FEED THE FUTURE

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

2020 Feed the Future Innovation Lab for Integrated Pest Management Semi-Annual Report

Center for International Research, Education, and Development

Outreach and International Affairs | Virginia Tech

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USAID FROM THE AMERICAN PEOPLE

VIRGINIA TECH

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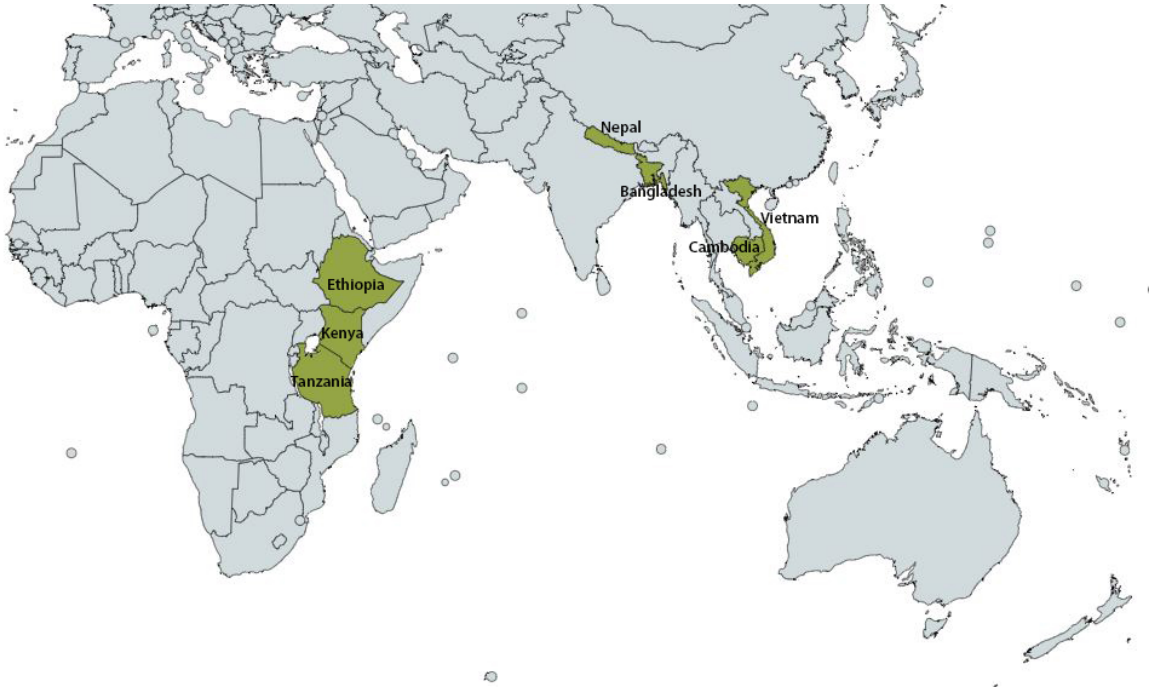
WHERE WE WORK



PROGRAM PARTNERS

U.S. Partners

Louisiana State University, New York State Agricultural Experiment Station, Ohio State University, Pennsylvania State University, University of California – Davis, Virginia State University, Virginia Tech, Washington State University, University of Virginia, North Carolina State University.

U.S. Governmental Agencies

USAID, U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS), Animal and Plant Health Inspection Service (APHIS)

International Agricultural Research Centers

French National Institute for Agricultural Research, French Agricultural Research Centre for International Development (CIRAD), International Centre of Insect Physiology and Ecology (ICIPE), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Institute of Tropical Agriculture (IITA), International Rice Research Institute (IRRI), International Development Enterprises (iDE).

ACRONYMS

BARI	Bangladesh Agricultural Research Institute
Bt	*Bacillus thuringiensis*
CARDI	Cambodian Agricultural Research and Development Institute
CEDAC	Cambodian Center for Study and Development in Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Agricultural Research for Development
FAW	Fall Armyworm
EPIC	Ecologically Based Participatory IPM Package for Rice in Cambodia
iDE	International Development Enterprises
icipe	International Center for Insect Physiology and Ecology
IITA	International Institute for Tropical Agriculture
INRA	French National Institute for Agricultural Research
IPM IL	Integrated Pest Management Innovation Lab
IRRI	International Rice Research Institute
KAVES	Kenya Agricultural Value Chain Enterprises
KALRO	Kenya Agricultural and Livestock Research Organization
NARC	Nepal Agricultural Research Council
NGO	Non-governmental Organization
PERSUAP	Pesticide Evaluation Report and Safe Use Action Plan
RUA	Royal University of Agriculture, Cambodia
SOFRI	Southern Horticultural Research Institute, Vietnam
SUA	Sokoine University of Agriculture, Tanzania
TAC	Technical Advisory Committee
USAID	United States Agency for International Development
VT	Virginia Tech

EXECUTIVE SUMMARY

The IPM Innovation Lab (IPM IL) participated in the World Food Day in Des Moines, Iowa on October 16, 2019 and hosted a table with exhibits. The team participated in the publication of the GAP report, a comprehensive report launched by Virginia Tech that focuses on global food security breakthroughs. In November 2019, IPM IL organized four symposia at the International Plant Protection Congress in Hyderabad, India. The topics of the symposia included Fall Armyworm, *Tuta absoluta*, Remote Sensing and Machine Learning for Determination of Spatio-Temporal Distribution of Invasive Species, and Ecologically-Based IPM for Cereal Crops. In addition, IPM IL also participated in the symposia on Biological Control and Conflicts in Biological Control of Cacti. Attending this congress were six IPM IL participants from Nepal, three from Bangladesh, three from Cambodia, and one from Ethiopia. Also, in November, IPM IL organized a symposium on Fall Armyworm for the Annual Meeting of the Entomological Society of America in St. Louis, Mo.

In January 2020, the inception meeting for the Nepal Mission Associate Award was conducted in Kathmandu. Sub-awards to iDE and NARC were executed. A visit to the USAID mission in Bangladesh was made for discussion on Fall Armyworm management. U.S. scientists from the IPM for Vegetables and Mango in Asia project visited Bangladesh, Cambodia, and Nepal for their annual review and planning meeting with host country partners. In March, IPM IL Director Muni Muniappan visited Tamil Nadu Agricultural University and participated in the International Symposium on Transboundary Pests. In March 2020, a planned trip to Nepal by the Management Entity team was cancelled due to the COVID-19 pandemic. Field activities in all the host countries have come to a standstill due to stay-at-home orders from their governments. A detailed report on the impact of COVID-19 on the program has been prepared and submitted to the AOR.

The natural enemies of *Parthenium hysterophorus* – *Zygogramma bicolorata* in Arba Minch, Ethiopia, and *Listronotus setosipennis* in Mojo and Wollo, Ethiopia – have field established. *Zygogramma bicolorata* has also field established in Kampala and Kiryondongo, Uganda. In Vietnam, IPM packages for mango, dragon fruit, longan and lychee have been developed and their dissemination to farmers is being scaled up. The fall armyworm egg parasitoids *Trichogramma chilonis*, *Trichogramma mwanzai,* and *Telenomus remus* are being mass-reared at the National Biological Control Program in Kibaha, Tanzania. When reared in the laboratory, *Trichogramma mwanzai* gave 70% parasitism of fall armyworm eggs. The efficacy of push-pull technology in controlling FAW needs to be further assessed and scrutinized.

Agricultural input dealers (agrovets) in the villages play a major role in advising farmers and supplying inputs needed in the fields. They are akin to frontline advisors to the farmers in developing countries. However, they lack formal agricultural education and are mostly self-educated based on job experience and information received from whole-sale pesticide and fertilizer distributors. Often, they misidentify crop problems and sell the wrong pesticide or input. Most government and NGO agencies involved in technology transfer have not recognized the importance of educating this group on pest and disease management. Recognizing the importance, the IPM Innovation Lab will be giving special emphasis to educate this group.

In Nepal, distribution maps of seven invasive plant species were developed using Landsat and

worldview images, and the increases/decreases in area of their coverage from 1990 was determined. Six invasive plant species showed an increase in coverage, revealing invasion in new areas, whereas *Ipomea carnea* ssp. *fistulosa* coverage decreased by 70%. Invasion was mostly from southwest to northern and eastern parts of CHAL. There was a 168% increase in area of *Lantana camara,* 234% of *Chromolaena odorata*, 309% of *Parthenium hysterophorus*, 425% of *Ageratina adenophora*, 450% of *Eichhornea crassipes,* and 831% of *Mikania micrantha* in CHAL area from 1990 to 2018. Based on the work done in Nepal on modeling the spread of *Tuta absoluta*, a proposal submitted to USDA for predictive modeling of its spread in the U.S.A was approved.

In Cambodia, field trials on Anaerobic Soil Disinfestation (ASD) are being conducted for control of soil-borne plant diseases.

MANAGEMENT ENTITY PUBLICATIONS AND PRESENTATIONS

Publications:

Virginia Tech scientist corrects history of biological control. *VT News*. 4-17-20

Pesticides and Post-Harvest: How Fruit Bagging Mitigates Losses, Improves Exports. *Agrilinks*. 4-15-20

Biocontrol of Fall Armyworm: The Chain Reaction that Led to Regional and Cross-Continental Management. *Agrilinks*. 3-19-20

Gender Research in Vietnam: Applications for Both Farmers and Scientists. *Agrilinks.* 3-18-20

Grant to help model potential arrival of invasive species and protect tomato crops. *CBS 19 News*. 3-5-20

Virginia Tech, University of Virginia work to safeguard U.S. tomato industry from invasive pest. *VT News*. 3-2-20

Virginia Tech, USAID partner to promote inclusive agricultural development in Nepal. *VT News*. 2-26-20

Integrating Gender in Agriculture Research Investments. *Agrilinks*. 2-25-20

Cambodian Farmer Implements and Modifies Machinery, Improves Quality of Rice. *Agrilinks*. 2-13-20

Rodents and Rice: Cambodian Farmers Find Safe and Productive Ways to Fight Furry Pests. *Agrilinks*. 2-12-20

Virginia Tech program plants seeds of innovation for Cambodian rice farmers. *VT News*. 2-11-20

A Private Sector Collaboration Keeps Pests at Bay, Partnerships Possible. *Agrilinks*. 2-10-20

Field Notes: Biocontrol of the Fall Armyworm - Long-term Resilience for Small-scale Farmers. *The Chicago Council on Global Affairs*. 2-10-20

UVA, VT receive federal funding to support agriculture industry. *CBS 19 News.* 1-16-20

IPM Program Prepares Farming Communities in Nepal for Impacts of a Changing Climate. *Agrilinks.* 12-18-19

Virginia Tech Taps Text Message Services to Assist Smallholder Farmers. *Agrilinks*. 12-13-19

Presentations:

Muniappan, R. 2019. IPM approaches for developing and developed nations. Annual Meeting of the Entomological Society of America, St. Louis, MO.

Muniappan, R. 2019. Role of IPM Innovation Lab in management of fall armyworm. Annual Meeting of the Entomological Society of America, St. Louis, MO.

Muniappan, R. 2019. Global activities of IPM Innovation lab in management of fall armyworm. XIX International Plant Protection Congress, Hyderabad, India.

Muniappan, R. 2019. Conflict between cactus grown for food and biocontrol of invasive cactus in Africa. XIX International Plant Protection Congress, Hyderabad, India.

Muniappan, R. 2019. Role of IPM Innovation Lab in management of *Tuta absoluta*. XIX International Plant Protection Congress, Hyderabad, India.

Muniappan, R. 2019. Conflicting reports from India on history of biological control. XIX International Plant Protection Congress, Hyderabad, India.

KEY ACCOMPLISHMENTS, SUCCESSES, CHALLENGES, AND FUTURE ACTIVITIES

Accomplishments:

- Receipt of an Associate Award from Nepal Mission.
- Collection and identification of egg parasitoids of FAW in Kenya, Tanzania, and Nepal.
- Mass multiplication of FAW parasitoids in Tanzania and Nepal.
- Scaling up IPM practices in host countries.
- Production and distribution of success stories through Agrilinks and other media outlets.
- Published 13 peer reviewed articles.
- Supported 37 graduate students.
- Conducted five symposia in international conferences.
- Identified weakness in the push-pull technique advocated for FAW.
- Field established natural enemies of the invasive weed, *Parthenium hysterophorus* in Ethiopia and Uganda.
- Development of trap cropping for control of rats in rice fields in Cambodia.

Successes:

- Identification of egg parasitoids of FAW in Kenya, Tanzania and Nepal.
- Field establishment of Parthenium natural enemies *Zygogramma bicolorata* and *Listronotus setosipennis* in Ethiopia and establishment of Z. *bicolorata* in Uganda.
- Secured an Associate Award from Nepal Mission for management of FAW and scaling up adoption of IPM packages for maize, rice, vegetable, and lentil crops.
- Developed a trap cropping system for controlling rats in rice fields in Cambodia.

Challenges:

- Incidence of COVID-19 in March 2020 and the resultant lockdowns resulted in stoppage of all laboratory and field activities in the host countries.

Expected Activities in the 2nd Half of FY 2020:

- Activities dependent upon termination of lockdowns due to COVID-19 and countries returning to normal operating conditions.
- Surveying for the local natural enemies recruited by FAW in Africa and Asia.
- Determination of efficacy of different natural enemies.
- Mass production of selected natural enemies and field releases.
- Scaling up of dissemination of IPM packages developed for different crops.
- Modeling spread of *Tuta absoluta* in Southeast Asia.
- Determination of invasive patterns of exotic weeds in Nepal.

Principal Investigator: George Norton, Virginia Tech

Collaborators:

USA: Megan O'Rourke and Maria Elisa Christie, Virginia Tech; Edwin G. Rajotte and Cristina Rosa, Penn State; Sally Miller, Ohio State; Naidu Rayapati, Washington State
Bangladesh: Yousuf Mian, Shahadath Hossain, M.S Nahar, AKM. Qamruzzaman, and M. Masud, Bangladesh Agricultural Research Institute
Nepal: Luke Colavito, Sulav Paudel, Lalit Sah, Komal Pradhan, and Khadga Gurung, iDE; P. Sharma and B. Mahto, National Agricultural Research Council (NARC); and others at Agricultural and Forestry University; Himalayan College of Agricultural Sciences and Technology (HICAST), the Center for Environmental and Agricultural Policy Research, Extension, and Development (CEAPRED) (Keshab Datta Joshi, Sunil Dhungel), and supporting partners at Plant Protection Directorate/ Department of Agriculture, Agricare Nepal Pvt. Ltd. Nawasamridhi Enterprises, National Agricultural Research Council, and Tripureshwor Kathmandu
Cambodia: Michael Roberts, Seng Kimhian, and An Chanratha, iDE; Ong Socheath, Tho Kim Eang, and others at Royal Agricultural University (RUA).

Project Activities:

Cambodia: Field trials were conducted with 12 cooperating farmers in the villages of Prasat Char, Banteay Srei, Paksneang Thmei, and Korkos Chhrum in the Siem Reap province. The trials consisted of three treatments: an IPM package, farmer practice, and a control. The cultural practices included liming, raised beds, mulching, drip irrigation, and fertilizer application, which

were standardized for all three treatments. The IPM package included healthy seedlings produced using coco-peat, *Trichoderma*, insect proof seedbed net, and field practices including pruning, staking, roguing of virus-affected plants, biological controls including *Bt, B. subitilis, B. bassiana, Trichoderma, Pseudomonas fluorescens*, orange oil, and neem oil, as well as yellow sticky traps and pheromone traps for *Spodoptera spp.* and *Helicoverpa armigera*. The farmer's practice mainly included application of conventional pesticides with no application of any biological control products, no pruning, and no roguing of virus-affected plants. The control had no pesticides nor biological control agents.

Field trials for cucumber IPM packages were completed with 12 cooperating farmers in the villages of Kauh Krabau, Au Kralanh, and Phnom Touch in the Siem Reap province. The packages and the practices were similar to the tomato IPM packages except that with cucumber, only pheromone traps for fruit fly *Bactrocera cucurbitae* was used.

A field trial for Anaerobic Soil Disinfestation (ASD) for tomato was completed with a cooperating farmer in Paksneang Thmei village. The field was infected with a soilborne disease *Ralstonia pseudosolanacearum*. The ASD approach is using carbon sources provided from locally available materials including mung bean, soybean, rice husk or rice branch, and molasses, and in combination with 4-6 weeks of solarization to disinfect the soil.

Four trials were being conducted by students at the Royal University of Agriculture (RUA). However, these trials were forced to stop because the university closed due to the COVID-19 pandemic.

A demonstration of ASD approach for tomato and bitter gourd has been established CESAIN technology park.

Bangladesh: Dissemination of mango bagging with double layer brown paper bag technology for controlling fruit fly, *Bactrocera dorsalis* in high rainfall and hilly areas of Bangladesh – Moulvibazar, Khagrachari and Rangamati Hill districts – has been implemented.

Dissemination of bio-rational IPM against tomato leafminer, *Tuta absoluta*, in the Panchagarh region of Bangladesh has been implemented. Five farmers' fields were selected in Haribhasa union, Panchagarh sadar upazila, Panchagarh district. Two farmer training programs were conducted.

Surveying and monitoring of fall armyworm has been underway in eight locations: Bogura, Comilla, Gazipur, Kishoregonj, Kustia, Manikgonj, Pabna, and Rangpur since December 2019 on maize, tomato, cabbage, cauliflower, and broccoli.

IPM package for white mold disease management of country bean in Bogura region have been implemented. The components of the IPM package were a) Raising seedlings in poly bag; b) Land sub-merged for 25 days to decay sclerotia; c) Tricho-compost; d) Weeding one or two times; e)

Rouging virus infected plants; f) Using sex pheromone to control *Maruca vitrata* and *Helicoverpa armigera*; g) BioNEEM for aphid control; h) Spraying of Tricho-leachate at 15 days intervals; and k) Crop rotation with non-host plants.

White mold disease reduction using the IPM package compared to the control plots was 61.36%.

Nepal: Crop/pest monitoring for *Tuta absoluta* is continuing for tomato and for fall armyworm, *Spodoptera frugiperda* on maize and tomatoes in Banke and Surkhet districts.

On-farm testing of an IPM Package to manage fall armyworm on maize, cabbage, and other crops has been delayed due to the COVID-19 lockdown.

Publications:

Hossain MS, Das AK, Akhter S, Mian MY, Muniappan R. 2019. Management of South American tomato leafminer, *Tuta absoluta* in Bangladesh. Journal of biological control. 33: 132–136.

Hossain MS, Sarkar BC, Hossain MM, Mian MY, O'Rourke ME, Rajotte EG, Muniappan R. 2019. Comparison of biorational management approaches against mango fruit fly (*Bactrocera dorsalis* Hendel) in Bangladesh. Crop Protection. https://doi.org /10.1016/j.croppro.2019.05.001

Hossain MS, Mian MY, Muniappan R. 2019. South American Tomato leafminer, *Tuta absoluta* in Bangladesh: meeting the challenge. IPM IL, Bangladesh site, HRC, BARI, Gazipur-1701.

Hossain MS, Sarker BC, Hossain MM. 2020. Fruit bagging: An effective and eco-friendly approach to protect fruit fly (In Bangla). 2nd Edition. IPM IL, Bangladesh Site Horticulture Research Center, Bangladesh Agricultural Research Institute, Gazipur 13 pp.

Paudel S, Lin P, Foolad MR, Ali JG, Rajotte EG, Felton GW. 2019. Induced plant defenses against herbivory in cultivated and wild tomato. Journal of Chemical Ecology 45: 693–707.

Presentations:

O'Rourke M. Sustainable pest management on farms and the influence of surrounding landscapes. presented at RUA, CE SAIN guest lecture series, February 6, 2020.

Jacobs J, Klass T. What are plant pathogens? presented at iDE CSmart office, December 18, 2019.

Jacobs J, Klass T. Managing soil borne disease with Anaerobic Soil Disinfestation (ASD), presented at Royal University of Agriculture, CE SAIN guest lecture series, December 19, 2019.

Hossain Md. S. Management of South American tomato leafminer, *Tuta absoluta* in Bangladesh, paper presented at XIX International Plant Protection Congress, November 10–14, 2019, Hyderabad, India.
Shamsunnahar M. Occurrence of white mold disease of country bean caused by *Sclerotinia sclerotiorum* (Lib.) de Bary in Bangladesh and its management paper presented at XIX International Plant Protection Congress, November 10–14, 2019, Hyderabad, India.

Afroz M. Differential colonization of *Solanum sisymbriifolium* and tomato by *Ralstonia solanacearum*, poster presented at XIX International Plant Protection Congress, IPPC-2019, November 10–14, 2019, Hyderabad, India

Sah LP, Lamichhaney D, Colavito LA, Norton G, Muniappan R. The Fall armyworm, *Spodoptera frugiferda* (J.E. Smith): Status and management options in Nepal, paper presented at XIX International Plant Protection Congress, November 10–14, 2019.

Sah LP, Colavito LA, Norton G, Muniappan R. Management of the South American tomato leafminer, *Tuta absoluta* on tomato in Nepal, paper presented at XIX International Plant Protection Congress, November 10–14, 2019, Hyderabad, India.

Paudel S, Lin PA, Rajotte EG, Felton GW. Asymmetric response to climate change: Temperature differentially alters herbivore success and host plants' response to herbivory, Annual Meeting of the Entomological Society of America, Nov. 17–20 2019, St Louis, MO.

Principal Investigator: Tadele Tefera, *icipe*, Ethiopia

Collaborators:

Ethiopia: Ethiopia Institute of Agricultural Research (EIAR), Bako Agricultural Research Centre; Debrezeit Agricultural Research Centre, Ministry of Agriculture and Natural Resources (MANR) of Hawassa Regional State Bureau of Agriculture and Natural Resources, Ambo University, Haramaya University, Addis Ababa University and Jimma University.
Kenya: Kenya Agricultural and Livestock Research Organization (KALRO): National Agricultural Research Laboratories (NARL- Nairobi), Nakuru and Naivasha counties Department of Agriculture, Kipkelion East Sub-County, AUSAID/Kenya Agricultural Value Chain Enterprises (KAVES), Kipkelion East Sub-County Agriculture office (Londiani).
Tanzania: Agricultural Research Institute, Dakawa; National Biological Control Programme, Sokoine University of Agriculture, University of Dar es Salaam, and Real IPM.

Project Activities:

Ethiopia

Chickpea: Integrated management of chickpea wilts using two improved varieties – Habru and Arerti – combined with seed dressing using Lamdex has been implemented. The two varieties were planted on raised bed and furrow (farmers' practices). Habru variety, seed dressed and planted on raised bed, showed considerable levels of resistance to wilt diseases and a high acceptance rate by demonstrating farmers. On-farm demonstrations were conducted with over 200 farmers.

Maize: Over 3,000 farmers have demonstrated on-farm push-pull technology in Hawassa, Fenote Selam, Guder and Halaba areas; farmers have benefited from reduction of stem borer damage, increased milk yields, and improved soil fertility.

Kenya

Maize: Over 600 farmers are implementing push-pull technology demonstrations in Bungoma, Nakuru, and Kericho counties to control stem borers. The push-pull plots performed well despite the challenges faced by farmers by fall armyworm and locust plague.

Tanzania

Biological control of the fall armyworm: Mass rearing of egg parasitoids of the fall armyworm, *Trichogramma chilonis, T. mwanzai,* and *Telenomus remus* is established at National Biological Control Program, Kibaha, Tanzania. The egg parasitoids were collected locally and are currently being reared in the lab for field release in Tanzania. Among the egg parasitoids, *Trichogramma mwanzai* is very active, causing high percentage of parasitism in the lab.

Economic burden of fall armyworm and stemborers, and farmer pest control strategies in Northwest Ethiopia

Findings show that fall armyworm significantly damages maize in Ethiopia. Specifically, when the fall armyworm alone occurs in the maize plot, it reduces yield by 10%. The results suggest that the stemborer does not reduce the yield for the production year considered. Farmers reported control strategies were not capable of mitigating the impact of pests compared to plots that used no strategies. Additional work in understanding and tailoring the available solutions suitable to the local production conditions remains crucial.

M&E and women's participation in the project

In terms of reaching households with IPM information in 2019, this project has achieved 84% of its targets, of which 16% were women. About 3,187 farmers (32% women) are directly involved in demonstrating IPM in the 3 project countries; this represents 213% of the project target. These farmers are practicing IPM on 312 hectares, 32% of which are covered by women. IPM maize covers 73% of the total area under IPM in the target countries. About 163 womens' groups are involved in demonstrating IPM technologies. These reports are the cumulative numbers since the inception of the project until March 2019; however, for 2020 these numbers have not yet been updated due to COVID-19.

Publications:

Kassie M, Wossen T, De Groote H, Tefera T, Sevgan S, Balew S. 2020. Economic impacts of fall armyworm and its management strategies: evidence from southern Ethiopia. European Review of Agricultural Economics, 1–29 doi:10.1093/erae/jbz048.

January B, Rwegasira GM, Tefera T. 2020. Impacts of plant spacing and nitrogen fertiliser on incidences and density of spotted and African pink stem borers in Tanzania, International Journal of Pest Management, doi: 10.1080/09670874.2020.1737342.

Tarekegn D, Tefera T, Negeri M, Damtew T, Sori W. 2020. Evaluation of *Beauveria bassiana*, *Metarhizium anisopliae*, and *Bacillus thuringiensis* for the management of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) under laboratory and field conditions. Biocontrol Science and Technology, doi: 10.1080/09583157.2019.1707481.

Tarekegn D, Tefera T, Negeri M, Damtew T. 2020. Effect of *Azadirachta indica* and *Milletia ferruginea* extracts against *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) infestation management in chickpea. Cogent Food and Agriculture. doi: http://dx.doi.org/10.1080/23311932.2020.1712145

Presentations:

Tefera T. Emerging IPM options against the fall armyworm for small holders in Africa. Entomological Society of America Annual Conference 17–20 Nov 2019, St Louis, Missouri, USA

Tefera T. IPM options against the fall armyworm (*Spodoptera frugiperda*) for small holders in Africa. International Plant Protection Conference, 10–14 Nov 2019, Hyderabad, India.

Tefera T. IPM activities in East Africa. IAPPS GB meeting, Hyderabad, Nov 9, 2019.

Tefera T. Rice, Maize & Chickpea IPM for East Africa: An overview of the project in the 3 countries. Annual planning meeting and external evaluation. Sept 27–28 2019, Dar Es Salaam, Tanzania.

Principal Investigator: Pramod Kumar Jha, Tribhuvan University
Co-Principal Investigator: Madhav Marathe, University of Virginia

Project Activities:

This project currently focuses on validation of distribution of invasive species in CHAL developed after several field visits. Distribution maps of seven invasive plant species were developed using Landsat and worldview images, and increase/decrease in area of their coverage from 1990 was determined. Six invasive plant species showed increase in coverage, revealing invasion in new areas, whereas *Ipomea carnea* ssp *fistulosa* coverage was found to have decreased by 70%. Invasion was mostly from southwest to the northern and eastern parts of CHAL. There was a 168% increase in area of *Lantana camara,* 234% of *Chromolaena odorata*, 309% of *Parthenium hysterophorus*, 425% of *Ageratina adenophora*, 450% of *Eichhornea crassipes* and 831% of *Mikania micrantha* in CHAL area from 1990 to 2018.

While comparing these results of Landsat images with Worldview high resolution images, results were satisfactory and it is concluded that Landsat images can also be employed for determining invasive species distribution, as Worldview images are expensive for research in developing countries. The overall accuracy of Landsat images of distribution of invasive species mostly ranged between 70% and 80%. Distribution maps of *Chromolaena odorata* (Fig.1) and data of *Mikania micrantha* (Table 1) are presented as examples.

Spatio-temporal distribution of *Chromolaena odorata*

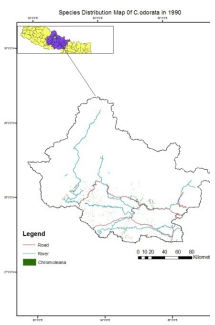


Figure 1a. Species Distribution Map of *Chromolaena odorata* oaf 1990

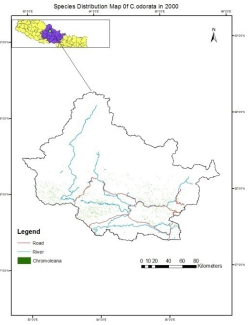


Figure 1b.:Species Distribution Map of *Chromolaena odorata* of 2000

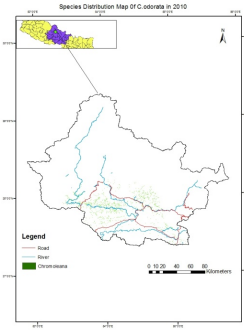


Figure 1c.:Species Distribution Map of *Chromolaena odorata* of 2010

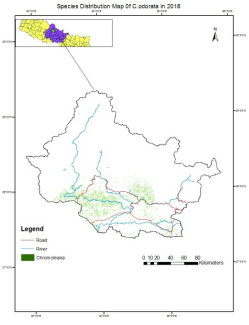


Figure 1d.:Species Distribution Map of *Chromolaena odorata* of 2018

S.N	Year	Area cover(sq.km)	Percentage(%)
1	1990	144	0.46
2	2000	234	0.74
3	2010	267	0.85
4	2018	337	1.07

Fig.1. Spatio-temporal distribution of *Chromolaena odorata* in CHAL during 1980-2018

Table 1. Spatio-temporal distribution of *Mikania micrantha* in CHAL area

Year	Area Covered by Mikania (sq km)	Area Covered by Mikania in CHAL (%)
1990	26.25	0.09
2000	42.02	0.13
2010	73.25	0.23
2018	241.45	0.77

Invasive species – particularly *Ageratina adenophora* and *Parthenium hysterophorus* – displaced valuable plant species in their vicinity viz. *Artemisia vulgaris, Trifolium repens, Centella asiatica, Chrysopogan aciculatus, Hyptis suarastens* and *Cannabis sativa*.

Selected Photographs of study species with their magnitude (Kan 3-7, 2020)

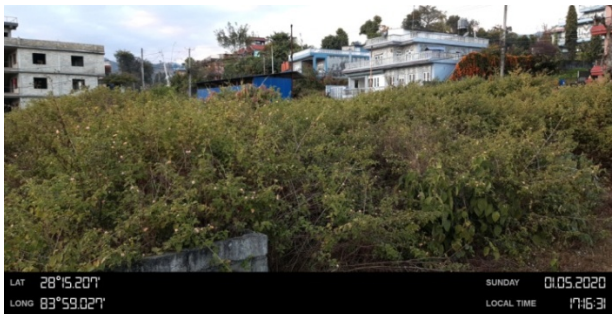
Mikania micrantha

Low Dense

Chromolaena odorata

Dense Low

Lantana camara



Low Dense

Publications:

Maharjan S, Shrestha BB, Joshi MD, Devkota A, Muniappan R, Adiga A, Jha PK. 2019. Predicting suitable habitat of an invasive weed *Parthenium hysterophorus* under future climate scenarios in Chitwan Annapurna Landscape, Nepal. Journal of Mountain Science 16: 2243–2256.

Khadka S, Jha SK, Jha PK, Anadon J, Mandal RA. 2019. Nutrients content in compost from water hyacinth and its effect on germination and growth of wheat. Journal of Handayama Geography and Archaeology (Japan) 7:51–158.

Maharjan S, Jha PK. 2019. Current distribution range of the leaf feeding beetle *Zygogramma bicolorata* on *Parthenium hysterophorus* in Nepal. IOBC Newsletter 105.

Luitel DR, Siwakoti M, Joshi M, Muniappan R, Jha PK. 2020. Potential suitable habitat of *Eleusine coracana* (L.) Gaertn. (finger millet) under the climate change scenarios in Nepal. BMC Ecology 20:19. https://doi.org/10.1186/s12898-020-00287-6.

Poudel AS, Shrestha BB, Jha PK, Baniya CB, Muniappan R. 2020. Stem galling of *Ageratina adenophora* (Asterales: Asteraceae) by a biocontrol agent *Procecidochares utilis* (Diptera: Tephritidae) is elevation dependent in central Nepal, Biocontrol Science and Technology, doi: 10.1080/09583157.2020.1749991.

Presentations:

Maharjan S, Devkota A, Shrestha BB, Baniya CB, Muniappan R, Jha PK. Prevalence of *Puccinia abrupta* var. partheniicola and its impact on *Parthenium hysterophorus* in Kathamandu Valley, Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal.

Luitel DR, Siwakoti M, Jha PK. Climate Change and its impacts on grain protein, potassium, Calcium and iron content of *Fagopyrum* spp. along elevation gradient in Central Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal.

Gyawali S, Devkota A, Jha PK, Poudel KP. Spatio-temporal distribution of *Chromolaena odorata* in Chitwan Annapurna Landscape, Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal.

Dhakal S, Shrestha BB, Jha PK, Poudel KP. Spatio-temporal distribution of *Lantana camara* in Chitwan Annapurna Landscape, Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal.

Yonjon H, Siwakoti M, Poudel KP, Jha PK. Spatio-temporal distribution of *Eichhornea crassipes* in Chitwan Annapurna Landscape, Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal.

Poudel S, Devkota A, Jha KP. Spatio-temporal distribution of *Mikania micrantha* in Chitwan Annapurna Landscape, Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal. National Conference on Integrating Biological Resources for Prosperity, Feb. 6–7, 2020 at Biratnagar, Nepal.

Poudel AS, Shrestha BB, Jha PK, Poudel KP, Adiga A, Marathe M, Muniappan R. Spatial distribution of an invasive weed *Ageratina adenophora* in Chitwan- Annapurna Landscape, Nepal using knowledge-based approach. IPPC, Nov. 10–14, 2019, Hyderabad, India.

Gyawali S, Devkota A, Jha PK, Poudel KP, Adiga A, Marathe M, Muniappan R. Spatial distribution of an invasive weed *Chromolaena odorata* in Chitwan-Annapurna Landscape Area, Nepal using knowledge based approaches. IPPC, Nov. 10–14, 2019, Hyderabad, India.

Dhakal S, Shrestha BB Jha PK, Poudel KP, Adiga A, Marathe M, Muniappan R. Spatial Distribution of *Lantana camara* in Chitwan Annapurna Landscape area Nepal Using Satellite Imageries. IPPC, Nov. 10–14, 2019, Hyderabad, India.

Maharjan S**,** Devkota A, Jha PK, Poudel KP, Adiga A, Marathe M, Rangaswamy M. Spatial Distribution of Invasive Weed *Parthenium hysterophorus* in Chitwan Annapurna Landscape (CHAL) Nepal using Knowledge Based Approach. IPPC, Nov. 10–14, 2019, Hyderabad, India.

Luitel DR, Siwakoti M, Jha PK. Climate change and its impacts on grain protein, calcium and iron content of finger millet along elevation gradient in Central Nepal. Nepal Academy of Science and Technology and Nepal Youth Council, Oct. 21–23, 2019, Kathmandu, Nepal.

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

Principal Investigator: Wondi Mersie, Virginia State University, USA

Collaborators:

Ethiopia: Lidya Alemayhu (VSU-Ethiopia); Mulualem Mersha (Southern Nations, Nationalities, and Peoples' Region – SNNPR; Bureau of Agriculture and Natural Resource Development – Arba Minch Plant Health Clinic Center (PHCC), Arba Minch; Germaw Dolisso (Southern Agricultural Research Institute), Arba Minch; Eyasu Assefa, Mizan Teppi Plant Health Clinic Center (PHCC), Mizan Teppi; Tesfaye Amare, Haramaya University (HU); Kassahun Zewdie, Ethiopian Institute of Agricultural Research (EIAR); Ferdu Azerefegne, Hawassa University.
Kenya: Muo Kasina, Kenya Agricultural and Livestock Research Organization (KALRO)
South Africa: Lorraine Strathie, Agricultural Research Council (ARC)
Uganda: Richard Molo, National Agricultural Research Organization (NARO)
USA: Maria Elisa Christie, Virginia Tech; Daniel Sumner, Virginia Tech

Project Activities:

Ethiopia: Two biocontrol agents – the leaf-feeding beetle *Zygogramma bicolorata* and the stem-boring weevil *Listronotus setosipennis* – are being reared at Ambo University's Guder campus (western Ethiopia). *Z. bicolorata* and *L. setosipennis* reared at this facility have been released at different sites in Amhara, Oromia and SNNPR.

At the Arba Minch Plant Health Clinic Center, *Zygogramma* was reared and released around the Arba Minch area, which is heavily infested by parthenium. This region of Ethiopia also has a relatively long rainy season that is ideal for the growth and reproduction of the beetle. Over 13,000 adults have been reared and released around Arba Minch in the last six months.

A new site at Mizan Teppi Plant Health Clinic Center was established for rearing and release of *Zygogramma* in the southern part of Ethiopia.

***Zygogramma bicolorata* and *Listronotus setosipennis* released in different regions of Ethiopia from October 1, 2019 to March 31, 2020**

Biocontrol agent	Region	No. of release locations in a Region	No. of adults released
Listronotus setosipennis	Amhara	2	1600
	Oromia	1	600
	SNNPR	2	1750
Total			3,950
Zygogramma bicolorata	Oromia	1	2,200
	SNNPR	1	23,135
Total			25,335

Listronotus was released on July 12, 2017 at Mojo in central Ethiopia. The site was monitored for the presence and spread of the weevil on January 17, 2020. Similarly, *Listronotus* also established at Wollo in northern Ethiopia.

Kenya (Kenya Agricultural and Livestock Research Organization): Application for a permit to introduce the biological control agents *Zygogramma* and *Listronotus* has been received from the Kenyan Government. However, due to the COVID-19 pandemic, shipments of *Zygogramma* and *Listronotus* could not be sent from South Africa to Kenya. Another attempt to ship the starter cultures of the two biocontrol agents will be made once the pandemic is over.

South Africa (Agricultural Research Council-Plant Protection Research Institute): The Agricultural Research Council reared parthenium biocontrol agents to provide starter cultures of biocontrol agents to Kenya. Lorraine Strathie traveled to Ethiopia to participate in review and planning of project activities in October 2019.

Uganda: *Zygogramma bicolorata* and *Listronotus setosipennis* have been mass produced in NARO's rearing facility and released in parthenium affected districts.

Release sites of *Zygogramma* and *Listronotus* and quantity released during October 2019 to March 2020

Region	District	Location	Biocontrol Agent	Quantity released	Release date
South Eastern	Kaliro	Lugonyola	*Z. bicolorata*	2,100	10.11.2019
			L. setosipennis	823	”
	Jinja	Township	*Z. bicolorata*	3,500	03.02.2020
			L. setosipennis	497	”
Mid-Western	Kiryandongo	Panyadoli	*Z. bicolorata*	3,100	12.09.2019
			L. setosipennis	653	”
Northern	Pader	Township	*Z. bicolorata*	4,200	02.0.2020
			L. setosipennis	756	”

Field establishment of *Zygogramma* and *Listronotus* were monitored. No recoveries of *Listronotus* were made in the release sites. However, *Zygogramma* has firmly established in some locations.

Recovery status of *Zygogramma* and *Listronotus* in some of the released sites during October 2019 to February 2020

Region /District	Release site	Initial release date	Monitoring date	Recovery status	
				Z. bicolorata	*L. setosipennis*
Eastern region					
Jinja	Township 4	10.11.18	11.10.19	absent	absent
Western Region					
Kiryandongo	Panyadoli 1	10.04.18	9.12.19	present	absent
Kasese	Queen Game Park 1	11.04.19	04.02.20	absent	not released
	Queen Game Park 2	09.07.19	04.02.20	absent	not released
Central Region					
Kampala	Kampala 1	06.07.18	04.12.19	present	absent
	Kampala 2	03.06.19	04.12.19	absent	absent
	Kampala 3	09.09.19	04.12.19	absent	absent

Publications:

Alemayehu L, Mersie W. 2019. Survival and dispersal of the stem-boring weevil, *Listronotus setosipennis*, and the leaf-feeding beetle, *Zygogramma bicolorata*, one year after their release for the control of the invasive weed, *Parthenium hysterophorus*, at two locations in Ethiopia. Journal of Biological Control 33: 178–184.

Presentations:

Strathie L. Biological control of *Parthenium hysterophorus* – successes and challenges. Research/Implementation meeting, Vredenburg Farm, Stellenbosch, November 18, 2019.

Developing Ecologically-based Participatory IPM Packages for Rice in Cambodia (EPIC)

Principal Investigator: Virender Kumar, IRRI, Philippines

Collaborators: Chou Cheythyrith, General Directorate of Agriculture; Khay Sathya, CARDI; Kim Eang Tho, RUA; Choun Saban, PDAFF - Prey Veng; Chhun Sokunroth, PDAFF-Battambang; Keo Rem, PDAFF- Takeo; Vouen Soma, PDAFF- Kampong Thom; Sotaro Chiba, Nagoya University; Chantheang Tong, CEDAC; George Norton, Virginia Tech; Doug Pfeiffer, Virginia Tech

Project Activities:

Completion of IPM demonstration trials: In Battambang, adaptive trials as technology demonstrations where groups of farmers work together and coordinate their cropping were conducted. One farmer per group volunteers part of his field for the community-based trap barrier system (CTBS). It includes a trap crop in one farmer's field that is planted several weeks before the surrounding crops. Due to the technology's ability to protect 8–10 ha surrounding the trap crop, it is expected to protect adjacent farms, so neighboring farm owners were encouraged to work together and coordinate their cropping as a group.

Evaluation of molluscicides for the control of Golden Apple Snail: Niclosamide and metaldehyde are two common molluscicide active ingredients available in the Cambodian market

to control Golden Apple Snails (*Pomacea* sp.). Results of a pot culture experiment indicated the niclomaside formulation causes higher snail mortality than metaldehyde formulations tested, but both metaldehyde and niclosamide are effective at reducing snail damage to rice seedlings when applied 5 days after sowing. These results indicate that both formulations are effective at reducing snail damage. However, we recommend that metaldehyde is promoted to farmers due to the lower environmental risk to non-target fauna.

Additionally, it was found that metaldehyde powder and abamectin had no effect on seedling growth. However, metaldehyde granules and niclosamide powder both caused stunting when applied at the same time as seed sowing. When these were applied 5 days after seeds were sown, no phytotoxic effects on seedling growth were observed. These results indicate that farmers should avoid using niclosamide powder and metaldehyde granules in rice fields within a few days of seed sowing to minimize negative effects to their rice crop.

Management of Fall Armyworm: To manage the spread of the fall armyworm, an experiment was conducted with treatments T1: *Beauveria bassiana* applied three times in the season, T2: Chlorantiniliprole followed by Emamectin Benzoate 5% and then another application of Chlorantiniliprole, T3: Emamectin Benzoate 4% applied once followed by Emamectin Benzoate 5%, and T4: control. Preliminary results from one season of the experiment showed treatment with *B. bassiana* had the highest yield (4.4 tons/ha, SD 0.5).

Biocontrol of fall armyworm and extension activities under GDA: GDA has initiated mass-rearing of natural enemies of fall armyworm. They were unable to continuously maintain the colonies. Presently, laboratory space has been allocated, and GDA has started to make budget plans for the continuation and expansion of the mass-rearing of natural enemies.

Dissemination of extension materials and awareness about Cellcard service for IPM advice: IPM Guidebooks were distributed to farmers in the village sites of the EPIC Project and introduced farmers to the newly introduced Cellcard 3-2-1 service. Through this interactive voice response system, farmers will be guided through pest identification and IPM recommendations by phoning into the free service.

Presentations:

Hadi BAR, Flor RJ, Rathmuny T, Castilla N, Stuart A, Kumar V, Cheythirith C, Sathya K. Envisioning rice IPM in tropical Asia. Presentation at the XIX International Plant Protection Congress 2019, Hyderabad, India on 10–14 November 2019.

Rathmuny T, Flor RJ, Hadi B, Kumar V, Cheythyrith C, Saban C, Sokunroth C, Soma V. Efficacy of two weed management recommendations for direct wet-seeded rice production in Cambodia. Presentation at the XIX International Plant Protection Congress 2019, Hyderabad, India on 10–14 November 2019.

Flor RJ, Rathmuny T, Stuart A, Maat H, Leeuwis C, Hadi B. Ecologically based IPM in Cambodia without a farmer field school: is there potential to scale out? Presentation at the XIX International Plant Protection Congress 2019, Hyderabad, India on 10–14 November 2019.

Sattler C, Hadi B, Makarakpakphea K, Settele J. Towards an integrative approach of ecological engineering in Cambodian rice fields. Presentation at the XIX International Plant Protection Congress 2019, Hyderabad, India on 10–14 November 2019.

Kumar V, Sokunroth C, Martin R, Srean P, Hadi B. Integrated weed management for direct-seeded rice in Cambodia. Presentation at the 27th Asian Pacific Weed Science Society Conference, Kuching, Malaysia, 3–6 September 2019.

Sothy U. Current status of fall armyworm in Cambodia. Presented at the Annual Meeting of the Entomological Society of America in St Louis, Missouri, USA on 17–20 November 2019.

Flor RJ. Going against a tsunami: How can Agricultural Research for Development (AR4D) support innovation for sustainable technologies. Presented at the International Conference on Agribusiness, Economics and Management in Davao, Philippines on 14–15 November 2019.

Project PI: Dr. Luis Cañas, Department of Entomology, Ohio State University

Collaborators: John Cardina, Professor, Department of Horticulture and Crop Science, OSU; J. Mark Erbaugh, Director of the Office of International Programs in Agriculture, OSU; Robert Gilbertson, Department of Plant Pathology, University of California – Davis; Matthew Kleinhenz, Department of Horticulture and Crop Science, OSU; Amon P. Maerere, Department of Crop Science and Horticulture, Sokoine University of Agriculture, Tanzania; Jesca Mbaka, Kandara/Deputy Director Horticulture Research Institute, Kenya Agricultural and Livestock Research Organization (KALRO), Kenya; Sally A. Miller, Department of Plant Pathology, OSU; George W. Norton, Department of Agricultural and Applied Economics, Virginia Tech; Cathy Rakowski, School of Environment and Natural Resources, OSU; Peter Sseruwagi, Mikocheni Agriculture Research Institute, Tanzania

Project Activities:

Tanzania (Tanzania Agricultural Research Institute – Mikocheni)

Contribution of agro-input dealers in vegetable production: It is evident that the role played by agro-input dealers to supply quality vegetable crop seeds, pesticides, fertilizers, and pest and disease management advice is critical to ensuring the sustainable production of healthy vegetables. The agro-input suppliers are closer to the farmers than extension/agricultural officers and research staff. In addition, the agro-inputs dealers are self-driven and independent on facilitation by anyone or institution. Unfortunately, most agro-input dealers lack the knowledge of vegetable (tomato) pests and diseases and depend on the farmers they seek to sell the agro-inputs. Coupled with the

desire to make higher sales and profits, many agro-input dealers contribute to the misuse of agro-chemicals, especially pesticides. For example, some informed the project that they advise the farmers to mix multiple pesticides to create a strong concoction to effectively kill pests and diseases. This is an area where future training and awareness creation is needed to build the knowledge levels of agro-input dealers on vegetable crop pests, diseases, and IPM.

Successful adoption of IPM strategies for tomato pests and diseases by Mr. Richard Pande, a smallholder tomato farmer: Mr. Richard Pande is one of the farmers who has participated in all three trainings on tomato production and IPM strategies in Kerege, Bagamoyo. He has already adopted the GAPs and IPM for tomato production in his new established field.

Since participating in the project led by the TARI-Mikocheni team, Mr. Pande has increased his tomato yields to 8.4 tons from 2.02 tons per 0.5 acres. The income earned from the sale of tomatoes equally increased from Tshs 1.4 M (USD 636.4) to Tshs 8.8 M (USD 4,000) due to increased yield and quality of the tomatoes. A key contribution to the increased profit margin was reduction in the quantity and cost of pesticides applied following the use of GAPs, and pest scouting for effective pesticide application and pest control.

Figure 1. Mr. Joseph Pande (in red T-shirt) talks to the USAID Tanzania Mission Development Outreach and Communication team about the successful adoption of tomato GAPs and IPM strategies in his new tomato field.

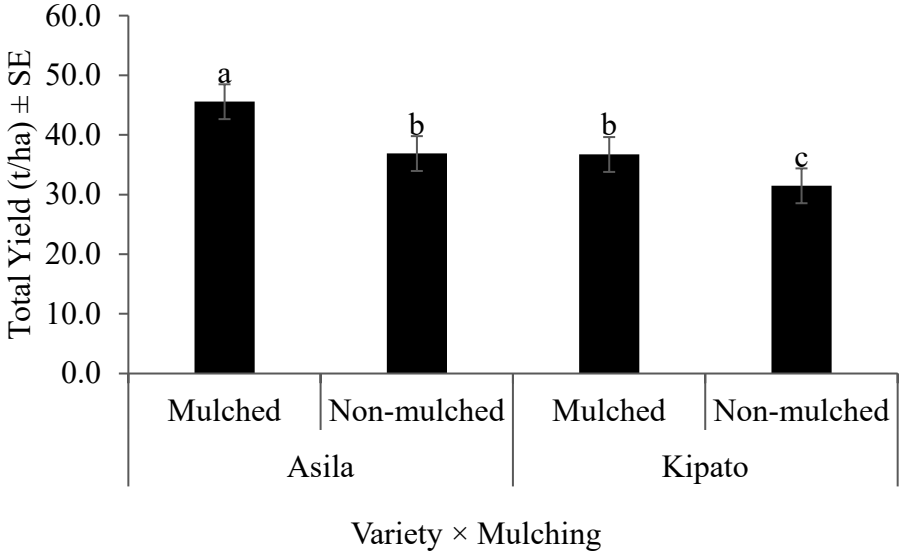
Sokoine Agricultural University (SUA), Morogoro, Tanzania

IPM technology package for tomato: Data analysis is being conducted, and a manuscript is being prepared, for IPM on tomato. Results indicate that mulching and staking has significant effects on fruit quality and yield. The quantity of fruits was significantly higher in mulched compared to non-mulched plots. The use of mulching alone gave significantly ($p < 0.001$) higher fruit number per plant compared to when a combination of staking and mulching was used. This may be because the selected varieties (Assila and Kipato) were semi-indeterminate.

The effects of variety and mulching on tomato fruit weight: Total tomato fruit yield was influenced by variety ($p < 0.001$), mulching ($p < 0.001$) and staking ($p < 0.001$) (figure below). Assila was higher yielding than Kipato. Mulching resulted in higher yields for both varieties. Non-

mulched Assila gave similar ($p > 0.05$) yields compared to the mulched and staked variety of Kipato. This indicates that variety selection is critical. It was further found that mulching alone led to similar yields compared to mulching combined with staking. Staking for both varieties had no significant effect on total yield. This is true for determinate varieties with less staking requirement.

The effects of variety on total tomato yield

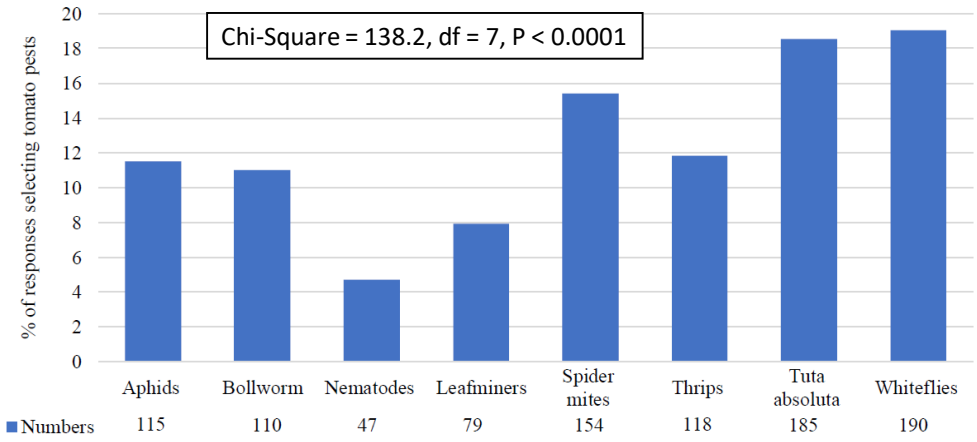


Kenya

Kenya Agricultural and Livestock Research Organization, KALRO, Kenya

Tomato pests: A survey was conducted in Kenya as a collaboration between Virginia Tech and Ohio State. Approximately 400 farmers were interviewed in the counties of Kirinyaga, Nyeri, and Tharaka Nithi. One of the questions asked was which pest caused the most damage for tomato. Most farmers selected whiteflies and *T. absoluta* as the most important pests of tomato (figure below).

Farmers identifying a major pest of their tomato crop (%). Total counts included at the bottom of each category (n = 193), multiple responses were allowed



On-farm validation of *Trichoderma* and biofertilizer: The on-farm study with *Trichoderma* and evaluation of "Plantmate" biofertilizer was repeated and validated for efficacy in management of bacterial wilt, nematodes, and other tomato diseases.

Trichoderma harzianum had the least wilt and nematode scores (2.29, 2.1, respectively), while untreated control had the highest mean wilt and nematode scores (5.57, 5.0, respectively). The biofertilizer performed well on nematodes (3.0) and satisfactory on bacterial wilt (4.52). The biofertilizer reduced nematodes better than *T. asperellum,* but scores were the same with *T. harzianum* + *T. asperellum*. There was no significant difference in the yields with combination of the *Trichoderma* species.

On-farm validation of selected biopesticides for management of tomato pests: Coragen 20SC (2.5 ml in 10 L), DC-Tron Plus (50 ml/10 L), Halt 5WP (6g/10 L), Pyegar 35.7 EC (10 ml/ 10 L), and Nimbecidine EC (30 ml in 10 l water) showed significant reduction of leaf damage. There was no significant difference between Coragen and the biopesticides evaluated in this trial.

Publications:

Kanyagha H, Rotondo F, Testen AL, Miller SA. 2018. Survey and characterization of *Ralstonia solanacearum* in Solanaceous crops in Tanzania. Phytopathology 108: S1.128.

Maerere PA, Mwatawala MW, Mtui HD, Mamiro DP, Baltazari A. 2020. Temporal distribution and management of the tomato leaf miner. International Journal of Vegetable Science 1–11. doi:10.1080/19315260.2020.1734709.

Presentations:

Kanyagha, H. Resistance of solanaceous rootstocks to *Ralstonia pseudosolanacearum* strains. Plant Health 2019, Cleveland, OH, August 4-7, 2019. Poster.

Ngugi CN, Mbaka JN, Wachira PN, Okoth S, Muriuki SJN. 2019. Evaluation of five entomopathogenic nematode isolates for their infectivity on *Tuta absoluta.* 19th Workshop on Horticultural Production in the Tropics, Tea Research Institute, Kericho, Kenya, 24th -30th November 2019.

Kihara SN, Mbaka JN, Ndungu BW, Kambo CM, Kuria SN, Muriuki SJN, Wepukhulu SB. 2019. Effect of selected biopesticides on management of root knot nematodes and yield in French beans in Tharaka Nithi County, Kenya. 19th Workshop on Horticultural Production in the Tropics, Tea Research Institute, Kericho, Kenya, 24th -30th November 2019.

Principal Investigator: Hoa Nguyen Van, SOFRI, Vietnam

Project Activities:

The crops addressed in the project are dragon fruit (Pitaya, *Hylocereus* spp.), mango (*Mangifera* spp.), longan (*Dimocarpus longan*), and lychee (*Lychee chinensis*). The IPM packages for these crops have been developed and validated.

Dragon fruit IPM package:

- Remove and compost pruned disease-infected cladodes from the field (canker disease)
- Set up a light trap for monitoring insect pest population, sweet baits or protein baits for fruit flies or ant control; sticky blue or yellow trap for thrips control
- Use overhead sprinkler irrigation at flower bud stage in dry season for thrips control
- Use bio-pesticides such as *Beauveria bassiana, Bacillus amyloliquefaciens,* and *B. subtilis* for control of pests
- Cover flower buds (12-15 days old) with plastic sleeves to prevent canker, anthracnose diseases, fruit fly damage, and other attacks from pests

Longan IPM package:

- Enhance use of organic fertilizer or compost inoculated with *Trichoderma*
- Prune low longan canopy for easy management of pests and diseases
- Prune and safely dispose of shoots affected by LWB
- Apply sulfur-containing pesticides (Kumulus 80WG) to control the eriophyid mite
- Set up light traps to monitor fruit borer and other pests

- Bag the fruit cluster 15 days after fruit set
- Set up Methyl Eugenol para-pheromone traps, sweet baits, and protein baits for control of fruit flies
- Use BTMET commercial product for mealybug control
- Use sweet baits for control of ants associated with mealybugs
- Apply *Beauveria bassiana*, neem and other bio-pesticides when needed
- Soft pesticides such as Chlorantraniliprole (Prevathon 5SC), Clothianidin (Dantotsu 50WG), Buprofezin (Applaud), and Azoxystrobin (Amistar 250SC) could be used to control mealybugs, fruit borers, and fruit rot when needed
- SOFRI and PPRI-trained farmers on adoption of IPM packages

Mango IPM Package:

- Prune trees for better aeration-ventilation
- Sanitize, remove, and properly dispose of fallen fruits from the ground
- Enhance use of organic fertilizer or compost inoculated with *Trichoderma*
- Set up Methyl eugenol para-pheromone traps and use protein baits for fruit fly control
- Spray *Bacillus* spp. for control of anthracnose and bacterial black spot diseases two days before bagging
- Cover fruits with paper bags to prevent fruit borer, fruit flies, anthracnose and bacterial black spot disease attack at the time 30-45 days after fruit setting
- Use BTMET commercial product, onion extract for pupal stage of thrips
- Soft pesticides such as Chlorantraniliprole (Prevathon 5SC), Clothianidin (Dantotsu 50WG), Buprofezin, Mancozeb (Dithane M45) and Azoxystrobin (Amistar 250SC) could be used as a last resort to control mealybugs, scales, thrips, and mango leafhopper

Lychee IPM Package:

- Prune disease-infected branches and dispose of them properly
- Use compost inoculated with *Trichoderma*
- Use *Beauveria/Metarhizium* for control of stinkbugs and inchworm
- As last resort, use Chlorantraniliprole/Spinetoram for control of shoot borer, Azoxystrobin/Tebuconazole for control of anthracnose, and Tebuconazole/Chlorothalonil for control of powdery mildew

Publications:

Hanh TTM, Hoa NV. 2019. Some result of IPM model on longan. Fruit Crops Newsletter online. SOFRI website. http://sofri.org.vn/NewsDetail.aspx?l=&id=912&cat=1&catdetail=5.

Hanh TTM. 2019. Management of major pests at flowering stage on mango, IPM project on fruit crops in Vietnam. Fruit Crops Newsletter, October 2019, SOFRI.

Hanh TTM, Hieu NT, Uyen DTK, Hoa NV. 2019. IPM project on fruit crops in Vietnam. Fruit Crops Newsletter, December 2019, SOFRI.

Thoa NTK, Giang NTC, Hoa NV. 2019. Evaluation of attractiveness of food traps for management of insect pests on the dragon fruit orchard. Journal of Vietnam Agricultural Science and Technology, 10: 127–131.

Tien DH. 2019. Export mango situation and trends. Fruit Crops Newsletter, October 2019, SOFRI.

Tien DH. 2019. Which varieties of Vietnamese dragon fruits better exports and trends. Fruit Crops Newsletter, December 2019, SOFRI.

Tien DH. 2019. Fruit and vegetable trade between Vietnam and the U.S., Growers and Businesses need to know and apply. Fruit Crops Newsletter, October 2019, SOFRI.

Hieu NT, Hue NT. 2019. Europe put more stringent quarantine requirements on imported mango. Fruit Crops Newsletter, December 2019, SOFRI.

Invasive Species Modeling for South American Tomato Leafminer and Groundnut Leafminer

Principal Investigator: Abhijin Adiga, University of Virginia, USA

Collaborators:

Young Yun Chung Baek, Madhav Marathe, Joseph McNitt, Henning Mortveit: Virginia Tech, USA; Thierry Brévault and Anaïs Chailleux, Cirad-Biopass, Dakar, Senegal; Nicolas Desneux, French National Institute for Agricultural Research (INRA), France; Mateus Ribeiro de Campos, INRA, France

Project Activities:

The project developed an epidemiological model to study the spread and impact of *Tuta absoluta*. In this phase, study of possible spread of *T. absoluta* in South and Southeast Asia region was completed.

Multi-pathway model to study the spread of *T. absoluta*, case study of Southeast Asia: A network-based propagation model was developed to study the spread of invasive species. It was applied to study the possible spread of *T. absoluta* in the region of Southeast Asia. In this phase, as per the request if the Technical Advisory Committee (TAC), the models are now being applied to Vietnam and Cambodia. The project is focused on monitoring, interventions, and economic impact. Data has been requested from contacts in Vietnam (Dr. Hanh and Dr. Hoa) and Cambodia.

Analysis of international and domestic trade: International trade networks (FAOSTAT) are being analyzed and U.S. domestic trade networks (Freight Analysis Framework) corresponding to four solanaceous crops have been obtained using the Food and Agricultural Organization trade database, using Moore-Shannon network reliability. This is extension of work presented in the Complex Networks conference in 2018.

PBDM Development

- Location: France
- Collaborators: Nicolas Desneux, French National Institute for Agricultural Research (INRA), France; Mateus Ribeiro de Campos, INRA, France; Philippe Bearez, INRA, France; Antonio Biondi, University of Catania, Italy; Luigi Ponti, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Centro Ricerche Casaccia, Italy; Andrew Gutierrez, Center for the Analysis of Sustainable Agricultural Systems Global (CASAS Global), USA; Abhijin Adiga, Virginia Tech, USA
- Achievements:

  a) Thermal biology of *Tuta absoluta*, biodemographic parameters and facultative diapause - Environmental Sciences Europe, Mateus Ribeiro de Campos, Philippe Béarez, Edwige Amiens-Desneux, Luigi Ponti, Andrew Paul Gutierrez, Antonio Biondi, Abhijin Adiga, Nicolas Desneux.

  b) Biodemographic parameters, oviposition preference and low temperature exposition of *Tuta absoluta* in tomato and black nightshade - Pest Management Science. Mateus Ribeiro de Campos, Antonio Biondi, Philippe Béarez, Edwige Amiens-Desneux, Nicolas Desneux.

East Africa Invasive Groundnut Leafminer DNA Sequencing Project

- Targeted sample collection locations – Ethiopia, Uganda, Kenya, Malawi, South Africa, India, Australia
- Achievements:
  a) Results indicate that the leafminer found in India, Uganda, and South Africa is *Aproaerema simplexella*
  b) Collection efforts in Indonesia, Bangladesh, Ethiopia, Kenya, Nigeria, and Benin heretofore have failed to find GLM and/or remain pending.

Presentations:

Adiga, Abhijin. Modeling the multi-pathway spread of agricultural pests using network science. XIX APPC, Hyderabad, India, Nov. 10-14, 2020.

Adiga, Aniruddha, Choo, E, Jha, P, Poudel K, Venkataramanan, S., Marathe, M, Adiga Abhijin. Modern AI techniques to understand the spatio-temporal spread of invasive alien plants. XIX APPC, Hyderabad, India, Nov. 10-14, 2020.

Adiga, Abhijin. Network Dynamical Systems: Theory and Applications. Seminar at Indian Institute of Technology, Hyderabad, India, Nov. 13, 2020.

LONG-TERM TRAININGS

IPM for Vegetable Crops in East Africa

Name	Gender	Home Institution	Training Institution	Degree (BS, MS, PHD, Postdoc)	Major	Start Date (month, year)	Graduation date (month, year)	Home Country
Hellen Elias Kanyagha	F	SUA	OSU	PhD	Plant Pathology	March, 2017	December 2020	Tanzania
Zuwena E. Msuya	F	SUA	SUA	MSc.	Plant Protection	2017	November 2020	Tanzania
Reagan Nyoni	M	SUA	SUA	MSc.	Plant Protection	October, 2018	November, 2020	Tanzania
Peter A. Maerere	M	SUA	SUA	MSc.	Plant Protection	October, 2017	November, 2018	Tanzania
Reagan Nyoni	M	SUA	SUA	MSc.	Plant Protection	October, 2018	September, 2019	Tanzania
Peter A. Maerere	M	SUA	SUA	MSc.	Plant Protection	October, 2017	September, 2018	Tanzania
Cecilia Ngugi	F	KALRO	University of Nairobi	PhD	Entomology	September 2016	To be decided once University opens	Kenya
Joshua Kinene	M	Chuka University	Chuka University	MS	Nematology	September 2017	October 18 2019	Kenya
Dennis Nyamu	M	Mwea Horticultural growers Self Help Group	OSU	MS	Entomology	August 2017	May 2020	Kenya

IPM for Exportable Fruit Crops in Vietnam

Name	Gender	Home Institution	Training Institution	Degree (BS, MS, PHD, Postdoc)	Major	Start Date (month, year)	Graduation date (month, year)	Home Country
Uyen, Dang Thi Kim	Female	Can Tho University	Can Tho University	PhD.	Plant Protection	October 2018	October 2020	Vietnam

Vu Thi Thanh Tuyen	Female	Nong Lam University	Nong Lam University	MSc.	Plant Protection	October 2018	October 2020	Vietnam

Ecologically-Based Participatory IPM Packages for Rice in Cambodia (EPIC)

Name	Gender	Home Institution	Training Institution	Degree (BS, MS, PHD, Postdoc)	Major	Start Date (month, year)	Graduation date (month, year)	Home Country
Socheath Ong	F	RUA	Nagoya University Satellite Campus	PhD	Plant Pathology		September 2020	Cambodia
Makarakpakphea Keo	F	GDA	Royal University of Agriculture	MS	Entomology	April 2018	April 2020	Cambodia
Corey Riedel	M	Virginia Tech University	Virginia Tech University	MS	Entomology		September 2020	USA
Luch Chhengleap	F	RUA	Royal University of Agriculture	BSc	Agronomy	June 2019	September 2020	Cambodia
Meng Sivchhing	F	RUA	Royal University of Agriculture	BSc	Agronomy	June 2019	September 2020	Cambodia

IPM for Vegetable Crops and Mango in Asia

Name	Gender	Home Institution	Training Institution	Degree (BS, MS, PHD, Postdoc)	Major	Start Date (month, year)	Graduation date (month, year)	Home Country
Sulav Paudel	Male	Penn State University		PhD	Entomology		Nov 2020	Nepal
Farhanaz Sharma	Female	Virginia Tech		PhD	Economics		August 2020	Bangladesh
Ram Khadka	Male	Ohio State University		PhD	Plant Pathology		May 2020	Nepal
Amanda McGowan	Female	Virginia Tech		MS	Agricultural Economics		Will move to Nepal associate award in July 2020	USA

IPM for Rice, Maize, and Chickpea in East Africa

Name	Gender	Home Institution	Training Institution	Degree (BS, MS, PHD, Postdoc)	Major	Start Date (month, year)	Graduation date (month, year)	Home Country
Bonaventure January	M	AfricaRice Centre	Sokoine University of Agriculture, Tanzania	PhD	Agricultural entomology	July 2016	July 2019	Tanzania
Ibrahim Hashim	M	Dakawa Agricultural Research Institute	Sokoine University of Agriculture, Tanzania	PhD	Plant Pathology	July 2016	October 2019	Tanzania
Josphat Korir	M	University of Nairobi	University of Nairobi, Kenya		Agricultural Economics	Sept 2016	Drop out	Kenya
Tarekegn Fite	M	Ministry of Agriculture	Ambo University, Ethiopia	PhD	Agricultural entomology	July 2016	June 2020	Ethiopia
Gezahegn Getaneh	M	EIAR (Ethiopian Institute of Agricultural Research)	Jimma University, Ethiopia	PhD	Plant Pathology	July 2016	June 2020	Ethiopia
Denberu Kebede	M	EIAR (Ethiopian Institute of Agricultural Research)	Addis Ababa University	MSc	Applied Microbiology	Jan 2017	Dec 2018	Ethiopia
Birhanu Sisay	M	EIAR (Ethiopian Institute of Agricultural Research)	Haramaya University	MSc	Crop Protection	Jan 2017	June 2018	Ethiopia

Modeling for Climate Change and Biodiversity

Name	Gender	Home Institution	Training Institution	Degree (BS, MS, PHD, Postdoc)	Major	Start Date (month, year)	Graduation date (month, year)	Home Country
Dol Raj Luitel	M	Department of Environment, Ministry of Forest and	Tribhuvan University	Ph.D	Botany	May, 2016	September, 2020	Nepal

		Soil Conservation						
Seerjana Maharjan	F	Department of Plant Resources, Ministry of Forest and Soil Conservation	Tribhuvan University	Ph.D	Botany	May, 2016	September, 2020	Nepal
Anju Sharma Poudel	F	Department of Plant Resources, Ministry of Forest and Soil Conservation	Tribhuvan University	Ph.D	Botany	June, 2016	September, 2020	Nepal
Ghna Shyam Bhandari	M	Nepal Agriculture Research Council	Agriculture and Forestry University	Ph.D	Entomology	Feb., 2016	September, 2020	Nepal
Hom Nath Giri	M	Agriculture and Forestry University	Agriculture and Forestry University	Ph.D	Horticulture	Feb., 2016	September, 2020	Nepal
Sita Gyawali	F	Agriculture and Forestry University	Tribhuvan University	M Sc	Botany	Sept., 2018	May 2020	Nepal
Srijana Poudel	F	Agriculture and Forestry University	Tribhuvan University	M Sc	Botany	Sept., 2018	May, 2020	Nepal
Sandeep Dhakal	M	Agriculture and Forestry University	Tribhuvan University	M Sc	Botany	Sept., 2018	May, 2020	Nepal
Himal Yonjon	M	Agriculture and Forestry University	Tribhuvan University	M Sc	Botany	Sept., 2018	May, 2020	Nepal
Abhisek Singh	M	Agriculture and Forestry University	Tribhuvan University	M Sc	Biodiversity & Environment Management	Sept., 2018	May, 2020	Nepal

IPM for Vegetable Crops in East Africa

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
Demonstration of IPM Package	Msufini	12/13/2019	Farmers	27	19	46	SUA	SUA
SUA–Hort Farm	Improved vegetable production under open field and greenhouse conditions	12-13/11/2019	Farmers and extension Agents	49	33	82	SUA	SUA
SUA – Hort Farm	Vegetable healthy seedlings production	10/12/2019	Undergraduate students	43	59	102	SUA	SUA
Training	Iringa	Oct. 2019 – Feb., 2020	Farmers, extension agents and Agrovets	116	383	499	TARI/MARI	MARI
IPM technology training	Bagamoyo	Oct. 2019 – Feb., 2020	Farmers	35	9	44	TARI/ MARI	MARI
Knowledge sharing workshops	Morogoro, Myomero, Iringa, Ilula, Kilolo, Bagammoyo	Oct. 2019 – Feb., 2020	Farmers	88	31	119	TARI/MARI	MARI
Workshop on Mangement of Pests	Morogoro	Oct. 2019 – Feb., 2020	Farmers	14	3	17	TARI/MARI	MARI
IPM system training IPM Communication	Kakamega County– Butere east &West	2nd, 10th, 15th, 23rd, 29 October 2019	Lead farmers, Tomato Leafy vegetables, Tomato Soya/ French beans Growers	150	200	350	KALRO	KALRO

Survey of farmers	Kirinyaga, Nyeri, Tharaka	Dec. 2019	Farmers			400	KALRO	KALRO, VT
Training on IPM technologies	Tharaka		Farmers	19	29	48	KALRO	KALRO
Control of Cabbage pests	Tharaka		Farmers			24	KALRO	KALRO
IPM system training IPM Communication	Vihiga County – Shinda sub-County	11th and 12th, 13th 14th &15th Nov 2019	Lead farmers, Leafy vegetable growers, Tomato	50	100	150	REAL IPM	REAL IPM
IPM system training IPM Communication	Bungoma County – Bukura ATC	10th, 11th, 13th & 16th Dec 2019	Farmers, French beans, Tomato growers	50	150	200	REAL IPM	REAL IPM
IPM system training IPM Communication	Makueni County	17th 18th Jan 2020	Lead farmers Tomato capsicum, Leafy Vegetable	50	200	250	REAL IPM	REAL IPM
IPM system training IPM Communication	Kisii County	7th, 8th, 10th 11th Feb 2020	Lead farmers French beans, Tomato, Leafy vegetables	100	150	250	REAL IPM	REAL IPM

IPM for Exportable Fruit Crops in Vietnam

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
IPM packages, GlobalGAP/VietGAP standards	Tien Giang, Long An, Dong Thap, Dong Nai		Farmers and Extension Staff	96	175	271	SOFRI	SOFRI

Training courses on "DF production, market requirements" and "Understanding and using agro-chemicals for canker disease management"	Long An	Sep 4th, 2019	Farmers and extension staffs	5	30	35	SOFRI	SOFRI
Integrated pest and disease management	Lecture supported to Center of Agriculture Service, Dong Thap province	Sep. 14th 2019	Farmers and extension staffs	2	27	29	SOFRI	SOFRI
Workshop of "Application of high-tech to improve DF industry towards sustainable production	presentation in workshop	Nov. 10th 2019	Farmers, extension staffs, and administration	22	78	100	SOFRI	SOFRI
Training courses on "DF production, market requirements" and "Understanding and using agro-chemical for canker disease management" and "Nature enemy diversity and pest control"	Dong Thap	Feb. 10, 2020	Longan growers in new enlarged model	12	21	33	SOFRI	SOFRI
Training courses on: - Advanced IPM package of longan - Role of women in longan production	Tien Giang	March 3, 2020	The wives of longan growers in enlarged model	0	34	34	SOFRI	SOFRI
Meeting with women's groups	SOFRI	Oct 25, 2019	Wives of farmers	15	0	15	SOFRI	SOFRI
Meeting with women's groups	SOFRI	Nov. 17, 2019	Wives of farmers	15	0	15	SOFRI	SOFRI
Meeting with women's groups	SOFRI		Wives of farmers	20	0	20	SOFRI	SOFRI
Meeting with women's groups	SOFRI		Wives of farmers	30	0	30	SOFRI	SOFRI
Meeting with women's groups	SOFRI		Wives of farmers	10	0	10	SOFRI	SOFRI

Bio-rational IPM technology for pest control	Dong Thap province	Jan. 13, 2020	Farmers and extension staff	9	16	25	SOFRI	SOFRI
Bio-rational IPM technologies for pest control	Dong Nai province	Feb. 13, 2020	Farmers and extension staff	10	5	15	SOFRI	SOFRI

Ecologically-Based Participatory IPM Packages for Rice in Cambodia (EPIC)

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
Training of trainers on IPM	CARDI	Nov 6-7 2019	Farmers, NGO, Extension staff	15	38	53	CARDI	EPIC, CARDI and GDA
Farmer field day	Battambang-Otagnea	Nov-29-2019	Farmers	12	30	42	GDA	PDAFF
Farmer field day	Battambang-Angpor	14-Feb-2020	Farmers	19	48	67	GDA	PADF
Training on IPM	Kampong Thom	Mar-10-2020	Farmers, NGO Extension	12	31	43	GDA	EPIC, PDAFF
Attendance to the Entomology Society of America Annual Meeting	USA	Nov-17-20-2019	Government	0	1	1	GDA	IPM IL
Outreach activities	Kampon Thom, Panna Chi	Nov. 2019 to March 2020	Farmers	9	23	32	EPIC	EPIC
IPM Guide distribution	Cambodia	Nov. 2019 to March 2020	Farmers	62	156	218	EPIC	EPIC

IPM for Vegetable Crops and Mango in Asia

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute

Training	Wooster, Ohio	Oct 26-Nov 07, 2019	scientists	1	1	2	RUA & iDE	Ohio State University
Lecture	Siem Reap Cambodia	Dec 18, 2019	farmers	1	9	10	iDE-CSmart & CE SAIN	Ohio State University
Guest lecture	Phnom Penh, Cambodia	Dec 19, 2019	students	10	10	20	Royal University of Agriculture (RUA)	Ohio State University
Guest lecture	Phnom Penh, Cambodia	Feb 06, 2020	students	2	7	9	Royal University of Agriculture (RUA)	Virginia Tech
IPM package trials undergraduate theses	Phnom Penh, Cambodia	Dec 2019 – May 20	students	2	2	4	Royal University of Agriculture (RUA)	RUA Virginia Tech
Field day	Siem Reap, Cambodia	Feb 26, 2020	farmers	40	36	76	iDE	iDE
Tomato IPM package trials	Siem Reap, Cambodia	May-Oct 2019	farmers	0	12	12	iDE	iDE
Cucumber IPM package trials	Siem Reap, Cambodia	Dec-Mar 2020	farmers	1	11	12	iDE	iDE
ASD tomato	Siem Reap, Cambodia	Dec-Apr	farmers	0	1	1	iDE	Ohio State University
Farmers training on Management of tomato leafminer, *Tuta absoluta*	Dabarbhangha, Panchagarh	Feb 09, 2020	farmers	6	44	50	IPM IL BARI	IPM IL BARI
Farmers training on Management of tomato leafminer, Tuta absoluta	Ziabari, Panchagarh	Feb. 10, 2020	farmers	4	46	50	IPM IL BARI	IPM IL BARI
Farmers training on Mango pest management	Rajnagar, Moulvibazar	March 14, 2020	farmers	0	50	50	IPM IL BARI	IPM IL BARI
Farmers training on Mango pest management	Srimangal, Moulvibazar	March 15, 2020	farmers	3	47	50	IPM IL BARI	IPM IL BARI

Training on IPM research activities	Banke, Surkhet Lalitpur and Kavre	June 10-Sept. 10, 2019	6 Agriculture Students from HICAST	3	3	6	HICAST	IPM IL
IPM training	Banke	February 19, 2020	Farmers	94	6	100	AVIPMIL	IPM IL
IPM package and FAW training	Binauna, and Shivapur, Banke	February 2, 10, 2020	Farmers	27	25	52	AVIPMIL	IPM IL
IPM training	ARS/NARC, Dashratpur	March, 17, 2020	Farmers	7	17	24	NARC	IPM IL
Training on FAW	Lekbesi MPC/Agri. collection center Lekbesi-9, Surkeht	Feb. 14, 2020	Farmers	17	1	18	Cooperatives	IPM IL
Provincial Level TOT Training on FAW Identification and Management	Krishi Upaj Bazar Nawalpur, Kawasoti, Gandaki Province	Dec. 3-4, 2020	GoN Staff and Project Staff	5	19	24	ADD, Gandaki Province,	IPM IL
Provincial Level TOT Training on FAW Identification and Management	Namaste Hotel, Birendranagar, Surkhet	Nov. 4-5, 2019	GoN Staff and Project Staffs	6	34	40	ADD, Karnali Province, & KISAN II	IPM IL
Provincial Level TOT Training on FAW Identification and Management	Hotel Flora, Dhangadhi	Nov. 17-18, 2019	GoN Staff and Project Staffs	1	29	30	ADD, Gandaki Province, & & KISAN II	IPM IL

Invasive Species Modeling for South American Tomato Leafminer and Groundnut Leafminer

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute

Modeling spread of agricultural pests using network science	IPPC, India	Nov 2019	Entomologists	10	40	50	University of Virginia	IPPC/ICRISAT
Network Dynamical Systems: Theory and Applications	IIT Hyderabad, India		Computer scientists	40	60	100	University of Virginia	IIT, Hyderabad

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

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
Training on rearing of Zygogramma and growing parthenium in pots	Arba Minch, Ethiopia	January 2 to 5, 2020		2	1	3		
Training on rearing of Zygogramma and growing parthenium in pots	Guder, Ethiopia	March 10 to 13, 2020		0	2	2		
Training on culturing, rearing and field releasing of Zygogramma	Mezan Teppi, Ethiopia	March 18 to 20, 2020	Technicians	2	3	5		Virginia State University
Annual Review and Planning Meeting of the IPM Innovation Lab on Biological Control of *Parthenium hysterophorus* in East Africa	Arba Minch, Ethiopia	September, 29- October 2, 2019	Scientists	8	24	32	Arba Minch	Virginia State University

IPM for Rice, Maize, and Chickpea in East Africa

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
Training of trainers for extension agents on management of fall armyworm	Kericho, Kenya	Feb 18-19, 2020	Extension agents	3	7	10	*icipe*, KARLO and the ministry of Agriculture	
Training of District Agricultural Experts on push pull technology in managing stem borers in maize	Finoteselam, Ethiopia	Feb 4-5, 2020		0	10	10	*icipe* and the ministry of Agriculture	

Modeling for Climate Change and Biodiversity

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
Ph D	CHAL	Feb 2016	3 Govt officers, 1Asst.Prof, 1 Student	2	3	5		3-TU 2 -AFU
M Sc	CHAL	2016-2018	Students	3	3	6		TU
M Sc	CHAL	2018-2020	Students	2	3	5		TU

Management Entity

Type	Location	Time	People trained	Female participant	Male participant	Total Participants	Home Institution	Training Institute
IPM in Sustainable Development	Virginia Tech	Oct. 28, 2019	Students	25	10	35	Virginia Tech	Virginia Tech
Tuta absoluta symposium	IPPC, Hyderabad, India	Nov 12, 2019	Scientists	10	60	70	Virginia Tech	IPPC/ICRISAT
FAW symposium	IPPC, Hyderabad, India	Nov, 11 2019	Scientists	80	250	330	Virginia Tech	IPPC/ICRISAT
Biological Control SymPosium	IPPC, Hyderabad, India	Nov 13, 2019	Scientists	25	65	90	Virginia Tech/NBAIR	IPPC/ICRISAT

FAW symposium	St Louis, MO	Nov. 18, 2019	Scientists	15	85	100	Virginia Tech	Entomological Society of America
Invasive species presentation	Tamil Nadu Agricultural University, India	March 5, 2020	Scientists and Students	100	200	300	Virginia Tech	Tamil Nadu Agricultural University
Conflicts in Biological control Presentation	IPPC, Hyderabad, India	Nov. 14, 2019	scientists	10	400	50	Virginia Tech	IPPC, Hyderabad

Institutional Development:

Nepal: One candidate completed his PhD in Entomology at Penn State University and returned to Nepal. Six scientists from Nepal attended the International Plant Protection Congress in Hyderabad, India, and presented papers.

Bangladesh: Three scientists from Bangladesh attended the International Plant Protection Congress in Hyderabad, India, and presented papers.

Cambodia: Four scientists from Cambodia attended the International Plant Protection Congress in Hyderabad, India, and presented papers. One scientist also attended the Entomological Society of America Annual Meeting in St Louis, MO, and presented a paper.

Ethiopia: One scientist from Ethiopia attended the International Plant Protection Congress in Hyderabad, India, and the Entomological Society of America Annual Meeting in St Louis, MO, and presented papers.

Innovation Transfer and Scaling Partnerships:

Plan of Action:

1) Steps taken:
- Worked with host country partners in collection of natural enemies of FAW.
- Assisted in identification of parasitoids by sending them to specialists.
- Participated in national and international conferences.
- Assisted in editing manuscripts from host country scientists.
- Scaled up adoption of IPM packages of various crops selected by host countries.

2) Partnerships made:
- AGTC – Pheromone producing company in India.
- Tamil Nadu Agricultural University in India.
- National Institute for Plant Health Management in Hyderabad, India.
- Agricare company in Nepal.

3) Technology ready to scale:
- Mass multiplication of natural enemies of FAW.
- Field release of natural enemies of FAW.
- Field release of natural enemies of the invasive weed *Parthenium*.
- Trap cropping for control of rats in rice fields of Cambodia.

4) Technologies transferred:
- Mass rearing of egg parasitoids of FAW in Nepal.
- Correcting history of biological control.
- Identifying flaws in the push-pull technique for management of FAW.

5) Technologies scaled:
- IPM packages for various crops.
- Field release of natural enemies of *Parthenium* in Ethiopia and Uganda.

Environmental Management and Mitigation Plan (EMMP)

- Procedures set in the Cooperative Agreement were followed in procurement and use of pesticides.
- Environmentally safe biopesticides were promoted.

Open Data Management Plan

The IPM IL had its data management plan (DMP) approved by the AOR and the ME ensures the program is compliant with ADS 579, including data registration and submission. Raw data from individual projects are available from the site coordinators in each country upon request. When mature data becomes available, the PIs and/or the ME will register and submit the data and data reference in the DDL.

Governance and Management Entity Activity

- Worked closely with AOR and Virginia Tech administration.
- Involved the program in national and international conferences.
- Involved host country scientists in international conferences.
- Prepared several success stories and released to the media.
- Actively promoted scientific publications.
- Set up Associate Award activities in Nepal.

Other Topics:

An Associate Award for $1.38 million was received from USAID Mission in Nepal for management of FAW and scaling up of adoption of IPM packages for maize, rice, vegetable and lentil crops.

Issues:

The COVID-19 epidemic has brought most host country activities to a standstill.

Future Directions:

Continue scaling up of IPM packages developed for vegetable, fruit, cereal, legume crops in host countries and beyond. Promote IPM technologies in international conferences. Scale up field release of natural enemies of *Parthenium* in Ethiopia and Uganda. Field test mating disruption technology for management of FAW in Nepal. Scale up mass production of natural enemies of FAW and implement augmentative biological control in host countries. Provide opportunities for host country scientists to participate in international conferences.

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VIRGINIA TECH

IPM

A Private Sector Collaboration Keeps Pests at Bay, Partnerships Possible

One of the tricks to building resilience against crop pests is adequately preparing for them, which is what one collaboration between a pheromone company and the Feed the Future Innovation Lab for Integrated Pest Management has been achieving for over a decade.

Chemist K.R.M. Bhanu is a lead scientist and Assistant Vice President of Production at Biological Control Research Laboratories (BCRL) in Bengaluru, India. Bhanu produces pheromones of different agriculturally important insect pests. The use of pheromones in the field helps monitor, trap, and suppress pests, and has risen in popularity as the adoption of sustainable farming practices and a demand for high-value crops also grows.

BCRL's relationship with the IPM Innovation Lab began in 2009 when BCRL was recruited as a program collaborator in India, developing pheromones for vegetable crops. Later, in 2013, the company assisted the IPM Innovation Lab with *Tuta absoluta,* a tomato pest with the potential to destroy 100 percent of crop yields.

One of the major advantages of pheromone traps is their ability to attract single species of an insect, which allows for timely detection of pest infestation and estimates of pest population density in a given area.

Different types of pheromone traps.

Bhanu in her lab in India.

Pheromone traps are also affordable, non-toxic, easy to manage, and help reduce insecticide use if multiple traps are implemeted over time.

Over the last ten years, Bhanu has helped educate and administer pheromones to smallholder farmers in India and beyond in part due to her attendance at IPM Innovation Lab trainings.

"Chemical pesticides used to be perceived as the norm," Bhanu said. "They supposedly yielded better results, both for pest controllers and end users. So the pioneering work that BCRL was doing with biopesticides and pheromones was not only ahead of its time, but also shaped the Indian pest control landscape into the industry it is today."

In 2013, Bhanu attended a *Tuta absoluta* awareness workshop hosted by the IPM Innovation Lab in Ethiopia, where participants learned about biology, threat, and other factors related to the pest. Preparing for *Tuta* to reach India, the workshop positioned Bhanu to distribute pheromones for monitoring and suppression of the pest. In addition to India, she distributed pheromone lures to Nepal and Bangladesh ahead of the pest's entry.

Bhanu also attended a *Tuta* awareness meeting in Vietnam in 2019, and has attended various symposia to share her experiences in the field. Based on leads from the IPM Innovation Lab, BCRL can manufacture and sample lures for testing and managing pests in the program's participating countries.

"Being a part of the IPM Innovation Lab's multi-national program has catapulted my understanding of the global pest control landscape," Bhanu said. "It has also introduced me to insightful cultural crop protection practices from nations beyond my own…My collaboration with the program has been an extremely important networking exercise and has given me the opportunity to establish possible trade relations."

Muni Muniappan, Director of the IPM Innovation Lab, said the program's collaboration with BCRL is mutual and multi-functional, as is almost any collaboration with the private sector. Establishing regional relationships, connections, and business prospects is a major factor in helping to reduce future reliance on foreign aid.

Through a connection forged by the IPM Innovation Lab, BCRL is currently sending pheromone traps and lures to East Africa and South Asia to help farmers monitor and suppress the fall armyworm, a dangerous pest that has already caused billions of dollars in damage across Asia and Africa.

"Working with BCRL," Muniappan said, "not only helps us to foster business prospects, but will assist us in getting in front of pests that could contribute to food insecurity and other issues for smallholder farmers."

Biocontrol of Fall Armyworm: The Chain Reaction that Led to Regional and Cross-Continental Management

(Left) Laouali Karimoune, (center) Peter Malusi, and (right) Laouali Amadou scope for fall armyworm pests in Niger.

Millions of people around the globe depend on maize, the fall armyworm's favorite food. They also depend on cotton, sorghum, rice, and hundreds of other crops the invasive pest devours. The fall armyworm, which reached Africa in 2016, is a destructive, yet resilient pest – it thrives in hot climates, feeds at all plant stages, is resistant to many chemical pesticides, and travels and reproduces rapidly. It took just three years for the pest to inflict over $10 billion in losses in Africa alone. It now resides in nearly every country in sub-Saharan Africa, and reached Asia in 2018.

Solving the Problem

When a pest moves as quickly as the fall armyworm, measures to control it need to be one step ahead of its spread. Virginia Tech's Feed the Future Innovation Lab for Integrated Pest Management looked at ways to catalyze previous programs and partnerships to combat the pest.

In 2018, the IPM Innovation Lab's collaboration with the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet involved working with scientists in Niger to implement augmentative biological control against the pearl millet headminer, a pest that attacks the country's staple crop.

Augmentative biocontrol involves mass-multiplying and releasing natural enemies to mitigate a damaging pest. To assist the team in Niger in improving their mass-production skills, the IPM Innovation Lab sent one of its technicians to Egypt for training.

"Upon returning from that training, I demonstrated to my coworkers in Niger how to better approach and implement the process," said Laouali Karimoune, a technician for the International Crops Research Institute for

the Semi-Arid Tropics in Niger. In trials of releasing natural enemies against the pearl millet headminer, increases in yields reached 34 percent.

Enter: the fall armyworm. The pest had begun to upend farming communities throughout East Africa, where the IPM Innovation Lab leads several projects.

After finding seven potential natural enemies for the fall armyworm, the program landed on two – *Trichogramma* species and *Telenomus remus* – known to be effective in suppressing populations of the pest in Central and South America. Based on the program's collaboration on the pearl millet headminer in Niger, the IPM Innovation Lab could replicate the same mass-production method against the fall armyworm. In fact, both pests' natural enemies could be reared on the same alternative host, a rice meal moth, which cuts costs in half.

Making Connections

The IPM Innovation Lab sent Peter Malusi, a technician for the International Centre of Insect Physiology and Ecology in Kenya, to Niger to receive training on the mass-production technique.

"With a pest invasion like the fall armyworm's, knowledge-sharing helps us to act as quickly as possible," said Muni Muniappan, director of the IPM Innovation Lab. "Combatting the pest using biocontrol reduces chemical pesticides, but it's also most effective when as many regions as possible implement the process."

Malusi followed up his training by teaching the mass-production technique to researchers throughout East Africa, leading to the development of numerous centers dedicated to mass-producing natural enemies of the fall armyworm. The "satellite" centers connect with small-scale farmers, medium-to-large scale farmers, value chains, and agriculture and rural advisory services in order to release them against the pests.

Trials in Kenya and Tanzania show that both natural enemies the IPM Innovation Lab is introducing have the potential to mitigate nearly three-quarters of fall armyworm eggs in the fields, which would make significant impacts on global food security in the region.

Multiplying Connections

In 2020, the IPM Innovation Lab was awarded a 3-year, $1.4 million-dollar award in Nepal, collaborating with the Nepal Agricultural Research Council and International Development Enterprises to introduce biocontrol against the fall armyworm, based on the program's history with the pest. The same natural enemies found in Africa that attack the pest are also found in Asia.

The project involves cooperating with large-scale farmers, farmers of rice mills, maize seed and poultry feed-producing companies, cooperatives, and others in developing hubs for mass-producing natural enemies to be used against the fall armyworm. Several researchers have already been trained on mass-production.

This is the first time augmentative biocontrol has ever been implemented in Nepal. As reliance on chemical pesticides increases in the country, with significant impacts on food and water resources, biocontrol is a sound alternative against a pest as formidable as the fall armyworm.

"Our initial instinct to improve scientific capabilities in Niger set off a chain reaction we could have never predicted," said Muniappan. "This is valuable evidence for the myriad of ways in which collaborative research can be catalyzed for countless efforts to improve livelihoods and crop production."