 (0.32)	147 (29)	11.3 (19.6)	23 (40)	71 (13)	7.2 (0.3)
- Ca	10	11.0 (3.56)	1.5 (1.21)	118 (83)	5.7 (6.0)	26 (22)	62 (47)	6.7 (1.0)
- micronutrients	11	16.8 (5.76)	2.7 (0.36)	173 (53)	20.3 (19.6)	90 (10)	88 (10)	7.2 (1.2)

Table 3b - Mean (SD)* Results for 11 Treatments in a Nutrient Omission Study, Run 1, Limyufumyufu Soil - Uganda

Parameter	Treatment	FW	DW	DM	Total nodules	Red nodules	Height	Leaf
		g plant ⁻¹		g kg ⁻¹	no.	%	cm	no. plant ⁻¹
No additions	1	5.7 (0.28)	0.8 (0.02)	136 (9)	0.0	-	31 (9)	3.5 (0.5)
All nutrients added	2	13.8 (1.86)	1.7 (0.24)	127 (10)	0.0	-	73 (14)	5.8 (0.3)
All nutrients + Rhizobium	3	8.2 (3.99)	1.0 (0.01)	126 (7)	0.0	-	36 (18)	4.8 (1.0)
- N + Rhizobium	4	11.8 (1.06)	1.1 (0.98)	93 (8)	13.2 (18.9)	56 (48)	76 (22)	5.8 (0.3)
- N	5	12.2 (0.74)	1.7 (0.12)	135 (8)	0.7 (0.8)	56 (51)	61 (18)	6.2 (0.3)
- P	6	5.7 (0.54)	0.8 (0.05)	132 (18)	0.0	-	31 (7)	3.7 (0.3)
- K	7	12.8 (1.69)	1.7 (0.26)	134 (5)	0.0	-	78 (7)	6.3 (0.3)
- Mg	8	13.5 (1.33)	1.8 (0.27)	134 (11)	0.0	-	78 (6)	6.3 (0.3)
- S	9	13.1 (1.32)	1.6 (0.40)	124 (26)	0.0	-	71 (20)	6.2 (0.3)
- Ca	10	14.3 (2.30)	2.0 (0.51)	139 (16)	0.0	-	78 (17)	7.7 (0.8)
- micronutrients	11	13.0 (2.58)	1.7 (0.25)	135 (8)	0.2 (0.3)	0	78 (29)	6.0 (0.9)

*For all parameters; n=3 pots with 2 plants per pot

Table 3c - Mean (SD)* Results for 11 Treatments in a Nutrient Omission Study, Run 1, Luyinjayinja Soil - Uganda

Parameter	Treatment	FW g plant ⁻¹	DW	DM g kg ⁻¹	Total nodules no.	Red nodules %	Height cm	Leaf no. plant ⁻¹
No additions	1	3.7 (0.35)	0.6 (0.17)	147 (40)	3.2 (5.5)	26 (46)	39 (28)	4.0 (1.7)
All nutrients added	2	12.0 (2.01)	1.4 (0.31)	118 (10)	1.2 (2.0)	0	59 (31)	6.0 (1.0)
All nutrients + Rhizobium	3	10.6 (2.68)	1.4 (0.37)	132 (2)	1.0 (1.7)	22 (38)	55 (23)	5.0 (1.3)
- N + Rhizobium	4	8.5 (2.15)	1.2 (0.32)	145 (19)	4.8 (2.9)	83 (18)	41 (15)	4.2 (1.0)
- N	5	9.0 (0.27)	1.2 (0.13)	135 (10)	7.2 (7.5)	55 (47)	50 (20)	3.8 (0.3)
- P	6	5.6 (0.81)	0.8 (0.09)	141 (39)	0.0	-	32 (7)	3.5 (0.0)
- K	7	12.6 (0.43)	1.8 (0.10)	143 (9)	1.5 (1.3)	38 (38)	75 (34)	6.0 (0.0)
- Mg	8	11.6 (1.18)	1.6 (0.20)	142 (22)	1.2 (1.0)	11 (19)	71 (3)	6.0 (0.0)
- S	9	12.6 (1.14)	1.8 (0.09)	142 (11)	0.7 (0.8)	33 (58)	71 (4)	6.8 (0.8)
- Ca	10	12.9 (0.13)	1.7 (0.19)	135 (16)	2.3 (3.6)	8 (13)	72 (39)	5.0 (1.3)
- micronutrients	11	12.8 (1.46)	1.7 (0.23)	136 (22)	1.2 (0.6)	56 (51)	57 (51)	5.7 (0.7)

*For all parameters; n=3 pots with 2 plants per pot

Table: 4 NOS Treatment levels

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

Figures

Figure 2. Major Nutrients of Soils of Four Project Communities - Gurué, Mozambique

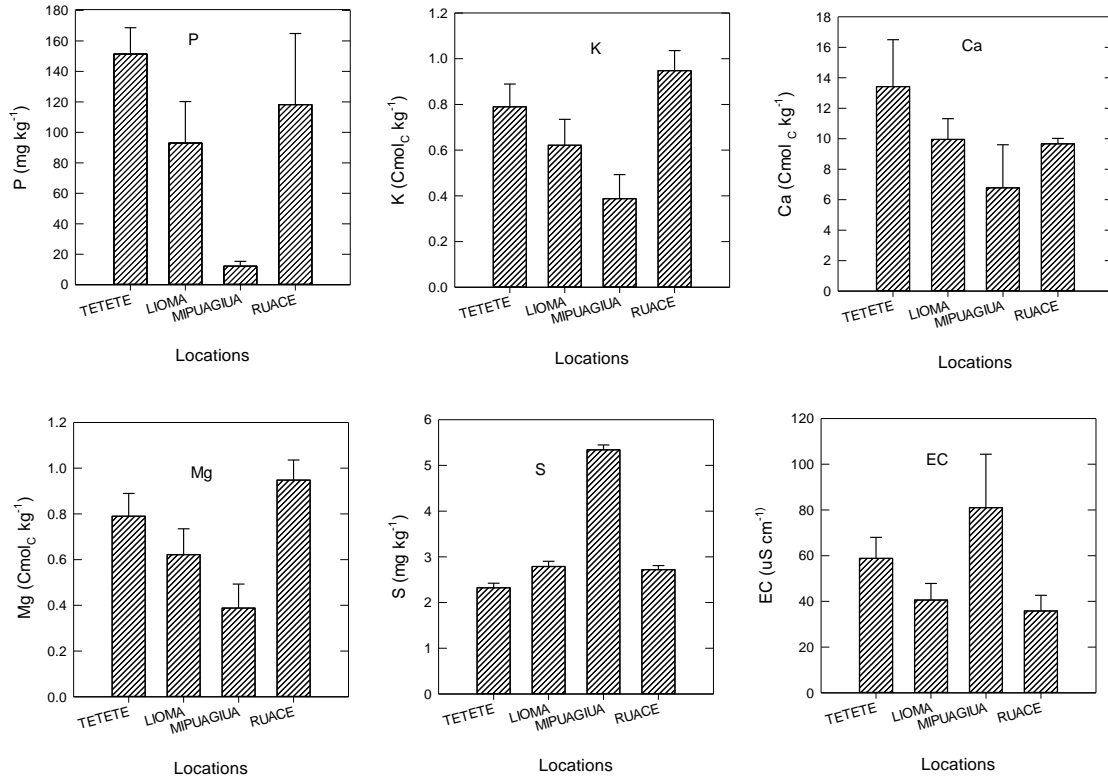


Figure 3. Soil Acidity, and Major Organic Constituents of Soils of Four Project Communities - Gurué, Mozambique

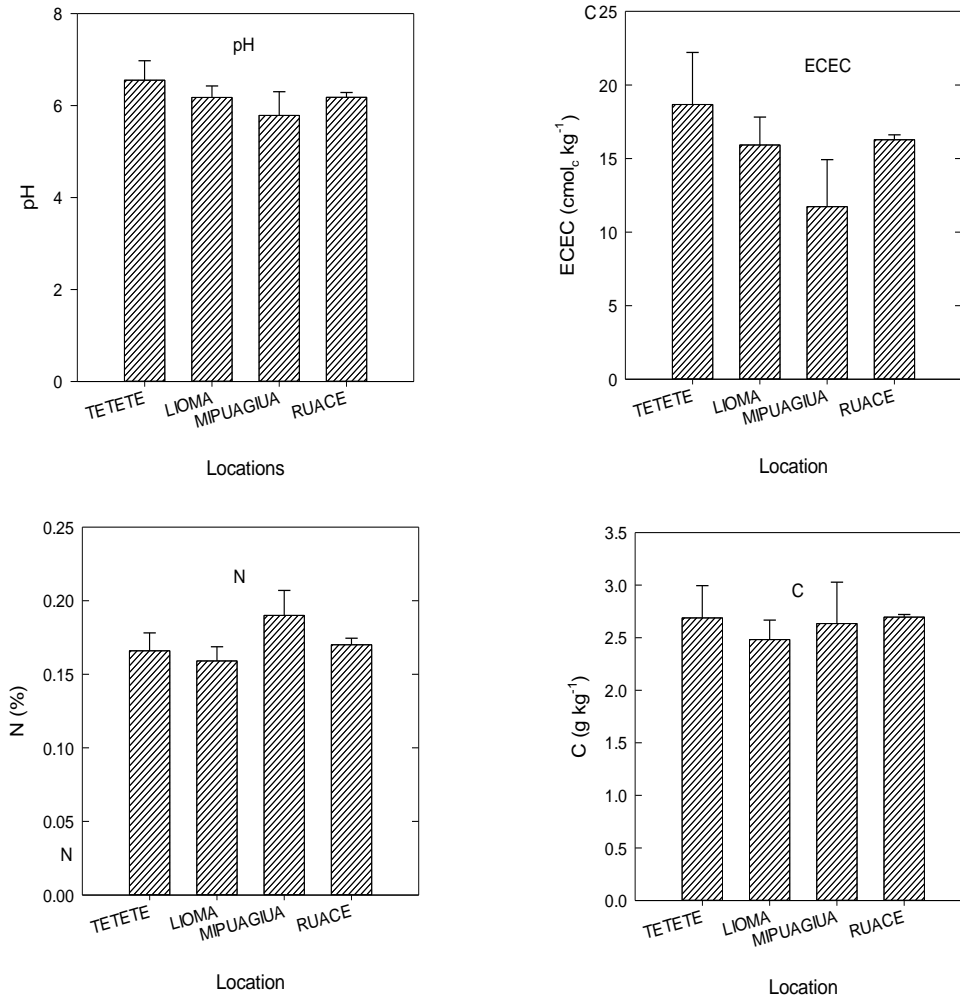
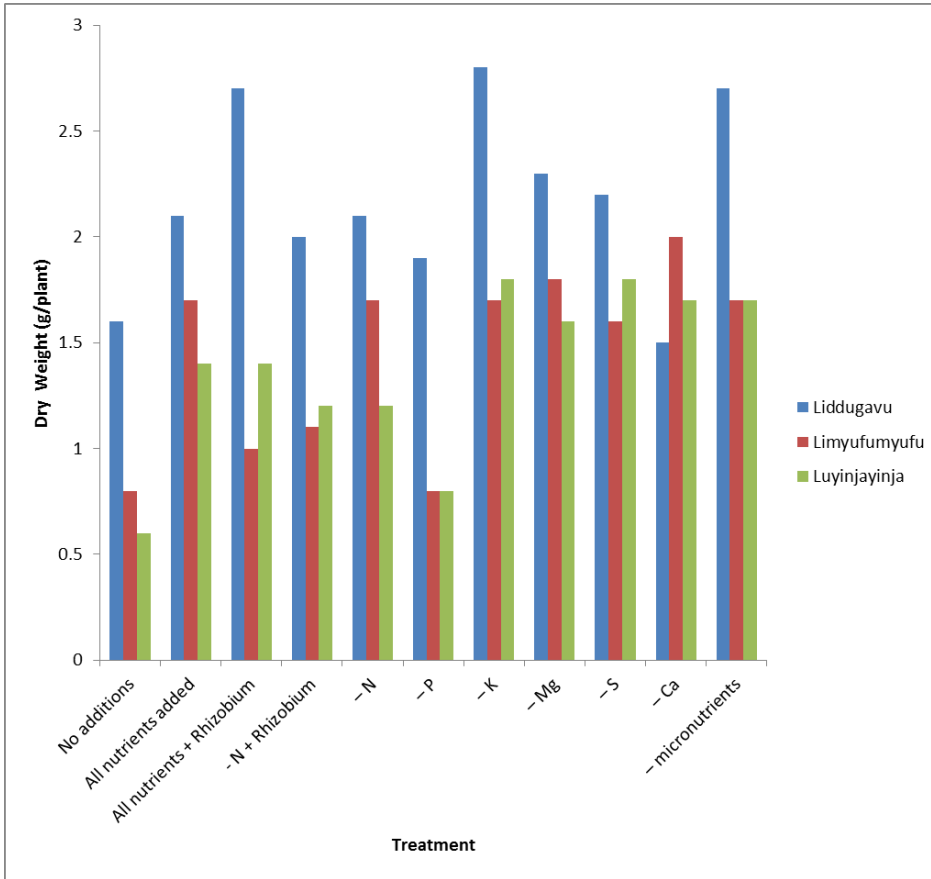


Figure 3. Nutrient Omission Study Dry Weight at Harvest in Three Soils, Uganda



Enhancing Pulse Value-Chain Performance through Improved Understanding of Consumer Behavior and Decision-Making (SO2.2)

Lead U.S. Principal Investigator and University

Vincent Amanor-Boadu, Kansas State University

Collaborating Host Country and U.S. PIs and Institutions

Gelson Tembo, University of Zambia

Lawrence Mapemba, Lilongwe University of Agriculture and Natural Resources, Malawi

Fredy Kilima, Sokoine University of Agriculture, Tanzania

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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 will 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 discrete 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

Grain legumes are not traditional staples in Zambia, Malawi and Tanzania, despite having significant nutritional benefits. Thus, increased consumption to support smallholder producer economic well-being must be based on a clear appreciation of how consumer characteristics and food attribute-level combinations shape consumers' decisions and choices. The fundamental problem of this project, therefore, is to develop new understanding of the forces and factors shaping and influencing consumers' food choice decisions in eastern and southern Africa and use this understanding to facilitate improvements in legume value chains. The project has three integrated dimensions. First, it develops an empirical foundation for understanding the factors and the extent that these factors influence food choices. This will be the first empirical evaluation of the complex factors influencing consumer choice of grain legumes in eastern and southern Africa. The research then employs the results of these factors and their extent of shaping consumer choices to engage industry

stakeholders and public institutions in a search for value creation and value expansion opportunities 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 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 that are occurring in eastern and southern Africa that are increasing urbanization; economic growth and increasing, but unequally distributed incomes; and changing demographics, including in agricultural production. This research's findings will provide insights into how and where these changes are affecting legume consumption. They will provide insights into how to overcome domestic consumption barriers and build stronger value chains to seize new markets.

Objectives

1. The climbing bean production
2. building equipment

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 to complete Objective 1. This method is superior to others (such as conjoint analysis) in that it is rooted in stated preference theory, which has its foundation in random utility theory. 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 and size as well as prices); (2) Consumer characteristics (including frequency of consumption, quantities consumed and expenditure shares) and preference influencers (cultural, and biologic ecologic variables). Its unique theoretical strength is that the choice set always includes at least one feasible alternative.

Because there is 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 discrete 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:

$$\rho(j|C_i) = \rho[(V_{ji} + \varepsilon_{ji}) > \max(V_{ki} + \varepsilon_{ki})] \quad \forall j, k \in \{C_i\} \quad (1)$$

The systematic components include attributes explaining differences in the choice alternatives and covariates explain 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} , individuals associate with each alternative as follows:

$$u_{ji} = V_{ji} + \varepsilon_{ji} \quad (2)$$

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.
- 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 even though they are all extremely 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. Developing and validating the code beforehand helps to ensure that the data analysis will be a smooth and efficient process.
- 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:

- “Consumer Choice and Preferences for Beans in Lilongwe: A Discrete Choice Modeling Approach”
- “Bean Production and Marketing in Tanzania”
- “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:
 - “Situation analysis of production and consumption of common bean in Malawi” and
 - “Market Participation Among Smallholder Bean Farmers In Tanzania”
 - 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.
- Malawian PI and his department (Department of Agricultural and Applied Economics) are actively recruiting students for the Master of Agribusiness program.
- 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.
 - 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.
 - Training is expected to start in January 2015.
 - The U.S. PIs and other host country PIs are providing guidance and support towards this training initiative, and the research team plans on developing similar needs assessment and training sessions in Tanzania and Zambia.

Major Achievements

During this reporting period, two major achievements occurred. The first achievement was the design and development of the electronic discrete choice survey instrument for all three focus countries. The second achievement was the strengthening of the relationships with upstream supply chain partners. These partners were included in the development sessions for the discrete choice experiment survey. Their involvement was crucial to the development of the survey, since they had a wealth of knowledge and expertise in bean varieties and bean attributes. These partners played an important role in determining which bean varieties to study for each of the three focus countries and which attributes and attribute levels to include in the discrete choice experiment. These partners provided expert advice and guidance and helped us to improve the quality and validity of the survey by identifying and, thus eliminating, all infeasible choice sets and options from our survey. Also, because the downstream partners were involved in the survey development, they have a clear understanding of what the output of this project will be, particularly outputs from Objective 1 and 2, and how those outputs will impact or benefit the supply chain partners. 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 what needs to be developed for specific markets and consumer profiles.

Research Capacity Strengthening

Discrete Choice Experiment Training

This training session was specifically developed for the host country PIs to enhance their capacity in discrete choice experiments and to increase their analytical skills. This training is necessary for the host country PIs to perform their responsibilities under Objective 1. The session was open to other interested parties from the university, including collaborating institutions, such as IAPRI, USAID Mission, UN Mission and WFP. The session, which was led by Kansas State University PIs, was held in Lusaka, Zambia during the week of January 27 to January 31, 2014. In addition to our research team, researchers from the University of Zambia were in attendance at the training session. In total, seven males and four females attended the session.

Training the Enumerators

Kansas State University PIs lead the first session of Training the Enumerators, which was also considered to be a part of the research team's training on discrete choice experiments. The host country PIs had the opportunity to observe how the discrete choice experiments were introduced to the enumerators before they will get a chance to help facilitate the enumerator training in Malawi and Tanzania. Also, we expect that the Zambian enumerators will also need short training session before going into the field to refamiliarize themselves with the discrete choice experiment section of the survey. We anticipate that the host country PIs will also conduct this training with the help of Kansas State University PIs.

Human Resource and Institution Capacity Development

Short-term Training

Training Activity #1

1. **Purpose of Training:** This training program is designed for the enumerators to introduce them to and familiarize them with the discrete choice approach. Enumerators need to familiarize themselves with the discrete choice experiment approach so that they can effectively and efficiently administer the experiment in the field as part of Objective 1.
2. **Type of Training:** Enumerator Training on Discrete Choice Experiments
3. **Country Benefiting:** Zambia
4. **Location and Dates of Training:** Lusaka, Zambia, January 31, 2014
5. **Number Receiving Training:** 14 males and 18 females
6. **Institution Providing Training or Mechanism:** Kansas State University

Achievement of Gender Equity Goals

Nothing to report, yet.

Explanation for Changes

The following activities were delayed until FY2015:

1. Discrete choice experiments in Zambia
2. Analyses of ranking and factors shaping bean/cowpeas consumption in Zambia; produce report and distribute to local USAID mission, collaborating institutions, policymakers in Zambia and SADC
3. Complete draft of policy brief and commence distribution for comment by collaborators and interest parties

Explanation

The subcontract with Zambia was delayed by the University of Zambia. This delay was an issue because Zambia was selected as the initial country for the discrete choice experiment because of the familiarity with the country from the previous project (PVCII). It was the decision of the research partners to stage the discrete choice experiments to minimize risks and increase the potential value of the outputs to create more effective impacts. This delay in signing the subcontract at UNZA affected some of the activities, primarily those in Zambia. To compensate for this delay in activities, we moved forward in developing the Malawian and Tanzanian surveys without incorporating lessons learned from the Zambian survey and developed a new survey timeline that we allow us to get back on track with our work plan schedule. We still intend to conduct the survey in Zambia first; however, we will adjust as schedules require accordingly, if the Zambian subcontract has not been signed by the New Year. We will conduct the surveys in Malawi and Tanzania first to give Zambia more time to resolve the contracting issue. We have planned for all surveys and discrete choice experiment summary report drafts to be completed by April 2015. At that time, we will be on track with our original timeline and have achieved our targeted milestones. Short term training activities will be conducted simultaneously with the discrete choice experiments when the research team is in country. Late contracting also affected student recruitment in Zambia. It is expected that new students will be recruited and involved in the research projects, e.g., situational analysis, by the end of December 2014.

Self-Evaluation and Lessons Learned

Lesson Learned

Limit dependence on partner institution to facilitate activities.

- Nonresponse by partner institution and not by host country PI can create challenges, constraints, and bottlenecks within the internal processing system of the partner institution. This can result in projects being held up and stalled.
- The solution for this nonresponse by partner institution is to strength the relationship between U.S. PIs and partner institution administration. Also, it is advantageous to the success of the project to develop effective strategies that limit the dependence on the partner institution and to encourage and/or increase the institution's willingness to partner in the research project and its affiliated activities.

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.

Progress in Implementing Impact Pathway Action Plan

The Impact Pathway Action Plan is still in effect and the timeline has only been altered for one output due to the delay in the subcontract with Zambia. The report on food hierarchies in Zambia is expected to be completed by Quarter Three of FY2015 and published on the project and partner websites by Quarter Four of FY2015.

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 (PI) and affiliated Lead U.S. University

Mywish Maredia, Michigan State University

Host Country and U.S. Co-PIs and Institutions

Eric Crawford, Michigan State University

Byron Reyes (Collaborator), Michigan State University

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

Abstract of Research and Capacity Strengthening Achievements

In FY 13–14, this project worked towards completing or initiating several activities under the 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 Lab projects to plan and 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. In FY13–14, 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 different socioeconomic and agricultural systems contexts and initiated the planning of implementing a study on willingness to pay for different types of seeds with a focus on northern Tanzania. Results of the analysis of the randomized field experiment conducted in Burkina Faso to assess the effectiveness of animated videos shown on the cell phone to train farmers on two postharvest cowpea storage technologies are presented. Towards the capacity building goal, two short-term training courses on the theory and methodology of doing impact evaluation were conducted 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 (R4D) 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) to 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. The climbing bean production
2. building equipment

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, as part of this project, the PIs worked with other research project PIs to assess the feasibility of integrating data collection and impact evaluation strategies as part of their Legume Innovation Lab project design. For many projects, the project team either participated in the planning meetings and /or had follow-up discussions while the teams were finalizing their workplans, to identify opportunities for collecting baseline data and integrating impact evaluation research as part of the project design.

After consulting with the PIs of each of the funded projects, several opportunities were identified for baseline assessments and/or impact studies and these are grouped into three types—activities for which there is agreement and resources to do the study, activities for which there is a need to explore resources, and activities which are not ready for impact assessment. The outcome of this consultation and review of each project was summarized in the workplan. As part of the FY 14 workplan, this project has collaborated on the following baseline data collection efforts:

1. 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 SO1.A1 project team under their objective "*Genetic improvement of climbing black beans for the highlands of Central America.*" This study is led by ICTA and is designed to establish a baseline about production of climbing beans in the highlands of Guatemala, and to better understand the current status of the climbing bean/maize intercropping production system. The plan is to collect information and data concerning cultivated area, number of different species grown, number of farmers utilizing this cropping system, production problems, seed quality and culinary preferences to help establish priorities for the climbing bean breeding program.

Status of this activity as of the end of FY 14: 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. This questionnaire will contain seven sections to collect:

- a. general information about the interviewee
- b. general information about the farm
- c. general information about the bean plots planted in the season of interest
- d. general information about bean production
- e. bean sales and postharvest management
- f. socioeconomic characteristics of household members
- g. importance of the bean crop and bean consumption in the household

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. The sampling will be done before the training of enumerators, which is planned for January 2015. Soon after the training of enumerators, data collection will begin. Data tabulation and cleaning will be done by ICTA, in collaboration with Legume Lab's SO4.1 project. It is expected that data would be clean and ready for analysis by the end of April.

2. Study on the market potential for biopesticides in Benin: This is a collaborative activity with the SO1-B1 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 will be the costs to enter the market place for small industries, what are skill sets that need to be developed for women’s groups to potentially 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 include:
 - a. Providing technical support to SO2.1 project: This project worked with the SO2.1 project team to provide input and technical support in the baseline survey and data collection efforts implemented by that project in the host countries in FY 14. This input was given in the form of discussions with the project PI during the survey

planning stage and the review of survey instruments designed to collect the baseline data in the project pilot sites.

- b. In collaboration with the SO1.B1 project PIs, we finalized the report of the biocontrol agent baseline assessment study conducted in Burkina Faso in 2012 and was designed to collect information about the 2011 production season. This report was published as an MSU Staff paper in December 2013. Given the importance of cowpea (*Vigna unguiculata*) as a staple in Burkina Faso and many other countries in West Africa, and being the legume pod borer (*Maruca vitrata*) one of the major cowpea pests affecting the crop, the Legume Lab project led by the University of Illinois is developing alternative strategies to control these insect pests and reduce the levels of pesticide used on the crop, including implementing a comprehensive biocontrol program. This study was designed to collect baseline data (and eventually end line data in year four of this extension phase) to be able to evaluate the long-term impacts of biocontrol research.

The sampling areas in this baseline survey were designated by first selecting target geographic provinces, then randomly selecting villages within these provinces according to their geographic location and then systematically randomly selecting households within each village. The sample design covered a total of 560 households distributed across 56 villages, 10 provinces, and two ecological zones called *bio-areas*. The results were disaggregated by province and bio-area to be able to assess the impact in areas where the beneficial insects will be released (i.e. south bio-area) versus in areas where they will not be released (i.e. north bio-area). Main results of the baseline survey are summarized below:

- Insects were the main biotic stress affecting the crop and drought was the main abiotic stress reported by farmers.
- More than one-half of farmers reported that the incidence of insect pests in 2011 was worse when compared with the two previous years.
- Insect incidence (especially of legume pod borer) was more problematic in the north bio-area. The use of chemical insecticides in 2011 on the cowpea crop was common, especially in the north bio-area, perhaps as a result of the higher incidence of pests in this bio-area.
- Farmers who applied insecticides to the cowpea crop mostly used three insecticides and very few farmers (less than one-third) reported that the trend on the quantity applied has decreased over time. It is expected that the number of farmers reporting using less insecticides will increase after the project intervention.
- Contrary to prior expectations from researchers regarding the quality of insecticides, farmers reported that they were satisfied with the effectiveness of the insecticides they used.
- The findings about pesticides management (i.e., proper storage, correctly identifying pesticides labels, sickness due to pesticide poisoning) suggest that farmers in the south

- bio-area may be better informed on how to manage and use pesticides than farmers in the north bio-area.
- Cowpea grain yields (adjusted for intercropping) from farm data averaged 317 kg/ha. While observed yields were much higher than yields observed in three regions of Senegal (average 241 kg/ha), these were lower than country-level yields estimated from FAOSTAT (470 kg/ha) and much lower than the yields reported in the village-level questionnaire (667 kg/ha).
 - Both the total grain harvested and the value of harvest were statistically significantly higher in the south bio-area (337 kg with a market value of CFA 97,710 or U.S. \$211 vs. 148 kg of grain with a market value of CFA 43,001 or U.S.\$93). Harvesting fodder was a common practice.
 - The importance of the cowpea crop as a source of income and food security was confirmed since across all households, cowpea grain sales as a source of income, share of annual grain consumption satisfied by own production, and length of time that food grain reserves of cowpea last after harvest were all important factors, especially among farmers living in the south-bio area.

Objective 2. Conduct ex ante and ex post impact assessments

Under this objective, following research studies and activities were accomplished in FY 2013–14.

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

The impact of research investment in crop improvement research is dependent upon the availability (supply) and affordability (demand) of seeds of improved varieties. Assessment of factors that contribute to the success and sustainability of seed systems for grain legumes in different socioeconomic and agricultural systems contexts is therefore an important area of research to enhance the impact of past research by the CRSP and future investments by the Legume Innovation Lab. This project conducted following field research to address the following research question.

What factors contribute to the sustainability of seed systems?

The seed dissemination project implemented in four countries in Central America under the Bean Technology Dissemination (BTD) project offers a good opportunity to do an in-depth analysis of the unique features of different models for seed multiplication and distribution so as to identify principles of sustainability present/absent from these different models and derive implications and lessons for broader applicability to other countries where Innovation Lab research programs are active. 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 (which was led by M. Maredia), and included the following components: a) Three surveys in Nicaragua (completed in 2012): i) A survey of 153 Community Seed Banks (CSB), 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 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. These interviews were conducted in July–August 2013 by Dr. Byron Reyes, Assistant Professor and David DeYoung, a graduate student in AFRE, MSU; both with the necessary language skills and extensive experience working in this region.
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. The field work was carried out in summer 2013 (July–August) through NITLAPAN of the *Universidad Centroamericana* (UCA). David DeYoung from Michigan State University participated in enumerator training and provided supervisory role during the field work, along with the staff of NITLAPAN. Data entry and cleaning were done by NITLAPAN and survey data files were submitted to Michigan State University for analysis and reporting in 2013. 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* and
 - b. Farmer perspective on the use of and demand for seeds of improved bean varieties: *Results of beneficiary surveys in Guatemala, Honduras and Nicaragua*. These reports were recently reviewed by the BTD project managers and will be published as MSU Staff Papers before December 2014.

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 the needs?

- **Diversity:** can the system supply adequate quantity and quality of diverse varieties of seeds to meet the 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)-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 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. According to the key informants interviewed in Honduras, the country has limited capacity to respond to this type of initiatives or that higher volumes would require improved facilities. Limited resources available for distributing seed was mentioned as a weakness and a constraint by key informants in all three countries.
- 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.
- There exists willingness to pay for seed with a premium over the grain price. However, in some communities meeting the seed needs based on 100 percent cost-recovery principle may not be possible. Scaling up efforts must be based on a two-pronged approach of subsidies and cost recovery. Model based on seed production closer to the end users may have better chance of recovering the cost of seed production in the form of in-kind payment.
- Flexibility in payment method and proximity/presence of seed production/distribution closer to the community are identified as the strength of the models used. Future seed system development efforts should integrate these features.
- Despite favorable quality rating, the average yield and seed to grain ratio reported by farmers were not very impressive. Thus, 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 C. America

Assessment of factors important for the sustainability of bean seed systems is a high priority area also for PABRA. Our interactions with the PABRA Theme Leader (J. C. Rubyogo) and CIAT

socioeconomist (E. Katungi) indicates some ongoing research by PABRA/CIAT in Uganda, Ethiopia and Tanzania to understand the complexity of legume seed availability and accessibility, and their keen interest to collaborate with us in expanding the research to other grain legumes (i.e., cowpea) and other countries. In FY 13–14, we explored collaborative research opportunities with the PABRA/CIAT researchers focused on following research topics:

- Role of grain market in sustaining seed demand
- Limitations and potential of private seed sector and farm based seed production in bean seed production and marketing
- Viability of quality declared seed (QDS)
- Strategies to reduce the cost of production and distribution of quality declared seeds or certified seeds
- Willingness of smallholder farmers to pay for quality seed over grain?

The scope of activities addressing these research questions in FY 14 and beyond was contingent upon availability of resources. As a priority, and based on available resources and interest from potential collaborators, we made a decision to implement research study in one country (Tanzania) addressing the question of willingness to pay for quality seed over grain. The methodology/ approach to address this research question consists of first conducting field experiments (FE) in farmers' fields to demonstrate the value of planting seed vs. grain of the same variety (to keep the genetic component of the planting material constant) and then conducting bidding experimental auctions (BEA) to test farmers' willingness to pay for seed vs. grain. These experiments will include treatments related to the type of materials used for planting: grain (saved from previous harvest or purchased from farmers), quality-declared seed, and certified seed (one and two). The experiments could be designed to understand the following elements of seed demand—quantity of seed, frequency of seed purchase, and willingness to pay for seed for a given quantity and frequency. The major field costs of doing this study will include conducting the field experiments in different sites (to represent different agroecological and socioeconomic conditions) and going to the field to conduct follow up visits and the BEA experiments.

To date, we have identified collaborators from the Sokoine University of Agriculture (SUA) and CIAT–Tanzania for this study about willingness to pay for seed, to be conducted in northern Tanzania. Two MSU faculty members (Byron Reyes and Robert Shupp) traveled to Arusha, Northern Tanzania, early in October to plan the study and meet with potential seed suppliers and collaborators. During this visit, the districts where this study will be implemented were identified and the draft study design was discussed. Currently, SUA and CIAT collaborators are collecting information about the price of several grades of seeds (i.e., certified, quality declared) and preparing a budget for this study. MSU faculty is preparing a final draft of the study design (draft available upon request from the authors). The planned activities for the coming months include purchasing all grades of seed that will be needed for the study, sampling of hamlets and farmers to be included in the study, implementation of field experiments (March 2015) and bidding experimental auctions (July 2015), and preparing survey instruments for baseline and follow up data collection (both to be done in June–July 2015).

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. These dataset include 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 explore these datasets and to apply descriptive and statistical/econometric analysis techniques to generate information that can help us understand:

- The role of grain pulses in farmers’ livelihood and food security strategies
- Factors influencing the adoption of productivity enhancing technologies in grain legumes by resource poor farmers

Results of this study will be made available in the form of a report as well an Impact Brief and will highlight major results of this cross-country study and include implications of the findings on what might the Legume Innovation Lab be doing to increase adoption and impact of its research investments.

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). The field activities for this study were concluded in January 2013 and data were submitted to MSU in late Spring 2013. Data analysis and report writing occurred as part of FY 13–14 workplan. The description of this study and the results are reported here.

Problem statement and study objectives

Cowpea bruchids (*Callosobruchus maculatus*) can cause damage to cowpea (*Vigna unguiculata*) seeds in storage, resulting in postharvest losses. To address these problems researchers have tested and come up with several nonchemical, low-cost and simple approaches such as (i) exposing the grain to the solar heat to kill the insects and eggs, and (ii) triple bagging the grain in plastic sacks, among other solutions. These techniques have been developed and well-recognized among the scientific community for a long time. Recently, as part of the “Scientific Animations without BordersSM” (SAWBO) project, researchers at the University of Illinois at Urbana Champaign (UIUC) and its partners have developed animated videos on these two technologies to increase accessibility of this knowledge to low-literate farmers around the world. These educational videos can be delivered at a low cost through the Internet and easily shared with a large number of end users through digital media such as cell phones and DVDs. This approach thus has the potential to bridge the gap that exists between research and impact by using the information and

communication technology and a community's own social networks as channels to transfer scientific knowledge at a low cost to a large number of farmers.

The success of this approach, however, depends on two critical ingredients:

1. the effectiveness of animated educational materials in inducing learning among low-literate farmers; and
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 (RCT) field experiment conducted in Burkina Faso in 2012–13 to primarily address the first issue. However, one of the indicators of learning (and thus the success of the knowledge delivery method) is the use/adoption of the technology/practice being conveyed through a delivery mechanism, and often the constraint to the adoption of a technology is that it is either not available or economically inaccessible to farmers in rural areas. 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

As part of the UIUC led CRSP project, the Agricultural and Environmental Research Institute (INERA) had planned to pilot test the deployment of the two videos on postharvest technologies in selected villages in Burkina Faso using the government extension system. This opportunity was used to design the pilot initiative as a field experiment based on the principle of randomization in the assignment of the treatments. The experiment consisted of two treatments (labeled 1 and 2) to address research question 1 (i.e., effectiveness of animated videos in inducing learning), and two treatments (labeled A and B) 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 1, 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 to the participants information on where to buy these plastic bags.

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.

Preliminary Results

The pre- and posttreatment data were used to estimate the treatment effect related to adoption of postharvest technologies promoted in the pilot project. Table 1 provides the mean outcomes of the two treatments and comparison of these groups. Just comparing the mean outcome, indicate 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 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 through cell phones 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

We would like to highlight the following emerging messages from the seed assessment study in Central America and the effectiveness of different extension models to disseminate science based technologies in Burkina Faso as technical advances resulting from project activities in FY 13–14.

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

1. Flexibility in payment method and proximity/presence of seed production/distribution closer to the community are identified as features of sustainable seed systems. Future seed system development efforts should integrate these features.
2. Despite favorable quality rating, the average yield and seed to grain ratio reported by farmers were 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
3. There is willingness to pay for quality seed with a premium over the grain price; but the amount farmers are willing to pay is highly correlated (not a surprise) with the economic status of bean farmers. Thus meeting the seed needs of the farmers across the spectrum

- based on 100 percent cost-recovery principle and private sector led model will not be a viable option for legume crops in many developing countries
4. Scaling up efforts must be based on a two- (or multi) pronged approach of subsidies and cost recovery (where possible)
 5. Models based on seed production closer to the end users (i.e., community-based systems) may have better chance of recovering the cost of QDS production in the form of in-kind payment

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

1. This study has shown that the effectiveness of using the ICT (video and cellphone) based method in inducing adoption may be context specific and depend on the type of technology being promoted and prior exposure of the technology by the farmers. For a technology that was already adopted by many farmers and for which farmers had received prior training from other projects, simply using the video-based method can be as effective as the traditional method in inducing re-adoption or first time adoption of that technology as was evident in the case of triple bag technology adoption outcomes. However, for a less popular technology or a technology for which farmers had relatively less experience/exposure, the traditional method of live demonstration was more effective in inducing behavior change (i.e., adoption) among farmers. This was evident from the significantly more (though still a low absolute number of farmers) adoption of the solar method by farmers trained using the traditional extension method versus those trained using the video on cell phone method.
2. 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 through animated videos (on cell phones or other medium) with the traditional extension method can be a cost-effective method of scaling out new technologies by using farmers' own knowledge sharing networks. The question remains on finding cost effective business models of incorporating the information and communication technology methods for delivering knowledge and information to a large number of farmers (i.e., scaling up)

Research Capacity Strengthening

Unlike other Legume Innovation Lab projects, this project does not have a country-specific collaborating HC institution. We serve as the crosscutting project that works towards building the institutional capacity and human resources in the area of impact assessment across all the projects of the Legume Innovation Lab. In FY 13–14, following activities were implemented towards this broader goal of capacity strengthening in the area of monitoring and impact evaluation:

1. Presentations and interactions with other Legume Innovation Lab research project teams: As part of the advisory role to the Management Office, the project team and project collaborator, Dr. Byron Reyes, helped develop the tools for impact pathway analysis and

the performance monitoring indicators guideline. We also 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 the Legume Lab researchers on the importance of doing research with the goal of achieving developmental outcomes. We believe this has helped contribute to enhancing the impact culture within the host country partner organizations.

2. All the research activities conducted under objectives one and two described above involve host country PIs/collaborators in the planning and conduct of field data collection. Through this collaboration 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.
3. Conducted two short courses on impact assessment in the LAC region. Having worked in developing countries for several years, one of the challenges we have faced is the absence of trained personnel to conduct impact assessment of Legume Lab projects and agricultural projects in general. Faculty at national universities and research centers often lack the theoretical and practical experience to conduct sound and rigorous social science research and impact assessment. This motivated the planning and implementation of these training courses, in collaboration with CIAT researchers, to help build local capacity in research centers and universities in the LAC region.

The two short-term training courses were implemented in FY 14 with a focus on novel methods to assess impact of agricultural projects. Originally the plan was to conduct this training activity during the PCCMCA meeting. But this plan was modified and instead conducted at CIAT and Zamorano because the allowable time at the PCCMCA meeting was not adequate (too short) to deliver the content of this training program. This course focused on teaching theoretical concepts and demonstrating practical applications of these concepts, including the use of statistical software. Researchers and economists from national research centers and universities (e.g. DICTA, FHIA, INTA, INIAP, Zamorano, CURLA, UNA, UNAN) were invited to attend. This course was led by Legume Innovation Lab Collaborator fluent in the local language and economists from CIAT. The duration of the course varied between four and four-and-a-half days. This was a joint activity in collaboration with local partners. Additional details are provided in Section VI.

Supplemental funds from the Legume Innovation Lab's Strengthening Host Country Institutional Capacity grants were used to partially cover the cost of the workshop in Honduras. CIAT contributed funding for the workshop organized in Colombia and local NARS and other partners covered the cost of supporting the participants.

Human Resource and Institution Capacity Development

Short-Term Training

Short-Term Training 1

1. **Purpose/description of training activity:** Conduct educational sessions at project planning meetings on constructing impact pathways and collecting/reporting performance indicators data
2. **Type of training:** Introduction to the concepts, tools and methods related to impact pathways and FTF performance indicators
3. **Country benefiting:** All Legume Lab program host countries
4. **Location and dates of training:** Various (Puerto Rico, Quito, Lusaka, Maputo, Accra, Dakar); May–June 2013
5. **Participants/Beneficiaries of Training Activity:** U.S. and HC PIs of the Legume Innovation Lab program
6. **Numbers receiving training (by gender):** 60 (45 male, 15 female)
7. **Institution providing training or mechanism (and PI/Collaborator responsible for this training activity):** M. Maredia and B. Reyes, Michigan State University

Short-Term Training 2

1. **Purpose/description of training activity:** Introduction to novel methods to assess impact of agricultural projects and practical applications (training course 1)
2. **Type of training:** Conducted a 4 day intensive training on current theory to assess impact and practical applications of this theory. The training also included basic use of statistical software (i.e. STATA) for data manipulation and analysis.
3. **Country benefiting:** Guatemala and countries from South America
4. **Location and dates of training:** Colombia (CIAT), April 2014
5. **Participants/Beneficiaries of Training Activity:** Economists and researchers from National Research Centers, Universities and International Research Centers.
6. **Numbers of Beneficiaries:** Colombia: 22 (7 female)
7. **Institution providing training or mechanism (and PI/Collaborator responsible for this training activity):** B. Reyes, Michigan State University and CIAT economists

Short-Term Training 3

1. **Purpose/description of training activity:** Introduction to novel methods to assess impact of agricultural projects and practical applications (training course 2)
2. **Type of training:** Conducted a 4.5 day intensive training on current theory to assess impact and practical applications of this theory. The training also included basic use of statistical software (i.e. STATA) for data manipulation and analysis.
3. **Country benefiting:** All host counties in Central America region
4. **Location and dates of training:** Honduras (Zamorano), September 2014.

5. **Participants/Beneficiaries of Training Activity:** Economists and researchers from National Research Centers, Universities and International Research Centers. The beneficiaries also included staff from collaborating Legume Lab projects from Honduras and Guatemala
6. **Numbers of Beneficiaries:** Honduras: 16 (3 female).
7. **Institution providing training or mechanism (and PI/Collaborator responsible for this training activity):** B. Reyes, Michigan State University and CIAT economists

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.

Explanation for Changes

The following outputs targeted to be achieved by the end of FY 2014 have been delayed:

1. One M.S. thesis paper: David DeYoung, a master's student in AFRE department at MSU was Partially supported by the Legume Innovation Lab project with the plan of completing his thesis paper based on the data collected on community seed bank model in Nicaragua. This has not been completed as of fiscal year end 13–14. The project PI and collaborators continue to provide advice and support to ensure that this output is delivered in the near future. The student has indicated that the thesis will be submitted during the first half of FY 15.
2. Two manuscripts for journal submission: We had set a target of two manuscripts for journal submission. To date only one manuscript is completed and submitted to a journal. Towards the second manuscript, the analysis is complete and we are in the process of writing up the results. The paper should be completed and submitted to a journal before the end of 2014.
3. Impact Briefs: We had planned to develop two Impact briefs in FY 2014. One of these was to be based on the thesis paper and the second on the field experiment paper targeted for the refereed journal. Since these two outputs have not been fully achieved, we were not able to complete the two briefs. But we plan to do this soon after the outputs (thesis paper and the RCT based journal article) are achieved.

Self-Evaluation and Lessons Learned

Challenges

Our project is a collaborative project cutting across all the other projects funded by the Legume Innovation Lab. We depend on the support and collaboration of the lead U.S. and HC PIs in

implementing our workplan. As such delays in the start-up of activities in some host countries (i.e., Benin under SO1-B1 and in Guatemala under SO1-A1) also impacted our workplan for objective 1. In the case of the Benin study, the lack of French language skills on our part was also a challenge in engaging with the HC collaborator in planning this activity and contributing to this study as we had planned.

Failures

Although, there are no failures in doing research, we do consider the delays in implementing the workplan or incomplete activities reported in this Annual Report as a failure on our part to properly manage time and available resources to meet the outputs set for this first 18 months.

Successes/Strengths

The support and collaboration we have received from other project teams during the planning meeting and subsequently at the global meeting is a strength of this program and a great recipe for success towards achieving the objectives of this crosscutting project.

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).

Presentations and Poster Papers

Magen, Benjamin, Crawford, Eric W., Maredia, Mywish. 2013. "Economic Impact of Research Investment in the Development and Dissemination of Improved Cowpea Varietal Technology." Poster paper presented at the Agricultural and Applied Economics Association Annual Meeting, Washington, D.C., August.

Maredia, M., Reyes, B. A., DeYoung, D. 2014. "An assessment of the Bean Seed Distribution Models Implemented under the Bean Technology Dissemination Project: Results of key

informant interviews and surveys conducted in Guatemala, Honduras and Nicaragua.” Final Regional Project Workshop of the BTB Project, Guatemala City, March 20.

Maredia, M., Bernsten, R. H.. 2014. "Monitoring, Evaluation and Impact Assessment of Agricultural Research for Development: Overview, Challenges and Best Practices." Presentation to the Research Management Team of the Indonesian Agency for Agricultural Research and Development (AARD), MSU, East Lansing, MI, August 18.

Maredia, M., Reyes, B. A., Ba, M., Pittendrigh, B., Bello-Bravo, J. 2014. "Can Animated Educational Materials Induce Learning And Adoption Among Low-Literate Farmers? A Field Experiment on the Dissemination of Cowpea Grain Storage Technologies in Burkina Faso." Seminar Presentation Given to the Faculty and Students at Sokoine University of Agriculture, Tanzania, June 25.

Maredia, M. and Donovan, C. 2014. "Scaling Up in Agriculture and Nutrition: Concepts and Models." Legume Innovation Lab Global Meeting, Athens, Greece, May 16.

Reyes, B. A. and Maredia, M. 2014. "Characteristics of a sustainable seed system: Application of the principles of sustainability to two models used in Central America." Innovations in Sustainable Seed Systems for Grain Legumes, May 14.

Progress in Implementing Impact Pathway Action Plan

For this project we have identified two project outputs to be achieved over the life of the project that will contribute towards developing and impact oriented research program that features: 1) Greater awareness among researchers of the importance of achieving developmental outcomes; and 2) Better design of research programs that incorporate strategies and partnerships to transfer research outputs into outcomes and impacts; and 3) Continued and increased support for investments in agricultural research in general, and on legume crops in particular. Towards the impact pathway of achieving this vision of success, the following was achieved as of the end of FY 2014 for each output:

1. Output 1: Development of impact pathway analytical tools and guidelines:
 - a. Transfer of analytical tools to project PIs and research teams: Completed as planned
 - b. Input and feedback to research teams on their impact pathway: Completed as planned
 - c. Monitor the progress towards projected outputs and strategies to achieving the vision of success as laid down in the impact pathways: Ongoing
2. Output 2: Evidence based assessments of potential and realized impacts of investments in agricultural research:
 - a. Publication of results of the assessments in technical reports and peer reviewed venues: Three technical reports and one manuscript for peer reviewed venue have been completed. Annexes

Annexes

Annex 1. Tables, Figures, and Photos Cited in the Report

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

	Average across all observations	Treatment groups		T-test
		2. Farmers trained using traditional method	1. Farmers trained using video-based method	
Number of observations (farmers)	569	283	286	
Triple bag technology related outcomes				
Percentage of HHs that used triple bag technology posttraining	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	

	Average across all observations	Treatment groups		
		2. Farmers trained using traditional method	1. Farmers trained using video-based method	
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	

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.

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

	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

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.



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