Improving Bean Production in Drought-Prone, Low Fertility Soils of Africa and Latin America – An Integrated Approach

Lead U.S. Principle Investigator and University:
Jonathan Lynch, PSU, US

Collaborating Host Country and U.S. PIs and Institutions:
Juan Carlos Rosas, EAP, Honduras
Magalhaes Miguel, IIAM, Mozambique
Kathleen Brown, PSU, U.S.
Jill Findeis, PSU, U.S.
Celestina Jochua, IIAM, Mozambique
Soares Almeida Xerinda, IIAM, Mozambique
Roland Chirwa, CIAT, Malawi
Rose Mongi-Henday, UyoleARI, Tanzania

Project Problem Statement and Justification
This project is premised on four well-established facts:
1. Drought and low soil fertility are principal, pervasive constraints to bean production in Latin America and Africa.
2. The vast majority of bean producers in poor countries cannot afford irrigation and intensive fertilization.
3. Bean genotypes vary substantially for root traits that determine their tolerance to drought and low soil fertility, making it feasible to increase yields in low-input systems through genetic improvement.
4. To exploit the potential of this approach, we need intelligent deployment of root traits in bean breeding programs, and better understanding of the socioeconomic and agroecological factors determining the adoption and impact of stress tolerant crops and cropping systems.

Drought and low soil fertility are primary constraints to crop production throughout the developing world, and this is especially true of common bean, which in poor countries is typically a smallholder crop grown in marginal environments with few inputs. Phosphorus limitation is the most important nutrient constraint to bean production, followed by the acid soil complex of excess Al, excess Mn, and low base supply. The importance of nutritional stress in bean production systems of Latin America and Africa cannot be overstated. Fertilizer use is negligible in many developing countries, especially in sub-Saharan Africa, which generally have the poorest soils. What is needed is integrated nutrient management, consisting of judicious use of fertility inputs as available, management practices to conserve and enhance soil fertility, and adapted germplasm capable of superior growth and yield in low fertility soil.

We have shown substantial variation in bean P efficiency that is stable across soil environments in Latin America. Analysis of the CIAT germplasm collection identified several sources with outstanding P efficiency - from 100 to 200% better than existent checks such as Carioca. Studies with these genotypes identified a number of distinct root
traits that contribute to P acquisition through topsoil foraging, including root hair length and density, adventitious rooting, basal root shallowness, and traits that reduce the metabolic costs of soil exploration such as root etiolation and root cortical aerenchyma. Genetic variation for these traits is associated with from 30 – 250% variation in growth and P uptake among related genotypes in field studies. Several of these traits can be evaluated in rapid screens with young plants, greatly facilitating breeding and selection.

Drought is a primary yield constraint to bean production throughout Latin America and Eastern and Southern Africa. Beans vary substantially in drought tolerance, due primarily to variation in root depth and thereby access to soil water, earliness (drought escape), and secondarily to seed filling capacity. Drought tolerance has been identified in several races of common bean, but is complex and associated with local adaptation. Utilization of specific traits in drought breeding, through direct phenotypic evaluation or genetic markers (eg QTL) would be useful.

Genotypes that are more responsive to inputs may promote the use of locally available inputs in improved Integrated Crop Management (ICM) systems. Several African countries have reserves of sparingly soluble rock P whose effectiveness may be improved by the use of nutrient-efficient bean genotypes. Beans are superior to maize in their ability to solubilize P in their rhizosphere. The introduction of bean genotypes with superior root systems may enhance the utilization of rock P, thereby improving P availability and N availability (through symbiotic N fixation) in maize/bean systems. Similarly, bean genotypes with deeper root systems may be synergistic with soil management techniques to conserve residual moisture. Our project will test these hypotheses.

We also need a better understanding of socioeconomic factors determining adoption of stress tolerant bean germplasm and the likely effects such adoption may have on household income and nutrition. Factors such as family structure may play a role in determining whether the introduction of more productive germplasm is likely to have positive or even negative effects on household income and nutrition.

Drought and poor soil fertility are primary constraints to pulse production in developing countries. Recent developments in our understanding of root biology make it possible to breed crops with greater nutrient efficiency and drought tolerance. Such crops will improve productivity, enhance economic returns to fertility inputs, and may enhance overall soil fertility and system sustainability, without requiring additional inputs. The overall goal of this project is to realize the promise of this opportunity to substantially improve bean production in Africa and Latin America.

**Planned Project Activities for October 1, 2009 - September 30, 2010**

**Objective 1:** Develop bean genotypes with improved tolerance to drought and low P

**Collaborators:**

*In Latin America:* INTA (Nicaragua), Nicaraguan farmers group, CIALs from Honduras, members of the Central American and Caribbean bean network, and NGOs.
In Africa: Manuel Amane (IIAM), Carvalho Ecole, IIAM, Centro Zonal Noroeste, IIAM, Public extension services, Patricio Augustin (World Vision International), farmers associations (APLA), Rowland Chirwa (CIAT- Malawi, SABRN), CIAT, Rose Mongi, Uyole Agricultural Research Institute, Tanzania.

Approaches and Methods:
Drought and poor soil fertility are primary constraints to pulse production in developing countries. Several specific root traits that enhance bean productivity under drought and low fertility stress have been identified. The overall goal of under objective 1 is to improve bean production in Africa and Latin America through genetic improvement.

The activities under this objective include collection of germplasm, phenotyping root traits, screening root traits for low P/drought tolerance, introgression of root traits into elite lines in Africa and Latin America, and evaluation and development of low P/drought tolerant varieties for farmers using PBV and PVS. Bean germplasm will be collected from various breeding programs in Africa and Latin America: CIAT, SABRN, BILFA and BIC, regional landraces, improved cultivars, advanced lines. Bean germplasm will be systematically screened for key root traits including root hair length, root hair density, basal root whorl number (BRWN), basal root growth angle (BRGA), and adventitious rooting. Phenotypic screens will be conducted under controlled conditions and also as field root crown evaluations. The Latin America germplasm to be screened will also include landraces and improved lines from the Mesoamerican and Andean gene pools of Phaseolus vulgaris useful for Central American and the Caribbean, and Interspecific lines from P. vulgaris x P. coccineus crosses developed by the LAC project during the previous Bean/Cowpea CRSP.

Introgression of root traits conferring greater drought tolerance and P efficiency will be carried out by developing inbred backcross (IB) populations. These IB populations will be composed of breeding lines which combine key root traits with multiple disease resistance and preferred seed types in the target regions. The initial cross will be made between the recurrent parent (selected elite cultivars and/or advanced lines for CA/C and African target countries) and the donor parents (selected germplasm with the higher expression of key root traits), followed by two backcrosses to the recurrent parent and three generations of selfing by single seed descent to develop IB populations.

Field selection will be based on the average performance of advanced IB lines in replicated drought and low P trials, complemented with field and greenhouse evaluations of root traits. Selected lines will be tested individually or in multiline combinations. The identified locations for testing include Lichinga, Gurue, Angonia, Sussundenga and Chokwe in Mozambique, and Zamorano, Yojia Lake, Yorio and El Paraíso in Honduras. Selection for some disease resistance will be conducted in the field. In addition, advanced lines will be evaluated in Malawi, Nicaragua and Haiti.

Participatory plant breeding (PPB) and PVS approaches will be used in the field trials for evaluation of the performance of the IB lines under drought/low P, agronomic adaptation and commercial seed types. Participants in the value chain of common beans (production,
processing, commercialization and export) in the target countries will be invited to participate in these evaluations. We will engage both male and female farmers in these activities with the goal of equitable representation of the local community.

**Estimated timeline for genetic improvement (as requested by TMAC):**

<table>
<thead>
<tr>
<th>Target Output</th>
<th>Description</th>
<th>Status/time expected to be completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markers</td>
<td>• Identification of chromosome location region/regions with candidate genes involved in BRWN a trait contributing for P acquisition efficiency in bean</td>
<td>Both genotypic and phenotypic data analysis has been completed. QTL analysis will completed by Sept. 2009.</td>
</tr>
<tr>
<td>Plant material</td>
<td>• Aggregation of the bean germplasm</td>
<td>Has been completed. Currently available germplasm include materials from CIAT-HQ, CIAT Malawi, national program and landraces from the farmers</td>
</tr>
</tbody>
</table>
| Plant characterization        | • Plants have been evaluated for root characteristics for P acquisition efficiency, promising genotypes identified and characterized in the field using a method (in development) for evaluation of a large number of materials in the field | Promising already genotypes identified  
• Field Method of genotype evaluation to be completed by April, 2010 |
| Superior cultivar development | • Bean varieties with better performance in low P soils and preferred by farmers in the Mozambique are in the last face of development (F5-6) | Crossing and introgression activities will be completed in Sept 2009.  
• On-station Performance test currently being conducted. |
| Seed availability             | • Multi-local evaluation for new varieties in the different regions of Mozambique, involving farmers.  
• Establishment of seed multiplication plots                                                                                     | To be completed by April, 2010  
To be completed by Sept 2010                                                                                                    |
| Variety readiness for release | • Availability of performance and yield stability of the new varieties  
• Work for variety release by the National Seed services at Ministry of Agriculture of Mozambique                                 | Not within the scope of this project                                                                                         |
**Objective 2:** Develop integrated crop management systems for stress tolerant bean genotypes

**Collaborators:**
Carvalho Ecole, IPM, IIAM, Mozambique
Momade Ibraimo, CZNd, Pedology, IIAM, Mozambique
Patricio Augustin WVI, Gurue, Mozambique
Domingos Dias, Agronomy, CZC, IIAM, Mozambique
Manuel I. V. Amane, Plant Nutrition, IIAM-HQ, Mozambique

**Approaches and Methods:**
A) *Evaluation of the effect of P efficient bean genotypes on soil erosion:*
   To conduct this study we will install erosion lysimeters at IIAM station in Lichinga in Mozambique. Using methods we have developed and used successfully in Costa Rica and Ecuador, these 2 by 1.6 m plots allow the measurement of soil and P lost from erosion from specific genotypes.

B) *Evaluation of the utility of local rock P with P efficient bean genotypes:*
   In this activity we will first obtain ground local rock phosphates from Monapo and Montepuez districts and evaluate their efficacy for bean genotypes with contrasting root traits in greenhouse and field conditions at Sussundenga and Lichinga. Results will test the hypotheses that more P efficient bean genotypes will have better utilization of local rock P than traditional genotypes, and that local rock phosphate can be a useful source of both P and Ca in red acid soils of Central and Northern Mozambique.

C) *Evaluation of synergy of water conserving soil management with drought tolerant genotypes:*
   Various methods of soil management such as mulching, crop residue management, crop rotations, microcatchment systems, and minimum tillage may conserve residual moisture during the dry season and periodic drought. Root traits may have synergy with these methods by for example permitting better exploitation of water deep in the soil profile. These issues have never been investigated.

   In this activity we will establish soil moisture plots to compare traditional and drought-tolerant genotypes under traditional versus moisture-conserving soil management to test the hypothesis that combined packages of novel genotypes and integrated soil management have greater potential impact than either approach in isolation. Plant materials to be evaluated will include those developed for drought tolerance by CIAT-Malawi.

D) *Evaluation of the effect of root traits in maize/bean intercrops:*
   The effects of BRGA, BRWN, and root hair length on root competition in maize intercrops will be the MS thesis research of one of the IIAM students at Penn State.
Closely related bean genotypes contrasting for root traits (RILs of L-88) will be grown in sole crop or intercropped with maize, with and without irrigation and at high and low P fertility, in field studies at the Rock Springs research station at Penn State. Root phenotypes will be confirmed through destructive sampling of root crowns as well as nondestructive root imaging with minirhizotrons. Soil cores at R5-R7 will permit analysis of root length by depth. Plant P acquisition and water status will be assessed over time. Results will test the hypothesis that root traits that benefit bean growth under drought and low P may or may not affect yields of maize intercrops depending on spatial niche segregation. Parallel studies with more genotypes and less intensive physiological sampling will be conducted at the IIAM Sussundenga research station in Mozambique.

**Objective 3:** Understand constraints to adoption of new bean technologies, income and nutrition potential, and intra-household effects and impacts.

**Collaborators:**
Bayou Demeke, Agricultural Economics, Penn State
Rachel Smith, Communication Arts and Sciences, Penn State
Feliciano Mazuze, CESE, IIAM, Mozambique
Maria Daluz Quinhentos, CESE, IIAM, Mozambique
Venancio Salegua, CESE, IIAM, Mozambique
Ana Lidia Gunguro, CESE, IIAM, Mozambique

**Approaches and Methods:**
During FY 2010, farm household surveys will be completed, coded and analyzed for four study areas in Mozambique (Sussundenga, Lichinga, Gurue, Angonia). Two villages have been selected for indepth study in each area, one village proximate to IIAM activities related to testing and diffusion of the low-P beans, and the other not currently (potentially) influenced by IIAM activities. The paired sites will be part of a quasi-experimental study to understand bean seed diffusion processes which are critical to ensuring widespread impacts.

A total of four survey instruments comprise the Mozambique Vulnerable Soil Vulnerable Household (VSVH) Survey: 1) Male Core Survey, 2) Female Core Survey, 3) Household Profile Survey, and 4) Agricultural Plot Survey. All participating households are asked to identify a) barriers to widespread adoption, b) constraints to achieving potential income and nutrition impacts, and c) intra-household impacts of introduction of new bean technologies. Survey questions related to the implications of human disease for production, marketing and health status are also included on the survey instruments. The Male Core and Female Core surveys include sets of identical questions asked of both the primary male and female in the household. This structure provides insight into potentially different perspectives on preferred legume characteristics; decision-making, and particularly that in regard to new agricultural technology; food production, market participation and food security; and relevant social and economic networks; as examples. In addition, the village municipal chief and traditional chief are asked to participate in a key informant interview to establish a historical perspective on changes in soil conditions, food security, and trends at the village and regional levels.
Large-scale laminated Google maps printed using Google Pro are used for all villages (both a fullview landscape map and a smaller scale ‘quadrant’ village map) to help participants identify households comprising their relevant networks, and those individuals (or households) that exert the most influence on their technology adoption decisions (food and health). Bean sharing networks are explicitly delineated both for male and female householders. All households in the local village site are numbered to facilitate network identification. Households asked to participate in the surveys are randomly sampled from the numbered households. The large-scale maps are also used to indicate all markets, scaler trader locations, fields, IIAM test sites, location of health clinics, and other relevant data. Basic GPS readings (longitude, latitude elevation) are taken for all locations, including all surveyed households. Complementary geo-referenced data are being linked to the Google maps using ‘crosswalk’ software developed at Penn State. All CESE IIAM personnel who participate in the interviewers are being trained by the project team in methods and software (network systems, GIS) being used, as part of IIAM capacity building.

The Mozambique Vulnerable Soil Vulnerable Household (VSVH) Survey (baseline survey) and related analyses will be completed by the close of Phase I. Ensuring ‘gender equity’ is a major goal of Objective 3. Women are interviewed in all households, to understand the direct and often nuanced impacts of the new technology on their livelihoods (income, food security, nutrition), participation in key decision-making within the household, and inclusion in farmer’s organization networks and market network chains at the village level and higher. Women in the villages are interviewed by women in the IIAM CESE unit and other women recruited for the survey effort. Similarly, male interviewers are used to survey male respondents.

**Objective 4: Capacity Building**
Increase the capacity, effectiveness and sustainability of agriculture research institutions which serve the bean and cowpea sectors in developing countries.

**Short-term Training:**
Type of training: in service
Description of training activity: in service training of Central American (Nicaraguan or Honduran) agronomists in root biology
Location: Penn State
Duration: 3 months
Scheduling of training activity: late spring to early fall 2008 and 2009
Participants/beneficiaries of training activity: Central American agronomists
Anticipated numbers of beneficiaries (male and female): 2

**Equipment (costing > $5,000):**
Specific type of equipment to be purchased: We are planning to purchase and install satellite dish for direct internet access at Chokwe research station, where part of project activities will take place.
Justification for equipment: to achieve workplan objectives: Internet access is very important during the implementation of the project. It will facilitate communication
between HC researchers and U.S. principal investigators, as well as information access and sharing among the scientific community.

Institution to benefit from equipment: IIAM will benefit from the equipment.

Institution to purchase equipment: IIAM

Amount budgeted for equipment item: $8,000

**Degree Training:**

*Trainee #1*
- First and Other Given Names: Virginia
- Last Name: Chesale
- Citizenship: Malawi
- Gender: Female
- Degree Program for training: MS
- Program Areas or Discipline: Horticulture (Plant Breeding)
- Host Country Institution to Benefit from Training: Malawi Ministry of Agriculture University to provide training: Penn State
- If enrolled at a US university, will Trainee be a ‘Participant Trainee’ as defined by USAID?: I suppose so - not quite sure of USAID definitions
- Supervising CRSP PI: Jonathan Lynch
- Start Date: as soon as a proper visa can be obtained- hopefully June 2009
- Projected Completion Date: 24 months after start date
- Type of CRSP Support (full, partial or indirect): full
- If providing Indirect Support, identify source(s) of leveraged funds: NA
- Amount Budgeted in Workplan, if providing full or partial support:
  - Direct cost: tuition = $27635, stipend = $32760
  - Indirect cost: this should be in the budget we submitted
- U.S. or HC Institution to receive CRSP funding for training activity: Penn State

*Trainee #2*
- First and Other Given Names: Herminio
- Last Name: Abade
- Citizenship: Mozambique
- Gender: Male
- Degree: M.S.
- Discipline: Plant Nutrition
- Host Country Institution to Benefit from Training: IIAM
- Training Location: English language training in the Republic of South Africa, followed hopefully by graduate study at Penn State
- Supervising CRSP PI: Lynch, Jonathan
- Start Date: 6/09 (language training)- 9/09 (graduate study)
- Project Completion Date: 5/11
- Training Status: Mr. Abade is about to begin language training as of this date
Type of CRSP Support (full, partial or indirect): Full (Category 1)

**Contribution of Project to Target USAID Performance Indicators**
The project will serve to improve food security and increase household incomes in broad areas of Eastern Africa through selection and breeding of beans well suited to local, degraded soils. The project will also result in 1) improvements in soil quality to enhance overall agricultural production in the region, 2) better seed systems that will significantly increase the number of households positively impacted by the new technologies being developed under this project, and 3) increase gender representation in research results and impacts.

**Target Outputs**
This is clearly identified in the benchmarks document, and target outputs are presented below.

The project will result in the following outputs:

- Identification of parents, traits, and markers for improved adaptation to low fertility, drought-prone soils of Eastern and Southern Africa.
- Phenotypic profiling of root traits in regional germplasm.
- Methods developed for phenotypic profiling of root traits and web-based training materials available for same in English, French, Portuguese, and Spanish.
- Information generated regarding effect of P-efficient bean genotypes on soil erosion.
- Information generated regarding effect of P-efficient bean genotypes on maize intercrop systems.
- Information generated regarding interaction of P-efficient bean genotypes with locally available P sources.
- Capability of African scientists to improve root biology of beans enhanced by training and improved infrastructure.
- Policy brief on seed systems (Objective 3)
- Summary report on Objective 3 survey results
- Full report on Objective 3 survey results, focusing on constraints, intra-household impacts, and technology diffusion and bean sharing networks
- Training of IIAM CESE personnel on GIS and network systems methodologies (Objective 3).

**Engagement of USAID Field Mission(s)**
In Mozambique, we will be reporting to the USAID Mission the progress made during the implementation of the activities as we achieve the expected benchmarks during each period of project implementation. In addition, we will be inviting USAID Mission staff members to perform field visits as a means to verify the benchmarks reported in each period, as well as to encourage the participation of USAID Mission staff members in field days with farmers.
The USAID Mission in Honduras has been very supportive of Bean/Cowpea CRSP research activities conducted by Zamorano over the last 18 years. They are aware of the impact of the cultivars released by the program in bean production in Honduras. EAP will be reporting to the USAID mission in Honduras about the progress made during the implementation of the project. In addition, when US PIs and MO staff visits project activities in Honduras, EAP will encourage them to perform a courtesy visit to the Mission, when it is possible.

**Networking Activities with Stakeholders**
The PIs participate in a range of research networks including Central American and African bean research networks.

**Leveraging of CRSP Resources**
This project is highly leveraged against synergistic activities under the supervision of the project participants, including an $800,000 grant from the McKnight Foundation to JL and MM and a colleague in China, two other Pulse CRSP grants to JCR, FAO/IAEA projects to JL and MM, an International Science and Education grant to JF, a $900,000 project from the Generation Challenge Program to JL, IIAM, and CIAT, a ca. $2M project from the Howard G Buffett Foundation to JL involving IIAM and CIAT, and over $1.5M in related root biology projects in the Lynch lab at Penn State.
**Dry Grain Pulses CRSP**  
Research, Training and Outreach Workplans  
(April 1, 2008 – September 30, 2009)

**PERFORMANCE INDICATORS/TARGETS**  
for Foreign Assistance Framework and the Initiative to End Hunger in Africa (IEHA)

**Project Title:** Improving bean production in drought-prone, low fertility soils of Africa and Latin America - an integrated approach  
**Lead U.S. PI and University:** Jonathan Lynch, Pennsylvania State University  
**Host Country(s):** Honduras

<table>
<thead>
<tr>
<th>Output Indicators</th>
<th>2010 Target</th>
<th>2010 Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Degree Training: Number of individuals who have received degree training</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of women</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number of men</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Short-term Training: Number of individuals who have received short-term training</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of women</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number of men</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Technologies and Policies</strong></td>
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<td></td>
</tr>
<tr>
<td>Number of technologies and management practices under research</td>
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<td></td>
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<tr>
<td>Number of technologies and management practices under field testing</td>
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</tr>
<tr>
<td>Number of technologies and management practices made available for transfer</td>
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<tr>
<td>Number of policy studies undertaken</td>
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<td></td>
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<tr>
<td><strong>Beneficiaries:</strong></td>
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<td></td>
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<tr>
<td>Number of rural households benefiting directly</td>
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<td></td>
</tr>
<tr>
<td>Number of agricultural firms/entities benefiting</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>Number of producer and/or community-based organizations receiving technical assistance</td>
<td>5 organizations</td>
<td></td>
</tr>
<tr>
<td>Number of women organizations receiving technical assistance</td>
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<tr>
<td>Number of HC partner organizations/institutions benefiting</td>
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<td></td>
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<tr>
<td><strong>Developmental outcomes:</strong></td>
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<td></td>
</tr>
<tr>
<td>Number of additional hectares under improved technologies or management practices</td>
<td>1,225</td>
<td></td>
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</table>
Dry Grain Pulses CRSP (budget template 10/1/09-9/30/10)

Improving bean production in drought-prone, low fertility soils of Africa and Latin America - an integrated approach

<table>
<thead>
<tr>
<th>Institution Name</th>
<th>PSU</th>
<th>PSU</th>
<th>IIAM</th>
<th>EAP</th>
</tr>
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<tbody>
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<td>h. Indirect Cost</td>
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<td>i. Indirect Cost on Subcontracts (First $25,000)</td>
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<td>$20,228.00</td>
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<td>j. Total Indirect Cost</td>
<td>$14,603.00</td>
<td>$20,228.00</td>
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<tr>
<td>Total</td>
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<td>$74,410.00</td>
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<td>Grand Total</td>
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Total direct cost budgeted for U.S. institution(s): $157,575.00
Total direct cost budgeted for H.C institution(s): #DIV/0!

<table>
<thead>
<tr>
<th>Cost Share</th>
<th>U.S. Institution</th>
<th>U.S. for Host Country</th>
<th>HC or U.S. Institution (1)</th>
<th>HC or U.S. Institution (2)</th>
<th>HC or U.S. Institution (3)</th>
<th>HC or U.S. Institution (4)</th>
<th>Total</th>
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<tbody>
<tr>
<td>In-kind</td>
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<th>Percentage of effort</th>
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Name of PI and Institution affiliation
## Objective 1: Breeding
- Phenotype root traits
- Screen for drought/low P tolerance
- Introgress root traits for drought/low P tolerance
- Field trial with selected genotypes

## Objective 2: Agroecology
- Analyze erosion study results Lichinga
- Establish soil moisture plots Chokwe
- Conduct greenhouse studies w RP (continued)
- Field evaluation of RP
- Identification of genotypes w best response to RP
- Intercropping study

## Objective 3: Socio-economics
- Code face-to-face surveys
- Clean coded data set
- Transcribe historical survey
- Conduct network analyses
- Analyze data
- Draft survey report 1

## Objective 4: Capacity building
- Training of Central American technicians
- Application of root phenotyping methods
- Recruit IIAM student/English training
- MS student coursework
- MS student research
- Maintenance of Internet Access in Chokwe
- Web resource root methods
- Short term training in use of RF

## Abbreviated name of institutions
<table>
<thead>
<tr>
<th>Abbreviated name of institutions</th>
<th>EAP</th>
<th>IIAM</th>
<th>PSU</th>
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## Name of the PI responsible for reporting on benchmarks
- J.C. Rosas
- M. Miguel
- J. Lynch

## Signature/Initials:

## Date: