The *Feed the Future Innovation Lab* for

Integrated Pest Management

Semi-Annual Report

2015-2016

April 30, 2016

IPM IL | Integrated Pest Management Innovation Lab

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Funded by the United States Agency for International Development under the Cooperative Agreement No. AID-OAA-L-15-00001 Feed the Future Innovation Lab for Integrated Pest Management.

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I. Executive Summary

The sub-awards for all eight of the following IPM Innovation Lab projects have been issued:

1. Biological control of the invasive weed *Parthenium hysterophorus* in East Africa
2. IPM for exportable fruit crops in Vietnam
3. Climate change and biodiversity
4. Modeling of invasive species
5. Rice IPM for Cambodia
6. IPM for vegetable crops in Asia
7. IPM for vegetable crops in East Africa
8. Grain crops IPM for East Africa.

This report presents the progress made so far in the five projects that have begun implementation early in the current reporting period. The other three projects were started at the tail end of this period, and will be included in the next report.

Some of the salient activities of this period (October1, 2015 to March 31, 2016) were the organization of planning meetings of the projects in Bangladesh, Cambodia, Ethiopia, Kenya, Nepal, and Tanzania.

At the planning meeting of the *Parthenium* project in Ethiopia in December 2015, two weed scientists from Israel participated due to their interest in collaborating with us on this project. One of the members of the Board of Visitors of Virginia Tech, Dennis Treacy, joined us on our trip to Ethiopia to participate in the planning meeting. The FAO regional plant protection officer for Near East and North Africa also indicated interest in collaboration, as this weed has established in some of the Middle Eastern countries. Natural enemies of *Parthenium*, *Zygogramma bicolorata* and *Listronotus sestosipennis*, are being mass reared for field release early in the coming rainy season in East Africa. In addition, Haramaya University in Ethiopia gave us a grant of 100,000 Birr to supplement this project.

A coordination of Impact Assessment of the projects Vegetable crops IPM for Asia, Vegetable crops IPM for East Africa, Grain crops IPM for East Africa, and Rice IPM for Cambodia have been established. To enhance inter-project collaboration, joint project planning meetings were facilitated between projects.

A Technical Advisory Committee meeting was held in Minneapolis, Minnesota in association with the annual meeting of the Entomological Society of America. A symposium on IPM packages for tropical crops was organized at that meeting.

The IPM Innovation Lab in association with International Association for Plant Protection Sciences (IAPPS) organized symposia on *Tuta absoluta* and IPM for food security at the International Plant Protection Congress in Berlin, Germany. At this congress, the IPM Innovation

Lab was given a merit award for its international activities. A *Tuta absoluta* working group of the IAPPS was also formed.

A symposium on the spread and management of *Tuta absoluta* and another one on IPM packages for tropical crops initiated by the IPM Innovation Lab have been approved by the organizing committee of the International congress of Entomology, September 2016. We will also hold a symposium on *Tuta absoluta* at the 12th Arab Congress of Plant Protection in Egypt, November 2017.

The Associate Award from the Nepal Mission for technology transfer of IPM packages developed for high value vegetable crops in the Banke and Surkhet districts ended on February 29, 2016.

And the management entity of IPM IL has created an online portal for PIs and collaborators to request and report travel activities, and submit semi-annual reports, technical workplans, and other relevant documents.

II. Research Progress Summary: Research Project Reports

1. Strengthening production and export of Vietnamese fruit crops through innovative and market-orientated IPM

Principal Investigator: Hoa Nguyen, SOFRI

Collaborating Institutions: Virginia Tech, CAB International, University of Florida, Washington State University, Plant Protection Research Institute, Fruit and Vegetable Research Institute, Plant Protection Department, Nong Lam University, Can Tho University, and Vietnam National University of Agriculture

Collaborating Scientists: Dinh Thi Yen Phuong, Le Quoc Dien, Nguyen Thanh Hieu, Trinh Xuan Hoat, Le Xuan Vi, Quyen Dinh Ha, Le Dinh Don, Phan Thi Thu Hien, Ngo Thi Thanh Truc, Nguyen Guy Hung, Dang Thi Kim Uyen, Huynh Thanh Loc, Dang Thuy Linh, Mai Van Tri, Le Cao Luong, Truong Thi Ngoc Chi, Russell Mizell, Maria Elisa Christie, Naidu Rayapati

Description

This project targets four major crops in Vietnam: dragon fruit (Pitaya, *Hylocereus* spp.), mango (*Mangifera* spp.), longan (*Dimocarpus longan*), and lychee (*Lychee chinensis*). These four key crops collectively represent the major portion of Vietnamese fruit exports to the United States markets. Currently, the U.S. market is ranked third (after China and Japan) in terms of the amount of imported fruits and vegetables from Vietnam. Despite the huge potential, Vietnamese fruit production and exports still have many key issues and challenges that need to be addressed. These issues are caused by pests and diseases; limited fruit acreage that is certified under the GAP (Good Agricultural Practices) scheme; poor quality of fruits; high costs of post-harvested irradiation

treatment; and lack of MRLs (Maximum Residue Levels) for the key fruits exported to the U.S. Thus, managing some of the key pests and diseases is pivotal to decrease losses as well as increase productivity and export value especially beneficial for the small land holder agro-ecosystem. Therefore, this project, led by Southern Horticultural Research Institute (SOFRI), is proposed to address the major production-limiting pests and diseases by developing ecologically-based integrated pest management strategies, practices, and taking a system in the context of market-driven imperatives for these four targeted fruit crops.

The over-arching objective of the project is to develop, pilot test, formulate, and implement ecologically-sound and innovative IPM technologies and packages for dragon fruit, longan, mango, and lychee crops in compliance with the entry requirements of the U.S. market. There are six specific objectives:

(i) Determine the current status of pest management in fresh fruit production for export (including key factors influencing pest management, current and new IPM practices).
(ii) Develop IPM technologies and packages for lychee, longan, dragon fruit and mango that meet U.S entry requirements with regards to SPS (quarantine pests and pest residue regulations).
(iii) Determine the impact of IPM technologies and packages through economic, ecological, and gender impact evaluation.
(iv) Improve communication and education to promote transfer of IPM technology through a dynamic technology transfer program.
(v) Build capacity to reform and strengthen policies and the local and national institutions that influence pest management.
(vi) Develop and integrate sustainable resource-based local enterprises into national, regional, and global markets.

Achievements
Capacity Building: One SOFRI staff member started her PhD program under this project.

Institutional Development

Steps are being taken towards improving the net-working with both the project partners and other research institutes and universities. At SOFRI, we are currently re-organizing four labs (insect lab, pathogenic fungus and bacteria lab, molecular lab, and beneficial fungus and bacteria lab) and are in the process of establishing two new labs for this project (plant parasitic nematode lab, and beneficial insect and nematode lab)

Technology Transfer and Scaling Partnerships

We conducted situational analysis encompassing stock-taking and assessment of current fruit production, pest lists, issues, and effectiveness of prevalent pest management measures. We also interviewed farmers to analyze and assess the production status of longan, dragon fruit, and mango.

- Longan: 90 farmer households, 3 nurseries and 3 agricultural offices of 3 provinces (Tiengiang, Vinhlong and Baria-Vungtau) were interviewed. A total 45 soil samples, 25 disease longan samples and 19 insect samples were collected from these provinces to be analyzed.
- Dragon fruit: 60 farmer households in two provinces (Tiengiang and Longan) were interviewed and 60 dragon fruit samples were collected. Farmers in the third province, Binhthuan, will be interviewed on 13th of April
- Mango: 60 farmer households of two provinces (Dongnai and Dongthap) were interviewed.
- Lychee: will be investigated in May.

In total, 210 households were interviewed and 178 interview sheets will be completed by May. Initial analysis and a general situation/status on fruit production in Vietnam will be available.

Adaption and implementation of IPM packages

Six orchards (0.5 - 1 ha) have been selected as field model to test the IPM strategies for longan (Vinhlong and Tiengiang), dragon fruit (Long An and Tien Giang), and mango (Dongnai and Dongthap). The other five orchards will be selected in Binhthuan (for dragon fruit), Baria- Vungtau and Hungyen (for longan), and Haiduong and Bacgiang (for lychee) in May. After the production status of dragon fruit, longan, mango and lychee are concluded and analyzed, an IPM package for each crop will be developed.

Research and development of new, bio-rational IPM technologies:

- *Longan Witches' Broom*: Longan leaf and branch samples (from both uninfected plants and plants with Witches' Broom symptoms in Baria-Vungtau) were sent to Washington State University for identification of the causal agent of Longan Witches' Broom. Efficacy of *Amblyseius* spp., *Paecilomyces* spp., garlic extract, and onion extract has been studied on the management of the longan eriophyid mite (*Eriophyes dimocarpi), which transmits Longan Witches' Broom disease.*
- Collected stink bug eggs infested by parasitoids (*Ooencyrtus phongi*) and by entomopathogenic fungi (*Paecilomyces* spp. and *Metarhizum* spp.) in the fields. The method of rearing *O. phongi* is also being developed to produce these parasitoids on a large scale. In addition, the efficacy of *Paecilomyces* spp. and *Metarhizum* spp. in controlling the longan stink bug is being investigated under lab and net-hose conditions.
- For anthracnose diseases (caused by *Colletotrichum* spp.) on dragon fruit and mango: Collected 67 isolates of *Colletotrichum* spp. from dragon fruit in 3 provinces (Tiengiang, Longan and Binhthuan) and 8 isolates on mango in Dongthap. These isolates are going to be phylogenetically analyzed.
- To control fruit borers (*Conogethes punctiferalis*) by entomopathogenic nematode (*Heterorhabditis* sp.): initial result showed that 100% *C. punctiferalis* died in the *Heterorhabditis* sp. treatment compared to 20% death rate of the water control treatment under lab conditions.
- Application of beneficial microorganisms:

- 10 *Bacillus* spp. isolates were isolated from soil that collected from dragon fruit orchards in Tiengiang and Longan; 10 *Bacillus spp.* isolates were isolated from soil that collected from mango orchards in Dongthap; 6 isolates of *Streptomyces* sp. were collected form dragon fruit orchards in Tiengiang
- 5 isolates of *Paecilomyces* spp., 4 isolates of *Metarhizium* spp. and 1 *Trichoderma* sp. isolate were collected from orchards of dragon fruit, mango and longan in Tiengiang, Longan, Dongthap and Vinhlong. The effectiveness of these bio-control agents is going to be tested against target pests in the selected model sites.

- Materials for fruit bagging:

  The effect and the use of fruit bags that were made from ten different materials were analyzed for dragon fruit production. Among these ten materials, Taiwanese paper and Vietnamese white chiffon cloth ("vải voan trắng") provided better protection for dragon fruits against canker (caused by *Neoscytalidium dimidiatum*) and anthracnose diseases (caused by *Colletotrichum spp.*) and no adverse effect on the fruit quality. Dragon fruits bagged by Taiwanese paper at 18 days after blooming were protected against canker and anthracnose diseases. In addition, these bagged fruits had bright skin color and nice bracts. Even though dragon fruits that were bagged by the white chiffon cloth did not have bright skin color, the canker and anthracnose diseases were reduced. Furthermore, chiffon bags allowed dragon fruits were bagged at 12 days after blooming that is six days earlier than Taiwanese paper bagging. The earlier the bagging, the better the disease control. It is inexpensive, easy, and ecofriendly to bag dragon fruits with chiffon bags. Therefore, the application of chiffon bags is going to be scaled up for dragon fruit production.

2. Innovative Scientific Research and Technology Transfer to Develop and Implement Integrated Pest Management Strategies for Vegetable and Mango Pests in Asia

Principal Investigator: George Norton, Virginia Tech

Collaborating Institutions: Virginia Tech, Penn State University, Ohio State University, North Carolina A&T, Washington State University, Bangladesh Agricultural Research Institute, Dhaka Univeristy, iDE Nepal, Nation Agricultural Research Council, Agricultural and Forestry Univerisity, Himalayan College of Agricultural Sciences and Technology (HICAST), the Center for Environmental and Agricultural Policy, Research, Extension, and Development (CEAPRED), iDE Cambodia, Royal Agricultural University

Collaborating Scientists/Researchers: George W. Norton, Megan O'Rourke, Maria Elisa Christie, Edwin G. Rajotte, Cristina Rosa, Sally Miller, Manny Reyes, Naidu Rayapati, Yousuf Mian, Shahadath Hossain, M.S Nahar, M. Masud, M. Hoq, Luke Colavito, Sulav Paudel, P. Sharma, B. Mahto, Michael Roberts, Seng Kimhian, N. Chhay, Khun Kimkhuy

Description
The Asian Vegetable and Mango IPM IL program implements ecologically-based, participatory IPM in Cambodia, Nepal, and Bangladesh, with a focus on pests of tomato, eggplant, cabbage, cauliflower, beans, cucurbits, Chinese cabbage, onion, and mango (the latter only in Bangladesh).

Research in Progress
U.S. collaborators visited Cambodia, Bangladesh, and Nepal, met with host-country collaborating partners, and planned and prioritized specific research and training activities for years one and two. They met with USAID mission representatives in each country, and with agricultural value chain project personnel. They initiated short and long-term training activities.

In Cambodia, after an extensive priority-setting effort, field trials were designed for Chinese kale, cucumber, and tomato for the growing season (wet season) that starts in late May/early June. IPM packages will be tested for Chinese kale and cucumber in farmers' fields in Siem Reap, and rootstock evaluation for resistance to *Ralstonia* will occur on station at Royal University of Agriculture. Insects and diseases of tomato will also be monitored in farmers' fields in Siem Reap. A baseline survey will be completed to assist with further prioritization and impact assessment, including gender impacts, a workshop on *Trichoderma* will be held, and a vegetable disease/virus survey will be undertaken. Dry season prioritization for crops will be: 1. head cabbage, 2. tomato, 3. cucumber, 4. long bean, 5. Chinese kale, 6. chili pepper, 7. sweet pepper, 8. cauliflower, 9. bitter gourd, 10. eggplant.

In Bangladesh, after a priority setting effort that involved development and review of specific research proposals from BARI and Dhaka University, the following activities were prioritized for the coming wet season: 1. management approach for mango fruit fly, *Bactrocera dorsalis*, 2. monitoring of South American tomato leafminer, *Tuta absoluta* in different regions of Bangladesh, 3. biology, yield loss, and integrated management of white mold of country bean, 4. assessment of suitable rootstocks for grafting tomato to combat bacterial wilt disease and develop an IPM package for summer tomato production in Bangladesh, and 5. development of an IPM package for bitter gourd, *Momordica charantia*. The program will also include testing on cabbage of bio-pesticides produced by a scientist at Dhaka University. During the winter

season, eggplant and tomato will take priority. An IPM eggplant package will be tested that includes *Bt* eggplant for control of fruit and shoot borer. One PhD student in agricultural economics has been recruited to work on impact assessment at Virginia Tech and a second student from Bangladesh Agricultural University is completing a PhD sandwich program in agricultural economics.

In Nepal, the group prioritized crops and pests and will be adding onion, okra, country bean, and chili to the previous set of crops that included tomatoes, crucifers, cucurbits, and eggplant. New IPM components that can be added to existing IPM packages include: anaerobic soil disinfestation (ASD); mustard cake as a carbon source and for nematode control in greenhouses; area wide lures for eggplant fruit and shoot borer along with clipping shoots and applying pesticides (Spinosad and Coragen) at three week intervals after first visual symptoms; tomato pith necrosis – polyculture, tomato surgery to remove infected pith and paint wounds with copper oxychloride, reduced nitrogen, and sanitizing tools with bleach during clipping. Fruit fly management for cucurbits and bitter gourd will include: protein bait, Cuelure; Capsicum *Phytophthora* blight to be managed with raised beds, compost amended with *Trichoderma* and *Pseudomonas*, and resistant varieties/grafting. There will be a pest survey/monitoring for Capsicum/chili, which will help develop the IPM package for next year. Management of *Tuta absoluta* will include detection, a field survey, and pheromone traps. When *Tuta* enters Nepal, the first strategy will be to go with chemical pesticides and then test other eco-friendly approaches. Mass media (FM, TV) will be used to create awareness. *Bt* plus Neem could be one option. For *Liriomyza*, large yellow sticky traps can be integrated into the package along with mass biocontrol release of *Trichogramma* and *Chrysoperla*. A PhD sandwich student from Tribhuvan University will work on the baseline survey and impact assessment.

Separately, a virus survey and workshop was held in Nepal.

Lessons Learned

A highly prioritized set of research and training activities are necessary given the extremely tight budget for IPM research on multiple crops in three countries and the need for short and long term IPM training. Scaling-up IPM diffusion will require close collaboration with our public and private sector partners who address vegetable and mango technology diffusion, and a foundation for that collaboration has been established in each country. Our U.S. and host country teams are well-constructed to address the research and training needs of the program. The USAID mission in Cambodia prefers to be more involved with decisions related to coordination of IL programs than most missions were in previous years. Enthusiasm for the IPM IL program is strong in most of the host country institutions.

Presentations and Publications

Many presentations were made during the planning meetings in each of the three countries by both U.S. and host country partners. For example, George Norton made a presentation in country entitled: “IPM IL: Integrated Pest Management Strategies for Vegetable and Mango Pests in Asia” (January 26, January 31, and February 4, 2016). Host country collaborators also

made presentations in the meetings. There were no publications related to this phase of the IPM IL during its first six months.

Institutional Development
Host country agricultural research and educational institutions (Bangladesh Agricultural Research Institute, Dhaka University, and Bangladesh Agricultural University in Bangladesh; General Directorate of Agriculture, Royal University of Agriculture, and Battambang University in Cambodia; National Agricultural Research Council, Agriculture and Forestry University, Tribbuvan University in Nepal) were involved in the IPM planning and priority setting and are currently involved in the implementation along with appropriate NGOs and private sector companies. Students from Battambang University, Royal University of Agriculture, BAU, AFU, HICAST, and Tribhuvan University will be involved in undergraduate and graduate thesis research. Procedures for IPM planning and implementation, including experimental design and filed surveys are being strengthened in the host country institutions.

Partners -- BARI, Dhaka University, Isphani, and BAU in Bangladesh; iDE-Cambodia, GDA, RUA, and Battambang University in Cambodia; iDE-Nepal, NARC, AFU, Tribhuvan U, HICAST, Agricare, and CEAPRED in Nepal

Technology Transfer and Scaling Partnerships

Steps Taken
Meetings and agreements to cooperate from public sector extension agencies, private companies, and USAID Feed-the-Future Agricultural Value Chain projects in each country.

Partnerships made
USAID HARVEST and New Zealand CODES projects, GDA (Cambodia), USAID AVC, Department of Agricultural Extension, Isphani (Bangladesh), USAID KISAN and PAHAL projects, Agricare, Department of Agriculture (Extension), Nepal.

3. Participatory Biodiversity and Climate Change Assessment for Integrated Pest Management in the Annapurna-Chitwan Landscape, Nepal

Principal Investigator: Nir Krakauer, CUNY City College

Collaborating Institutions: Tribhuvan University, Agriculture and Forestry University, City College and Queens College—CUNY, Institute of Global Agriculture and Technology Transfer (IGATT)

Collaborating Scientists: Ajay Jha, Pramod Kumar Jha, Mohan Siwakoti, Bharat Baby Shrestha, Anjana Devkota, Sanjay Kumar Jha, Sundar Tiwari, Min Raj Pojhrel, Naba Raj Devkota, Mohan Sharma, BR Ranabhat, Tarendra Lakhankar, José Daniel Anadón, David Lohman

Description

Nepal is famous for diverse types of flora and fauna. It has around 3% and 1% respectively of the world's flora and fauna species. There are 118 ecosystems and 75 vegetation types in Nepal, but due to climate change and biological invasion, many species are under threat. Farmers have been facing hardships every year due to insects and pests while farming vegetables and crops. Insecticides and pesticides are widely used and cause serious environmental health problems. In this context, "Participatory Biodiversity and Climate Change Assessment for Integrated Pest Management in the Annapurna-Chitwan Landscape, Nepal" is intended to find the appropriate solution through research, capacity building, and dissemination. This first semiannual report is prepared to show the progress to date on this project, including training and technology transfer activities and launch of research components.

Capacity Building

Start-up workshop: January 27 to February 3, 2016

Research team members from the USA, Tribhuvan University, and Agriculture and Forestry University organized a start-up workshop, meetings, and a three-day field visit. The purpose of the workshop was to fine-tune the project activities and interact with academicians, experts, and policy makers in relevant fields. This one-day workshop was organized on January 29, 2016 to share the project activities. There were 78 participants in the workshop. Meetings were also held with Hariyo Ban, WWF, USAID, and iDE. The research team visited field sites in the CHAL region from January 30 to February 1, 2016: Puranchaur, Kaski, Chyangchyandi Syangja, Fulbari Chitwan and Gaidakot, Nawalparasi. One purpose of the visits was to share project activities with farmers around the selected field sites and also get their feedback.

Visit between March 27 to April 4, 2016: Dr. Tarendra Lakhankar from CUNY visited Nepal from March 27 to April 4, 2016. There were two main purposes for this visit: (i) to build the capacity of the students and (ii) to update the project implementation activities. The training was conducted from March 28 to 31, 2016, for MSc and PhD students on effective use of Microsoft Word, Excel, Powerpoint, GPS handling, and application of GIS, as well as remote sensing. Moreover, a series of meetings were organized to share progress on the project and begin preparation for an international conference on climate change and biodiversity which is going to be held from January 10 to 12, 2017.

Farmer level training
Two training events were conducted for farmers specifically focusing on orientation about the project. The first training was conducted on April 7 at Gaidakot, Nawalparasi and second at Fulbari, Chitwan on April 8. There were 20 participants at each training session. The training was coordinated by Mr. Basnat Ranabhat and facilitated by Professor Mohan Sharma, Dr. Ram Asheshwar Mandal. Mr. Praseed Thapa, and Mr. Min Raj Pokhrel. The training curriculum included climate change and its impacts, damage due to insects and pest in the crops, and their management.

Field coordinators' visit
Both field coordinators, Dr. Ram Asheshwar Mandal and Mr. Praseed Thapa, visited the field from April 5 - 11, 2016. They visited Gaidakok and Kawasoti of Nawalparasi, Fulbari of Chitwan, and Jaynagar Gorusinghe of Kapilwastu. The purpose of this visit was to share the project activities, identify the training gaps, and also to select suitable field research sites.

Lessons Learned
The lessons we have learned from the project during this six month period are:

(i) To develop an effective organizational and coordination structure for research and outreach involving US and Nepal academic partners.

(ii) To develop financial reporting at the participating Nepal institutions as per USAID requirements.

(iii) To familiarize students at TU and AFU with the American academic system as they prepared individual research proposals for their thesis work under the project.

(iv) To select field sites and developing a framework for efficient and effective field activities.

Presentations and Publications
Peer-reviewed publications supported/leveraged by the project over the report period include:

IC Pérez Hoyos, NY Krakauer, R Khanbilvardi, RA Armstrong (2016) A review of advances in the identification and characterization of groundwater dependent ecosystems using geospatial technologies, *Geosciences*, 6(2): 17, doi: 10.3390/geosciences6020017

AK Jha, R Malla, M Sharma, J Panthi, T Lakhankar, NY Krakauer, SM Pradhanang, P Dahal, ML Shrestha (2016) Impact of irrigation method on water use efficiency and productivity of fodder crops in Nepal, *Climate*, 4(1): 4, doi: 10.3390/cli4010004

P Dahal, NS Shrestha, ML Shrestha, NY Krakauer, J Panthi, SM Pradhanang, A Jha, T Lakhankar (2016) Drought risk assessment in central Nepal: temporal and spatial analysis, *Natural Hazards*, 80(3): 1913-1932, doi: 10.1007/s11069-015-2055-5

Technology Transfer and Scaling Partnerships

i. A semiannual team meeting was organized from March 18-20, 2016 at Rampur, Chitwan. The main purpose of the meeting was to share the update of the project, gather the field data collection plan and preparation of the international conference to be organized for January 10-12, 2017.

ii. The Central Department of Botany, Kirtipur has developed the field plan for students. Two students have already gone into the field as of April 1, 2016 and other students are going to the field in mid-April.

iii. Both field coordinators hired for the project, Dr. Ram Asheshwar Mandal and Mr. Praseed Thapa, completed their first field visit from April 5-11, 2016.

iv. A planning meeting was held on April 1, 2016 to discuss the international conference to be organized in 2017. Materials have been prepared for the website and brochure.

Partnerships made
There are two main implementing partners of this research project in Nepal. They are CDB-TU and AFU. There was also regular interaction with other entities who may help us with scaling up our project successes, including USAID Nepal Mission, Hariyo Ban, and iDE. Additionally, AFU has enlisted Agri Care Chitwan and Sahayogi Agro Vet as private-sector partners for delivering IPM supplies to the project areas.

Technologies Transferred
Training was conducted to transfer knowledge and skills to the students by Professor Tarendra Lakhankar from March 28-31, 2016 on effective application of Microsoft Word, Excel, and PowerPoint. Additional focus of the training was to learn about the GIS and remote sensing and how to handle GPS geolocation in the field.

Technologies scaled
On the scholarship training side, technologies disseminated among students and researchers in Nepal during the first six-month period include effective use of software for scientific writing and presentation and GPS for geolocation.

4. A High-resolution Interaction Based Approach to Modeling the Spread of Agricultural Invasive Species

PI: Abhijin Adiga, Virginia Tech

Collaborating Institutions: French Nation Institute for Agricultural Research (INRA), French Agricultural Research Centre for International Development (CIRAD), Indian Institute of Horticultural Research, Institute for Dryland Agriculture

Collaborating Scientists: Madhav Marathe, Srinivasan Venkatramanan, Achla Marathe, Nicolas Desneux, Thierry Brevault, R. Asokan, Y.G. Prasad, R. Venugopalan

Description

The long-term goal of this project is to develop an integrated modeling framework representing the spread of invasive pests, and apply it to study the spread of the two leafminers: the South American tomato leafminer, *Tuta absoluta*, and the groundnut leafminer, *Aproaerema modicella*. Here, we describe our activities since the start of the project in February, 2016. In this phase of the project, our main objectives have been: (i) identifying various pathways of spread (ii) exploring strategies for modeling the spread, and (iii) collecting and organizing the data that will feed our models. Our current focus is to study the possible pathways of spread of *T. absoluta* if it enters the U.S. or more generally North America. The pest, native to South America, has already progressed to Costa Rica, and stakeholders are concerned about the possible entry of *T. absoluta* into Mexico and subsequently, the U.S. There is also a high possibility of the pest entering from Europe through imports. Therefore, there is an urgent need to study this hypothetical scenario. More importantly, this effort will act as a catalyst for creating the basic framework required to model the spread in other parts of the world. A primary concern about modeling the spread in many parts of Asia and Africa is that data is either not readily accessible or altogether unavailable. This study will drive data exploration in these data-sparse regions.

Pathways of spread

Broadly, we have categorized the different pathways of spread of *T. absoluta* into natural and human-mediated pathways. Natural pathways correspond to spread through natural means across the agricultural landscape. Mainly, this is influenced by biotic (biology, hosts, predators, etc.) and abiotic (climate, soil, etc.) factors. Human-mediated pathways include but not limited to production mechanisms, trade, and travel. In this phase, our focus is on the human-mediated pathways. We will now briefly describe the major pathways of spread due to human activities.

> ***Production***: This aspect is intended to capture the logistics of production in farms, particularly those managed by small/medium sized firms. The participation of such firms in the North American tomato industry has rapidly increased. They grow in either open fields or greenhouses, with products ranging from fresh tomato produce to tomato seedlings. These firms use state-of-the-art technology, have several facilities spanning multiple countries, and are possibly well networked. If one location is infected, because of interactions, it might lead to other locations also being infected. Also, greenhouses in particular act as reservoirs of the pest during winter and other unfavorable weather conditions. Therefore, it is important to study the operations of such firms.

Trade: This pathway corresponds to supply chain logistics of tomato products from the producer to the consumer. For the purpose of spread of the pest, we will focus on two commodities – fresh tomatoes and seedlings. We will be modeling the flow of tomatoes from farms to storage units, then to retailers, and then from retailers to consumer. Consumers include both individuals as well as farms (which buy seedlings). Figure 1 corresponds to a partial network constructed using FAO data on import and export (details in Data Collection section).

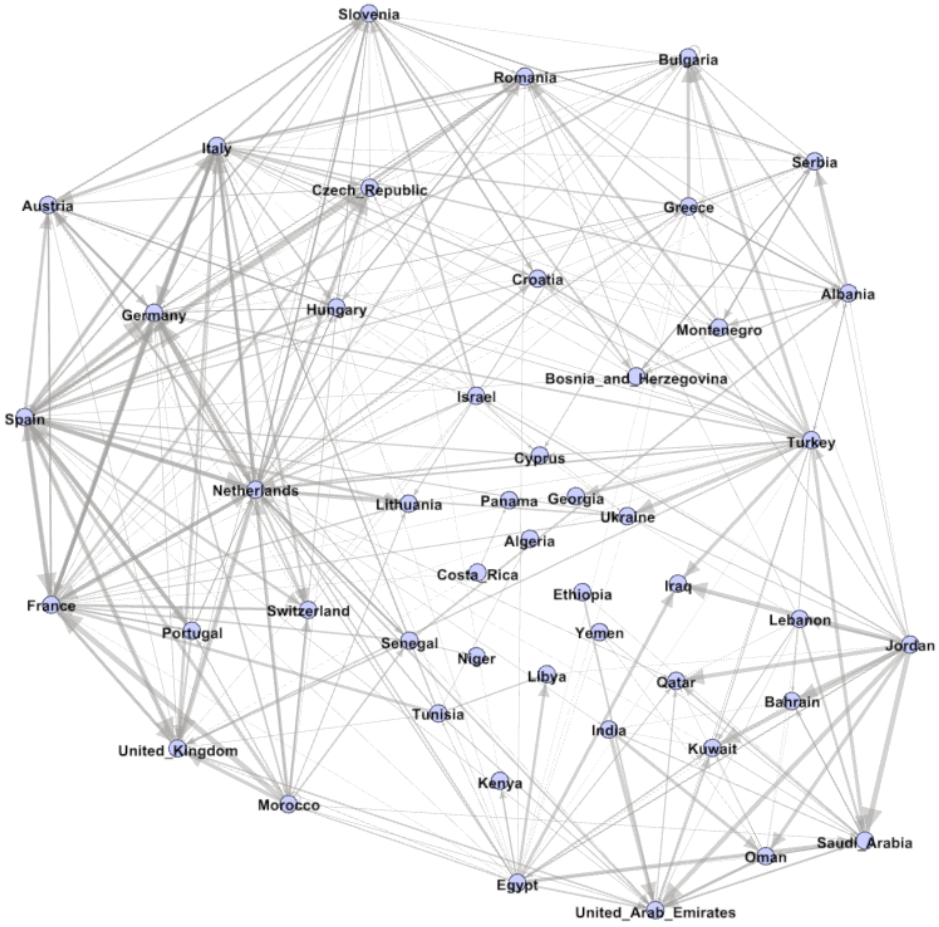

Figure 1. A weighted trade network constructed using FAO data. Every edge corresponds to export from source country to destination country. The edge thickness is proportional to trade volume.

Travel: This pathway will capture the spread of *T. absoluta* through human travel. The aim is to identify and study the flow of people such as migrant farm workers to assess the risk of spread of *T. absoluta* by individuals. The pest can be spread by individuals intentionally carrying the plants or fruits or by hitchhiking.

Data analysis and model design

The three major pathways described above will be represented using networks, and the dynamics will be captured using agent-based models defined over these networks. For model design, we will draw concepts from the rich theory of network-based epidemiological models used in the study of human diseases and social science. In the current phase, our main focus will be on constructing data structures such as networks, which capture trade, travel, etc., and analyze them. The analysis will be aimed towards answering study questions such as what are the important nodes of the network from the point of view of sampling, detection and management, and which edges should be removed to mitigate or stop the spread, etc. To this end, we will draw concepts from computer science and pest modeling literature (Nopsa et al., 2015 and Sutrave et al. 2012).

Data collection

We are in the process of identifying possible sources of information for modeling the spread of *T. absoluta*. Several datasets have been identified. All data used by our models will be ingested and managed using database management systems. We will now describe each dataset that we have already collected in detail.

Table 1. A summary of created data tables and their sources.

Dataset	Description	Source
International tomato trade matrix	Contains pairwise export/import trade volume of tomatoes between countries (annual, 1961-2013)	FAO http://faostat3.fao.org/
Country-level tomato production	Contains area harvested, yield, production, and producer prices and production value for tomatoes per country (annual, 1961-2013)	FAO http://faostat3.fao.org/
Tuta absoluta Reported Timeline	Reports of Tuta Absoluta (monthly, 2006-2015) containing location info (country/state/county), and possibly the reporting site (field, greenhouse, packaging station, etc.)	EPPO Reporting Service https://gd.eppo.int/reporting/
Nationwide (US) acreage estimate of Tomato cultivation	Geo-referenced, crop-specific land cover data for continental US using satellite imagery and agricultural ground truth	NASS CropScape https://nassgeodata.gmu.edu/CropScape/
Agricultural census (US)	State-level and county-level data on agricultural activity including data on number of farms, acreage harvested for processing/fresh market	USDA Census of Agriculture http://www.agcensus.usda.gov
Commodity Flow Survey (US)	National and state level data on domestic freight shipments including origin-destination, volume, value and mode of transport	Bureau of Transportation Statistics http://www.rita.dot.gov/bts/

Timeline of T. absoluta invasion: We have been collecting and organizing information about the confirmed record of *T. absoluta* events in various locations across the world. This information is essential for analyzing the dynamics of the pest and calibrating our models. The information includes month and year of the report, location (country, region, county, and location), and source of information. When available, it also contains information on whether the pest was observed in greenhouses, packing stations, or open fields. See Table 2 for a snapshot of this data. The main source of this data is the European and Mediterranean Plant Protection Organization (EPPO) website (EPPO *T. absoluta,* 2016). It contains more than 50 reports on the record of *T. absoluta*. We went through each report, extracting information including but not limited to location, time, and extent of infestation. Further, we also browsed through articles pertaining to *T. absoluta* to gather more details. Also, team members and other collaborators contributed several records.

Table 2. A snapshot of the timeline of *T. absoluta* records.

Year	Month	Country	Location	Source
2006	12	Spain	Castellon	Urbaneja A, Vercher R, Navarro V, GarcÃ–a MarÃ– F, Porcuna JL (2007) La polilla del tomate, Tuta absoluta. Phytoma-EspaÃ±a no. 194, 16-23.
2006	12	Spain	Islas Baleares	Urbaneja A, Vercher R, Navarro V, GarcÃ–a MarÃ– F, Porcuna JL (2007) La polilla del tomate, Tuta absoluta. Phytoma-EspaÃ±a no. 194, 16-23.
2008	4	Morocco	Bouareg	NPPO of Morocco, 2008-09.
2008	4	Algeria	Mostaganem	NPPO of Algeria, 2008-07. Guenaoui Y (2008) Nouveau ravageur de la tomate en AlgÃ©rie. PremiÃ¨re observation de Tuta absoluta, mineuse de la tomate invasive, dans la rÃ©gion de Mostaganem, au printemps 2008. Phytoma-La DÃ©fense des VÃ©gÃ©taux no. 617, 18-19.
2008	4	Italy	Cosenza (Calabria)	Regional Plant Protection Services of Campania, Sardegna, Sicilia (IT), 2009-02. Tropea Garzia G, Siscaro G, Colombo A, Campo G (2009) Rinvenuta in Sicilia Tuta absoluta. Lâ€™Informatore Agrario no. 4, p 71. Viggiani G, Filella F, Delrio G, Ramassini W, Foxi C (2009) Tuta absoluta, nuovo lepidottero segnalato anche in Italia. Lâ€™Informatore Agrario no. 2, 66-67.
2008	7	Italy	Cosenza (Calabria)	Regional Plant Protection Services of Campania, Sardegna, Sicilia (IT), 2009-02. Tropea Garzia G, Siscaro G, Colombo A, Campo G (2009) Rinvenuta in Sicilia Tuta absoluta. Lâ€™Informatore Agrario no. 4, p 71. Viggiani G, Filella F, Delrio G, Ramassini W, Foxi C (2009) Tuta absoluta, nuovo lepidottero segnalato anche in Italia. Lâ€™Informatore Agrario no. 2, 66-67.
2008	10	France		NPPO of France, 2009-01. FREDON Corse. La mineuse de la tomate. Tuta absoluta. http://www.fredon-corse.com/ravageurs/Tuta_absoluta.htm
2008	10	Tunisia	Akkouda	NPPO of Tunisia, 2009-02.
2008	10	France		NPPO of France, 2009-01. FREDON Corse. La mineuse de la tomate. Tuta absoluta. http://www.fredon-corse.com/ravageurs/Tuta_absoluta.htm
2008	11	Italy	Campania (Portici, Napoli)	Regional Plant Protection Services of Campania, Sardegna, Sicilia (IT), 2009-02. Tropea Garzia G, Siscaro G, Colombo A, Campo G (2009) Rinvenuta in Sicilia Tuta absoluta. Lâ€™Informatore Agrario no. 4, p 71. Viggiani G, Filella F, Delrio G, Ramassini W, Foxi C (2009) Tuta absoluta, nuovo lepidottero segnalato anche in Italia. Lâ€™Informatore Agrario no. 2, 66-67.

Production: There are several aspects concerning production that influence the dynamics of the pest. Currently, we are pursuing the following: (i) quantity of tomato produced (country/state level), (ii) size and connectivity of the landscape dedicated to producing tomato, and (iii) logistics of large and medium-sized tomato producing companies. Our focus is on datasets for the U.S. We will explore similar datasets

corresponding to Europe and Africa for the purpose of verification & validation of our models. For (i) and (ii), we have estimates of tomato produce from two agencies of United States Department of Agriculture (USDA): Economic Research Service (ERS) and National Agricultural Statistics Service (NASS). For (ii), we are considering using the geospatial product called Cropland Data Layer from NASS (CropScape, 2016).

The third aspect we consider is the way large firms producing tomato are structured. For example, companies such as Red Sun Farms (http://www.redsunfarms.com/) have greenhouses in locations stretching from Mexico all the way up to Canada. These companies use state-of-the art technologies, and seem to be highly networked. It is possible that their internal logistics (movement of seedlings from one greenhouse to another, for example) can provide a strong pathway for the spread of *T. absoluta*. The same argument holds for companies producing tomatoes in open fields and nurseries supplying tomato seedlings for farms, retail stores and individuals. Therefore, it is important to study the logistics of such companies. Currently, we are collecting information about the locations and purpose of the various installations of such firms. This is a challenging task as there is no one dataset which provides all the information. Reports such as those by ERS (Cook and Calvin, 2005) and web searches have been successful in providing prominent fresh tomato producing firms. More information was collected by searching the websites of these firms, news articles, and other sources such as certification agencies, which maintain audit information about these firms. See Table 3 for a snapshot of the information being gathered.

Table 3. A snapshot of table on tomato producing firms.

Name	Country	State	Location/Purpose	Source
Naturesweet Tomatoes	Mexico	Colima	greenhouse	http://naturesweet.com/wp-content/uploads/2015/08/NatureSweet-2014-Sustainability-Report.pdf
Naturesweet Tomatoes	Mexico	Nayarit	greenhouse	http://naturesweet.com/wp-content/uploads/2015/08/NatureSweet-2014-Sustainability-Report.pdf
Naturesweet Tomatoes	USA	Arizona	greenhouse	http://naturesweet.com/wp-content/uploads/2015/08/NatureSweet-2014-Sustainability-Report.pdf
Naturesweet Tomatoes	USA	Texas	business	http://naturesweet.com/wp-content/uploads/2015/08/NatureSweet-2014-Sustainability-Report.pdf
Red Sun Farms	USA	Virginia	greenhouse	http://www.redsunfarms.com/contact-us/ and google maps verification
Red Sun Farms	Canada	Ontario	greenhouse	http://www.redsunfarms.com/contact-us/ and google maps verification
Red Sun Farms	USA	Texas	storage & distribution	http://www.redsunfarms.com/contact-us/ and google maps verification http://www.andnowuknow.com/headlines/red-sun-farms-24000-sq-ft-expansion-its-texas-distribution-center-and-cold/jordan-okumura/43533#.VwUfDBIrKRs http://www.producenews.com/component/content/article/9-news-section/story-cat/14431-phase-two-of-red-sun-farms-virginia-greenhouse-to-be-under-way-soon
Red Sun Farms	Mexico		greenhouse	http://www.redsunfarms.com/contact-us/ not verified
Red Sun Farms	USA	Arizona	storage & distribution	http://www.redsunfarms.com/contact-us/ and google maps verification http://www.producenews.com/component/content/article/9-news-section/story-cat/14431-phase-two-of-red-sun-farms-virginia-greenhouse-to-be-under-way-soon
Red Sun Farms	Canada	Quebec	storage & distribution	http://www.redsunfarms.com/contact-us/ http://theproducenews.com/more-company-profiles/company-profiles/14553-red-sun-farms-announces-receipt-of-organic-certification-at-its-new-greenhouse http://www.producenews.com/component/content/article/9-news-section/story-cat/14431-phase-two-of-red-sun-farms-virginia-greenhouse-to-be-under-way-soon

Trade: We are collecting information to construct trade networks. The Food and Agricultural Organization (FAO) provides yearly data at the country level; tomato production for each country, and import and export estimates for country pairs (FAO stat, 2016). For the U.S., ERS and NASS provide production data at the county level. To construct county level trade network for the US, we are exploring various datasets (Metroinvasive, 2016).

Activities of subawardees

As far as the subawardees are concerned, due to administrative processing, the project work is yet to start. Here, we briefly provide a plan for this phase by BIOPASS, Senegal.

BIOPASS, Senegal activity plan

We will start our activities with two master's students. The first study (from May to October) will evaluate the impact of high temperatures on *Tuta absoluta* and its major natural enemy in Senegal, *Nesidiocoris tenuis*, and the impact of such temperatures on its ability of predation. We also have an undergraduate student, Bryan Kaperick, who is working towards a B.S. in Applied Computational Mathematics at the Virginia Tech honors college working with us. The objectives are to (i) establish life tables of Senegalese strains of *T. absoluta*, and to (ii) assess predation capacity of *N. tenuis*, e.g. under high temperatures and low relative humidity as experienced in Senegal during the dry season. The second study will assess the population dynamics of *Tuta absoluta* adults during the rainy season (from April to October). Field monitoring in the most infested area (Niayes) showed that *Tuta absoluta* populations decrease dramatically during this period. The objective is to identify factors that may explain this pattern (climate, resource availability, natural enemies, etc.), and particularly to identify host plants on which *T. absoluta* populations can persist. Results will give us insights on factors shaping *T. absoluta* invasion and persistence in unstable tropical agro-ecosystems. We also plan to conduct a survey to collect information on tomato trade in Senegal, and on agricultural practices (particularly insecticide use) in the Vallée du Fleuve area, where hectares of tomatoes are planted for processing industries.

Achievements

1. Presentations and Publications: None. Abhijin Adiga attended the symposium titled "Emerging plant disease and global food security symposium", hosted at North Carolina State University in Raleigh, NC. There were several talks related to modeling plant diseases, which provided information on the current status of models and data sources. This opportunity was also used to meet several staff members of USDA APHIS and NSF CIPM who work in the area of plant disease modeling.
2. Project Meetings: Until now, the team has had four meetings. We have discussed in detail each team member's plan for the project, current status of pest progress in their respective geographic locations, possible venues for interaction, etc.

5. Project Title- Biological Control of the Invasive Weed *Parthenium hysterophorus* in East Africa

Principal Investigator: Wondi Mersie, Virginia State University (VSU)

Collaborating Institutions: Virginia Tech, AGRA, Haramaya University, Ambo Univeristy, Ethiopian Institute of Agricultural Research, Amhara Regional Agricultural Research Institute, Nation Agricultural Research Organization – Uganda, CABI Africa, Kenya Agricultural and Livestock Research Organization, Tanzanian Ministry of Agriculture, Food Security, and Cooperatives, ARC-Plant Protection Research Institute, Sokoine University of Agriculture, Hebrew University of Jerusalem

Collaborating Scientists: Million Abebe, Maria Elisa Christie, Samuel Assefa, Eshetu Bekele, Lisanework Nigatu Gebreyes, Mulugeta Negeri Tulu, Kassahun Zewdie, Agajie Tesfaye, Birru Yitaferu Woldetsadik, Richard Molo, Arne Witt, Muo Kasina, Beatrice Pallangyo, Lorraine Strathie

Description

Parthenium **(***Parthenium hysterophorus* L.), a native plant of tropical and sub-tropical South and North America, adversely affects food security, biodiversity, and the health of both humans and livestock in eastern Africa. In eastern Africa, Parthenium reduces the yield of many major crops such as sorghum and corn, competes with preferred pasture species, and, when consumed by domestic animals, taints their milk and meat, thereby reducing their value. It also causes human health problems such as severe contact dermatitis and respiratory problems. In addition, because of its ability to release toxic chemicals, Parthenium can replace natural vegetation, thus adversely affecting plant biodiversity. Despite its aggressiveness, Parthenium is successfully managed in Australia and India using biological agents such as insects, pathogens, and competitive smother plant species. South Africa has also released bio-control agents against Parthenium. The goal of this proposal is to build on the accomplishments of the two previous USAID-IPM IL-funded Parthenium projects to abate the spread and impact of the weed in east Africa. Specific objectives of the project are to:

(i) scale-up the rearing and release of the two approved bio-control agents, the leaf-feeding beetle *Zygogramma bicolorata* and the stem-boring weevil *Listronotus setosipennis* in Parthenium infested areas of Ethiopia;

(ii) evaluate the establishment and impact of these released agents on Parthenium, crops, and biodiversity;

(iii) evaluate new Parthenium bio-control agents for their safety to non-target plant species under quarantine and, if specific to the weed, seek a permit for their release;

(iv) scale-up the release and monitoring of *Zygogramma bicolorata* in Tanzania, obtain the necessary permits for field release of Zygogramma in Kenya and Uganda, and release Listronotus and other natural enemies (evaluated in Ethiopia) in Kenya, Tanzania, and Uganda.

Under the first objective, the plan includes establishing mass-rearing facilities throughout Parthenium infested regions of east Africa to increase the availability of approved bioagents. The lead institution for this proposed project in the U.S.A. is Virginia State University (VSU). Dr. Wondi Mersie, a weed scientist at VSU, is the principal investigator. A total of 15 scientists from

six countries including South Africa will collaborate in implementing the project. This team is composed of entomologists (6), weed scientists (2), a crop protection specialist, a pathologist, a nematologist, an agricultural economist, a plant ecologist, a land use management specialist, and a gender specialist from Virginia Tech, U.S.A.

ETHIOPIA: Submitted by Million Abebe (VSU-Ethiopia), Teshale Daba (EIAR), Wondi Mersie (VSU) and Lisanework Nigatu (HU)

Ambo University (AU)

Mr. Tesfaye Amare, a faculty member, and Mr. Fula`a Galana, a research staff member from AU, were trained in rearing and culturing bioagents at Wollenchiti. After receiving training, they have started to make the necessary preparations to receive bioagents approved for release, the leaf-feeding beetle, *Zygogramma bicolorata*, and the stem-boring weevil, *Listronotus bicolorata*, at Guder (AU branch campus where College of Agriculture is located). The Parthenium Project has provided AU with mesh, wooden poles, supplies and funds to erect two walk-in cages. Benches have been installed in the cages, along with a nursery to grow Parthenium for the bioagents that have been established. Small cages to rear Listronotus have also been given to AU. Graduate students from AU will also be recruited to conduct research on the survival of the two bioagents at different soil moisture levels and their performance after release. The students will be supported by the project while conducting their thesis research. The recruiting process has started and at least two students will be identified by this summer.

Amhara Regional Agricultural Research Institute (ARARI) at Sirinka/Kobo

A research staff member, Mr. Alebel Eskzia from Sirinka Agricultural Research Center (SARC) of ARARI, was trained in growing Parthenium and rearing the leaf-feeding beetle (*Zygogramma bicolorata*) at Wollenchiti rearing site in Central Ethiopia. A total of 200 Zygogramma adults were taken to Sirinka Center and kept within a small breeding cage provided from Wollinchiti. The trainee was accompanied by the Parthenium project coordinator in Ethiopia while the starter colony of Zygogramma was taken to Sirinka. Later the center was provided with two large breeding cages (5 x 7 m) and three smaller breeding cages (0.5 x 0.5 x 1.9 m), 25 pots, counters, dissecting kit, gloves, mouth and head cover. The culture was moved later to Kobo about 25 km away from Sirinka where there is irrigation set up needed to grow Parthenium. There are now about 1200 adults at Sirinika and Kobo. A female contract worker has been employed to handle the transplanting of *Parthenium* and rearing of Zygogramma. There is a plan to hire an additional worker to assist in the rearing.

Ethiopian Institute of Agricultural Research (EIAR) –Ambo Plant Protection Research Center (APPRC)

The quarantine facility at APPRC has been upgraded in the anticipation of receiving a new bioagent, the seed-feeding weevil (*Smicronyx lutulentus*), for host-range evaluation. The upgrade included installing air conditioner units, sealing of the greenhouse, repairing all the breeding cages, installing shelves for pupation boxes and improving the lighting of the facility. Materials were also provided to the Center, including safety supplies and items for sealing the cages and the facility to prevent escape of the weevil. All the breeding cages were also repaired.

Ms. Lorraine Strathie from ARC-PPRI South Africa reared and delivered a starter culture of 1800 *Smicronyx lutulentus* adults to the Ambo quarantine facility on December 13, 2015. Ms. Strathie also gave hands-on training on techniques of culturing Smicronyx to staff from EIAR and ARARI on December 13 and 20, 2015. Staff has also received documents that explain the biology and the culturing of this weevil.

Staff at Ambo quarantine facility have faced several challenges in rearing Smicronyx since its introduction. The culturing and handling techniques of this bioagent are very different from that of Zygogramma and Listronotus, and staff had to learn many new procedures. In addition, Smicronyx requires different set-up and environmental control, and it is prone to escape from cages because of its small size. No adult has emerged so far from pupation boxes. The lack of adult emergence from pupae has caused a precipitous decline in its population. Currently, the cause of this decline is being investigated to determine a course of action for the future.

The quarantine facility at APPRC also houses the two bioagents that are approved for release, *Zygogramma bicolorata* and *Listronotus setosipennis*. Cultures of Zygogramma and Listronotus are maintained in separate sections of the quarantine facility. Adults of these bioagents are periodically transferred to rearing sites for release. Currently, there are 700 and 900 adults of Zygogramma and Listronotus, respectively.

Haramaya University (HU)

A bioagent rearing facility has been established on the campus of Haramaya University. The University contributed 5000 USD towards the establishment of the walk-in cages and benches and to the purchase of supplies for culturing Zygogramma. A nursery to raise Parthenium was prepared to grow the weed from seed to feed the bioagents. Zygogramma has been reared successfully and there are now 3255 adults at the site. There is a plan to release this bioagent in the campus of HU in June 2016. The establishment and impact of these released agents will be evaluated following the release. A graduate student, Ms. Belaynesh Assema from HU has been recruited to work on gender issues under the direction of Dr. Maria Christie at Virginia Tech. The title of her thesis research is: *Gauging women's interest in and ability to participate in the adoption of bio-control agents for control of Parthenium.*

Lessons Learned

Quality Parthenium stock is critical for mass rearing of Zygogramma and Listronotus. So, there is a need to improve plant growth conditions (light, temperature) at the Wollenchiti mass-rearing facility. Similarly, the environmental conditions inside the quarantine facility and in the adjacent nursery need to be controlled better to achieve the desired quality and quantity of Parthenium for the bioagents. There is also a need to collect as much Parthenium seed as possible every year. Staff have found that the germination of freshly collected Parthenium seed is very poor compared to seeds stored for a year.

Presentations and Publications

The International Parthenium Workshop on Biological Control and Management of *Parthenium hysterophorus* in East Africa was held at the Samrat Hotel in Dire Dawa. About 26 participants

from six countries (USA, Ethiopia, South Africa, Kenya, Uganda, Tanzania, and Israel) attended Day 1 of the workshop. Presentations were given by dignitaries from Virginia Tech, IPM Innovation Lab, Haramaya University, and Oromia Agricultural Bureau (OAB), followed by oral presentations on the social and economic impacts of Parthenium and on the distribution and management of Parthenium in Ethiopia, Israel, Kenya, Tanzania, and South Africa.

The following oral presentations were made by participants from ARARI, HU, OAB, Virginia Tech and VSU:

- Abebe, M. 2015. Mass rearing of the biological control agent, *Zygogramma bicolorata* in Ethiopia. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Assefa, S. 2015. Parthenium distribution and socio economic impacts in Oromia. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Christie, E. 2015. Gender perspectives in the implementation of the Parthenium Project in East Africa. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Mersie, W. 2015. Biological control of the invasive weed *Parthenium hysterophorus* in East Africa. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Mersie, W. 2015. Scaling-up the rearing and release of *Zygogramma bicolorata* and *Listronotus setosipennis* in *Parthenium*-infested areas of Ethiopia and Tanzania. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Muniappan, R. 2015. OIRED Overview. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Nigatu, L. 2015. The Impact of *Parthenium* on the Life of the Ethiopian Farmers. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Yitaferu, B. 2015. Brief overview of the Amhara National Regional State and the Amhara Agricultural Research Institute. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.

CABI, KENYA, TANZANIA, UGANDA: submitted by Arne Witt (Principal Investigator – CABI)

Achievements

There was a delay in the signing of the subaward agreement between Virginia Tech and CABI, which delayed the onset of project activities. Agreements between the partner organizations and CABI have been reviewed and should be signed within the next few weeks. Despite delays, activities have commenced in some countries regardless of the lack of any formal agreements.

Three students have been identified in Tanzania, and project titles have been agreed upon. Initial discussions have been held with regards to the importation and mass rearing of biocontrol agents. Applications for the renewal of import permits for *Zygogramma bicolorata* have been submitted. In Uganda, discussions are underway to acquire additional funds to undertake host range testing of *Z. bicolorata*. With the establishment of a National Invasive Species Coordination Unit, there is increased impetus to manage invasive species such as Parthenium.

Capacity Building

The Project Initiation Workshop, which was held in Dire Dawa, Ethiopia, in December 2015, contributed to raising awareness of the threats posed by Parthenium and the costs and benefits of biological control. Issues related to gender and the impacts and management of Parthenium were also highlighted. The workshop included training on aspects related to reporting and general rules and regulations pertaining to USAID-funded projects

Lessons Learned

It is still too early in the Project to highlight any issues related to 'lessons learned'; it is sufficient to say, at this point, that the extent of the Parthenium infestations in East Africa makes biocontrol a critical component of a regional integrated management strategy.

Presentations and Publications

Project participants gave three presentations at the Project Initiation Workshop in Ethiopia. Muo Kasina from KALRO gave a presentation on the current status of Parthenium in Kenya. Samora Macrice from Sokoine University of Agriculture gave a similar presentation on the situation pertaining to Parthenium in Tanzania while Arne Witt from CABI gave a presentation on "Opportunities and Challenges for Classical Biological Control."

SOUTH AFRICA: submitted by Lorraine Strathie (Principal Investigator – ARC-PPRI)

Achievements

Capacity Building

A culture is being established for assessment of its host specificity and suitability for release in Ethiopia. Additionally, a supplementary culture of 1200 *Listronotus setosipennis* adults was supplied by ARC-PPRI to increase the small cultures at EIAR Ambo and the mass-rearing facility at Wollenchiti for mass-rearing for release. The necessary phytosanitary certificate for importation of the agents into quarantine in Ethiopia was obtained by ARC-PPRI from the South African Department of Agriculture, Forestry and Fisheries, prior to departure. The agents were hand-carried by L. Strathie to Ethiopia on December 12, 2015.

East African project partners were trained on biological control agents for *Parthenium hysterophorus* through direct practical training by L. Strathie from ARC-PPRI, as well as through presentations and discussions at the International Workshop on Biological Control of

Parthenium hysterophorus in East Africa, held from December 17-18, 2015 at Dire Dawa, Ethiopia. Presentations on *Zygogramma bicolorata*, *Listronotus setosipennis* and *Smicronyx lutulentus* by L. Strathie during the International Workshop informed project participants on the agents and their host range and field establishment. The experiences obtained from discussions and visits to mass-rearing facilities in Ethiopia benefitted all project partners.

Research staff (researchers, technicians, assistants) from the Ethiopian Institute of Agricultural Research and Amhara Regional Agricultural Research Institute were provided hands-on training by L. Strathie from ARC-PPRI on the biology and culturing techniques of the seed-feeding weevil *Smicronyx lutulentus* on December 13 and 20, 2015 at the EIAR quarantine facility at Ambo. The technical requirements in terms of facilities and equipment for rearing of *S. lutulentus* were provided to the project coordinator and EIAR researchers by L. Strathie. Visual materials and relevant literature on Parthenium agents, particularly on *S. lutulentus*, were also provided to EIAR researchers.

IPM IL Parthenium project funding to ARC-PPRI, together with funding from the South African Department of Environmental Affairs Natural Resources Management Programs, has supported the contract employment of Miss Ethel Xolile Magoso as a Junior Research Technician at ARC-PPRI from February 15, 2016 for a two year period. In January 2016, Ms. Magoso completed requirements for her National Agricultural Diploma after an in-service training year at ARC-PPRI during 2015. Her employment will enable her to register for a B Tech Diploma during 2016 or 2017. Ms. Magoso assists with technical support to the Parthenium biocontrol research project, including mass-rearing of biocontrol agents, some of which are supplied to East Africa for the IPM IL Parthenium project. Ms. Magoso also assists with training activities such as Farmers Days (of which three events were held in Northern KwaZulu-Natal province of South Africa from January 19-21, 2016, to train about 157 small-scale farmers on Parthenium and biological control). Ms. Magoso has also received further training on Parthenium and weed biocontrol research activities during her recent employment at ARC-PPRI Cedara.

Notice of the forthcoming short course on Weed Biological Control at Rhodes University in South Africa from August 29 to September 2, 2016 was circulated during March to project partners. An invitation to visit ARC-PPRI Cedara research station and receive practical training on Parthenium biocontrol agents was extended to project partners.

Lessons Learned

Experiences from mass-rearing of Parthenium biocontrol agents (*Zygogramma bicolorata* and *Listronotus setosipennis*) in South Africa and Ethiopia were shared through discussions and presentations by project partners during the International Workshop, beforehand, and during visits to mass-rearing facilities (Ambo, Wollenchiti, Haramaya University) in Ethiopia. Improvements to rearing of plants and insect agents were discussed.

Information on the biology, rearing techniques and briefly, the host range, of the seed-feeding weevil *Smicronyx lutulentus* was transferred from ARC-PPRI to researchers from EIAR Institute of Agricultural Research and Amhara Agricultural Research Institute, through practical training at the quarantine facility at EIAR Ambo.

Though presentations and discussion it was evident that there are difficulties experienced in obtaining permission to import weed biocontrol agents into some countries e.g. Israel, Kenya. Differing protocols for importation of biocontrol agents exist in different countries e.g. Tanzania has a more streamlined application and approval process than Kenya, and some countries lack legislation for such activities.

Improved understanding of the extent and impacts of Parthenium in Africa was obtained through presentations and discussions at the workshop and during engagements before and afterwards. New knowledge of the extent of Parthenium in Israel was obtained through visiting participants to the workshop.

Discussions around management practices, in particular biological control, before and during the workshop in Ethiopia, will assist to improve the management of this invasive alien plant in Africa.

Presentations and Publications

Oral Presentations:

- Strathie, L. 2015. Weed biocontrol quarantine facility at Ethiopian Institute of Agricultural Research PPRC at Ambo. Meeting of project partners prior to the International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Addis Ababa, Ethiopia, 13 December 2015.
- Strathie, L. 2015. Establishment of *Zygogramma bicolorata* and *Listronotus setosipennis* on *Parthenium hysterophorus* in South Africa and beyond. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Dire Dawa, Ethiopia, 17-18 December 2015.
- Strathie, L. 2015. *Smicronyx lutulentus*: A new agent in South Africa and recent importation into Ethiopia. International Workshop on Biological Control of *Parthenium hysterophorus* in East Africa. Dire Dawa, Ethiopia, 17-18 December 2015.

Semi-scientific/Popular publications:

- Strathie, L. 2016. South Africa collaborates in an international project to manage *Parthenium hysterophorus* in East Africa using biological control. *Plant Protection News* 106, in press.

Institutional Development

Collaboration between project partners from East and South Africa through the IPM IL Parthenium project is improving the understanding and management of the invasive Parthenium in Africa, particularly pertaining to the use of biological control. Institutional and national capacity is being developed by facilitating interactions at an international level through events such as workshops and training and by supporting research and implementation activities in East Africa.

During this reporting period, biological control research and implementation capacity was developed through training interactions between ARC-PPRI and EIAR and ARARI researchers, and the coordinators at the mass-rearing facility at Wollenchiti and Haramaya University. It was

also developed through interactions with project partners from Kenya, Tanzania and visiting participants from Israel.

EIAR and ARARI research capacity was developed through training (on agent rearing and biology) by ARC-PPRI on a new biocontrol agent *Smicronyx lutulentus*.

Biological control of Parthenium capacity in Israel was developed through participation of invited participants and technology transfer through presentations and discussions with them.

Improved knowledge of mass-rearing of Parthenium biocontrol agents in South Africa and Ethiopia is being developed through the IPM IL Parthenium project through sharing of experiences during interactions at the project workshop and visits to facilities.

Technology Transfer and Scaling Partnerships

Steps Taken

L. Strathie from ARC-PPRI travelled to Ethiopia to train East African project partners in December 2015. Ethiopian researchers from EIAR and ARARI received 1-2 days of training on *Smicronyx lutulentus*.

Literature and visual materials on *Smicronyx lutulentus* were prepared by L. Strathie and provided to EIAR researchers.

Training of relevant East African researchers in South Africa (weed biological control short course at Rhodes University; practical training on Parthenium biocontrol at ARC-PPRI) was recommended for future consideration, if funds permit.

Rearing guidelines for *Smicronyx lutulentus* are being compiled by ARC-PPRI for dissemination to project partners.

Preliminary arrangements have been made with CABI Africa who have requested that *Z. bicolorata* be supplied by ARC-PPRI to Tanzania in mid-2016 for initial mass-rearing efforts there.

Partnerships

Through face-to-face discussions in Ethiopia during December 2015, researchers from ARC-PPRI, EIAR, ARARI, Haramaya University, Virginia State University – Ethiopia, CABI Africa; KALRO; Sokoine University of Agriculture; and The Hebrew University of Jerusalem formed new connections or continued previous connections for dissemination of technology. These interactions benefitted all project partners.

Technologies Transferred

ARC-PPRI trained EIAR and ARARI researchers on protocols for introduction of new material into quarantine, rearing techniques and the biology and aspects of host-range testing of *Smicronyx lutulentus*.

Aspects of pre-release and post-release research and field implementation activities on *Z. bicolorata* and *L. setosipennis* were discussed in Ethiopia from December 13-20, 2015 during

visits to mass-rearing and research facilities and during the International Workshop on Parthenium biocontrol.

Technologies Scaled

Improvements to mass-rearing techniques for *Zygogramma bicolorata* and *Listronotus setosipennis* in Ethiopia (also relevant to other East African countries) were discussed during visits to mass-rearing facilities from December 13 to 20, 2015. Future efforts could focus on quantifying the most efficient rearing systems for the greatest production outputs in mass-rearing facilities.

Recommendations were made by L. Strathie for improved Parthenium plant production and insect agent production at research and mass-rearing facilities in Ethiopia, during discussions with researchers and in the trip report.

Technologies Ready to be Scaled

More extensive mass-rearing of *L. setosipennis* in Ethiopia would be advantageous in view of its ready establishment in areas with erratic or low rainfall. Although labor intensive to rear in large number, the weevil is hardy and fairly tolerant of dry conditions, although it spreads slowly, requiring limited site disturbance for its establishment. Mass-rearing of *Z. bicolorata* is better suited for release of the beetle in areas with reliable, higher rainfall.

Technologies on the laboratory rearing for research purposes, host-specificity testing, and mass-rearing of biocontrol agents are ready to be used in other East African countries that are able to adopt such practices, provided they have the appropriate authorization for import and/or release.

II. Human and Institutional Capacity Development

a. Short-term training

Innovative Scientific Research and Technology Transfer to Develop and Implement Integrated Pest Management Strategies for Vegetable and Mango Pests in Asia:

Type	Location	Date	Number Female Participants	Number Male Participants	Total Participants	Home Institution (if applicable)	Training Institution
Virus Workshop	Nepal	March	9	31	40	NARC	NARC

Biological Control of the Invasive Weed *Parthenium hysterophorus* in East Africa:

Type	Location	Date	Number Female Part-icipants	Number Male Part-icipants	Total Participants	Home Institution (if applicable)	Training Institution
1-day training (Quarantine processing and handling of weed biocontrol materials after importation, Parthenium biocontrol agents, and equipment and culturing techniques for *Smicronyx lutulentus*)	Ethiopian Institute of Agricultural Research (EIAR), Biocontrol quarantine facility at Ambo, Ethiopia	13/12/2015	1	4	1 trainer + 5 trainees (research staff from EIAR PPRC Ambo and Amhara Agricultural Research Institute (Kobo & Sirinka))	EIAR Plant Protection Research Centre, Ambo	ARC-PPRI South Africa (funded by Virginia Tech IPM Innovation Lab)
Meeting (Introduction to the IPM Innovation Lab, IPM IL Parthenium project, and weed biocontrol and quarantine procedures, and EIAR PPRC Ambo quarantine facility)	Nexus Hotel, Addis Ababa, Ethiopia	14/12/2015	3	11	14 (Researchers from USA, Ethiopia, Kenya, Tanzania, Israel, and IPM IL management entity)	Meeting run by Virginia Tech IPM Innovation Lab and Virginia State University	Virginia Tech IPM Innovation Lab; Virginia State University; ARC-PPRI South Africa
Field day (View commercial rose enterprise near Debre Zeit and activities at the IPM IL Parthenium biocontrol mass-rearing facility at Wollenchiti)	Minaye Flower Centre at Debre Zeit, Ethiopia, and Parthenium biocontrol mass-rearing facility at	15/12/2015	3	15	~18 (Researchers from USA, Ethiopia, Kenya, Tanzania, Israel, South Africa, and IPM IL	Virginia Tech IPM Innovation Lab and Virginia State University	Minaye Flower Centre; IPM Innovation Lab's Wollenchiti mass-rearing facility

	Wollenchiti near Adama				management entity)		
International workshop on biological control of *Parthenium hysterophorus* in East Africa	Samrat Hotel, Dire Dawa, Ethiopia	18 & 19 /12/2015	5	~21	~ 26 (Researchers from USA, Ethiopia, Kenya, Tanzania, Israel, South Africa, and IPM IL management entity)	Virginia Tech IPM Innovation Lab, Virginia State University, and Haramaya University	Virginia Tech IPM Innovation Lab and Virginia State University; project partners from South Africa, Ethiopia, Kenya and Tanzania, and Israel
1-day training (Biology, culturing and basic host-specificity testing techniques for *Smicronyx lutulentus*)	EIAR Biocontrol quarantine facility at Ambo, Ethiopia	20/12/2015	2	3	1 trainer + 5 trainees (research staff from EIAR Ambo)	EIAR Plant Protection Research Centre - Ambo	ARC-PPRI South Africa (funded by Virginia Tech IPM Innovation Lab)

Participatory Biodiversity and Climate Change Assessment for Integrated Pest Management in the Annapurna-Chitwan Landscape, Nepal

Type	Location	Date	Number Female Participants	Number Male Participants	Total Participants	Home Institution (if applicable)	Training Institution
Effective use of Microsoft word, excel, power point and Remote sensing	CDB, TU Kirtipur Kathmandu	28 -31 March, 2016	9	14	23	CDB, TU	Dr. Tarendra City College—CUNY, New York, NY, USA
Orientation Training	Gaidakot Nawalparasi	7 April, 2016	22	1	23		AFU and ECOSCENTRE, Bharatpur-2, Kshetrapur, Chitwan, Nepal
	Fulbari Chitwan	8 April, 2016	19	6	11		AFU and ECOSCENTRE, Bharatpur-2, Kshetrapur, Chitwan, Nepal

b. Long-term training

Strengthening production and export of Vietnamese fruit crops through innovative and market-orientated IPM:

Name	Gender	Home Institution	Training Institution	Degree	Major	Start Date (month/year)	Graduation Date (month/year)	Home Country
Ms. Dang, Thi Kim Uyen	Female	Southern Horticultural Research Institute	Can Tho University	PhD	Plant Protection	11/2015	11/2020	Vietnam

List of Undergraduate Students in Plant Entomology Lab:

Sr. No.	Name	Time	Name of university/college	Title	Supervisor
1	Trinh, Phuoc Loi	3-9/2016	Nong Lam university	Study on entopathogenic fungi against longan fruit borer	Tran, Thi My Hanh
2	Dao, Luu Hau	3-9/2016		Study on fruit bagging to control longan fruit borer	
3	Vu, Thi Thanh Tuyen	12/2015-3/2016		Study on entopathogenic fungi and plant extracts against dragon fruit stink bug *Nezara viridula* L. (Hemiptera: Pentatomidae)	
4	Nguyen Thi Kim Thoa	12/2015-3/2016	Southern Agriculture College	Study on entopathogenic fungi against longan stink bug *Tessaratoma* sp.	
5	Nguyen Anh Thu	12/2015-3/2016		Study on entopathogenic fungi against mealybug	
6	Nguyen Hoang Nam	12/2015-3/2016	Nong Lam university	Study on light trap to attractive/go repel longan fruit borer	Tran Thi My Hanh
7	Truong, Thanh Tay	4 – 8/2016		Entomopathogenic nematodes to control fruit borers	Huynh, Thanh Loc
8	Le, Cong Tao	4 – 8/2016			Huynh, Thanh Loc
9	Tran, Quoc Thang	4 – 8/2016			Huynh, Thanh Loc

Innovative Scientific Research and Technology Transfer to Develop and Implement Integrated Pest Management Strategies for Vegetable and Mango Pests in Asia:

Name	Gender	Home Institution	Training Institution	Degree	Major	Start Date (month/year)	Graduation Date (month/year)	Home Country
Farhanaz Sharma	Female		Virginia Tech	PhD	Economics	January 1, 2016 (on this project)	Expected: July 2017	Bangladesh
Arjun Khanel	Male	Tribbuvan University	Tribbuvan University & Virginia Tech	PhD	Economics	January 1, 2016 (on this project)	July 2018	Nepal
Sadique Rahman	Male	Bangladesh Agricultural University	Bangladesh Agricultural University	PhD	Economics	January 1, 2016 (on this project)	December 2017	Bangladesh

			& Virginia Tech					

Biological Control of the Invasive Weed *Parthenium hysterophorus* in East Africa:

Name	Gender	Home Institution	Training Institution	Degree	Major	Start Date (month/year)	Graduation Date (month/year)	Home Country
Belaynesh Assema	Female	HU	HU	M.S.	Sociology	June 1, 2016	May 30, 2018	Ethiopia