

## **Crop Rotation Collapses as a Pest Management Tool for Western Corn Rootworms: In Search of a Solution**

*Natural selection plays the central role in shaping the biological world, yet its glacial pace makes the evolutionary change occurring around us appear all but invisible. Occasionally, exceptional circumstances permit us to witness the process of natural selection. Such circumstances exist today in east central Illinois; the behavior of the western corn rootworm, Diabrotica virgifera virgifera, an important pest of maize is changing under intensive selection by crop rotation circumventing the most cost effective and environmentally benign management tool.*

### **Executive Summary:**

Because of the loss of crop rotation as a pest management approach for western corn rootworms, *Diabrotica virgifera virgifera* LeConte, Illinois producers have been saddled annually with an additional \$100 million in crop damage and management costs. Western corn rootworm rotation resistance is fundamentally a problem of movement: egg laying females now disperse from cornfields to deposit their eggs in soybeans and other crops rotated with corn. Despite the rotation of corn and soybeans, by the end of the 2002 growing season, over 4.5 million acres of corn produced across 30 counties of Illinois were susceptible to western corn rootworm larval injury. In addition, approximately 3.5 to 4.0 million acres of rotated corn are now susceptible to rootworm larval injury in Indiana (personal communication with John Obermeyer, Extension Entomologist, Purdue University). During the summer of 2002, western corn rootworm adults could be found in soybean fields in 59 Illinois' counties. In 2007, rotated cornfields in the northern 2/3 of Illinois will be susceptible to economic losses caused by the variant western corn rootworm. Illinois producers and those in neighboring states such as Indiana, western Ohio, and southern Michigan have responded to this new western corn rootworm variant by increasing significantly their use of soil insecticides. In 2006, entomologists at Iowa State University reported that variant western corn rootworms could be found in southeastern Iowa and to a more limited extent as far west as central Iowa. The potential economic, environmental, and human health and safety benefits of restoring the utility of crop rotation are enormous. Illinois surveys, during the early 1990s, indicated that producers were treating only 13% of rotated corn acres with a planting-time soil insecticide (Pike et al. 1991); however, since 1995, insecticide use has risen significantly in east central Illinois and northern Indiana and now parallels that of non-rotated corn (over 90% treated annually). Although soil insecticides can be used effectively to limit yield losses, they cannot replace the population management tool that crop rotation once was. Without the option of using rotation, producers are, in effect, required to use insecticides year after year, fulfilling the "pesticide treadmill" prophecy. With fewer and fewer effective pest management options for this western corn rootworm variant, producers also are increasing their use of transgenic (Bt) corn raising the specter of resistance development overtime. Because of the overwhelming adoption of transgenic (Bt) corn rootworm hybrids, it becomes increasingly imperative that we lessen the selection pressure that will be exerted across the agricultural landscape on this new technology by restoring the pest management usefulness of crop rotation for western corn rootworms. More selective, and perhaps, even prescriptive use of transgenic cultivars in corn production systems might help meet this goal.

## **Objectives and Goals:**

The debate continues within the entomological community regarding the fundamental explanation for the egg-laying shift of western corn rootworms away from the restrictive relationship with corn to include that of other crops, primarily soybeans. One theory suggests that the rigid cultural practice of crop rotation has placed selection pressure on the east central Illinois population of western corn rootworms for at least the last two decades eventually triggering the behavioral abandonment of corn as the primary egg-laying site. Another contemporary theory suggests that the agronomic trend towards earlier corn planting dates (along with the use of earlier maturing corn hybrids) has resulted in corn becoming a less attractive egg-laying target as compared with nearby soybean fields late in the summer. This latter theory rests on the assumption that laying eggs within soybean fields has been expressed only recently (since mid-1990s) due to the exaggerated phenological asynchrony that exists between corn and soybeans; however, the genes responsible for this ovipositional plasticity have not changed appreciably compared with western corn rootworms that entered Illinois 35 years ago. To a large extent our research efforts focused on these two hypotheses in seeking an explanation for the collapse of crop rotation as a pest management tactic. It was our objective to determine which hypothesis is correct, and then to find a solution to this incredible adaptation.

C-FAR funding has allowed us to initiate several research investigations with the specific objectives of both understanding the problem and generating information for immediate use by producers. Primary objectives included: (1) to define the spread of populations of the new strain of western corn rootworm, (2) to characterize the physiological and environmental stimuli that influence movement of western corn rootworms, and (3) to develop practical economic thresholds, enabling producers to make informed decisions concerning the use of insecticides or transgenic (Bt) hybrids. It was hoped that these research efforts would contribute to the preservation of crop rotation as a management tactic for western corn rootworms and provide significant details for the development of insect resistance management strategies for transgenic corn for rootworm control. As yet, the former has not been achieved and the variant western corn rootworm continues its expansion across the eastern Corn Belt.

## **Principal Investigators:**

Michael Gray – Department of Crop Sciences, University of Illinois

Mark Band – Keck Center for Comparative and Functional Genomics, University of Illinois

Scott Isard – Department of Geography, University of Illinois

Eli Levine – Center for Economic Entomology, Illinois Natural History Survey

Harris Lewin – Biotechnology Center & Keck Center, University of Illinois

Lei Liu – Keck Center, University of Illinois

Paul Mitchell- Department of Agricultural Economics, Texas A&M University

David Onstad – Department of Natural Resources & Environmental Sciences, Univ. of Illinois

Jose Pardinás – Keck Center, University of Illinois

Susan T. Ratcliffe – Department of Crop Sciences, University of Illinois

Hugh Robertson – Department of Entomology, University of Illinois

Joseph Spencer – Center for Economic Entomology, Illinois Natural History Survey

## **Outcomes and Impacts:**

As a result of this research project, we more fully understand the behavioral response of the variant western corn rootworm that has allowed it to overcome the pest management benefits of crop rotation. Due to the rigid rotation of corn and soybeans across central Illinois and the trend towards earlier planting of corn we have selected a variant of the western corn rootworm in which female beetles have expanded their ovipositional range to include many other crops including soybeans, wheat, alfalfa, oats, and wheat double-cropped with soybeans. This finding meant that switching to another rotational scheme for Illinois' producers was not an effective management option. Consequently, unless corn producers scout their fields and use economic thresholds (developed with previous C-FAR funding), they will need to consider the use of a soil insecticide or transgenic (Bt) corn rootworm hybrid on rotated or continuous corn acres throughout the northern two-thirds of Illinois.

In addition to the on-farm research and outreach efforts of this project, many of our team members are engaged in unraveling any potential genetic explanations that may explain this behavioral adaptation by western corn rootworms. The Expressed Sequence Tag database portion of the project is complete as well as the microarray hybridization assays. Sequencing of the cDNA library has been completed. A total of 20,736 reactions have resulted in 16,797 sequences. Following trimming and filtering, 16,172 sequences were further analyzed. It is estimated that 7,000 unique sequences will result from the project. Using samples collected during the 2002 field season, microarray hybridization assays were conducted to determine if the collection method induced a stress/alarm response in the beetles. Thus far, we have not detected gene expression differences in the brains of these two strains of beetles that might help explain the adaptation of east-central Illinois corn rootworm beetles to crop rotation.

C-FAR Sentinel Grant support of western corn rootworm genomic studies generated information about western corn rootworm genetics and gene expression that provided a 'critical mass' of research and researcher interest leading to the formation of the *Diabrotica* Genetics Consortium, a Non-Funded Cooperative Agreement (NFCA), administered by Thomas W. Sappington, USDA-ARS, CICGRU, Genetics Laboratory, Iowa State University, Ames, IA 50011. Members of this group (including Sentinel Grant PIs) are providing leadership in the study of western corn rootworm dispersal, ecology, and population genetics in the USA and in Europe.

Collaborative relationships have been developed with the University of Nebraska - Lincoln and the Institut National de la Recherche Agronomique (INRA), France to address insecticide resistance and population genetics objectives as described: 1) to assess the level of genetic differentiation of US western corn rootworm populations specialized on corn and those adapted to both corn and soybean; 2) to retrace the routes of introduction in western America and in Europe using genetic assignment methods; 3) to assess the possibility of multiple introduction events (now confirmed); and 4) to estimate the number of founders in new populations using simulation programs based on the coalescent theory. In 2005, we hosted a scientist from the Institut National de la Recherche Agronomique to collect samples for genetic research to determine the origin of the western corn rootworm population in Europe. In addition, several projects with INRA and the University of Illinois have resulted in co-authored publications. INRA has provided funding to address the western corn rootworm issue in Europe and specifically France. These collaborations with European scientists continue as evidenced by recent participation by Mike Gray and David Onstad at the recently concluded International Working Group on *Ostrinia* Conference held in Vienna, Austria, November 5-8, 2006. Joe

Spencer also will travel to France in March 2007 to continue these collaborations with INRA researchers. Results of our modeling work (led by David Onstad) permitted the United States EPA and industry to more efficiently develop plans designed to prevent evolution of resistance by corn rootworm to transgenic insecticidal corn. The United States EPA resistance management regulations took advantage of our model results. These results also demonstrated that integrated pest management (IPM) should account for resistance management but IPM should not be ignored during the management of resistant or potentially resistant insect populations.

**Published Journal Articles (peer reviewed) Resulting from Sentinel C-FAR Funding:**

- Isard, S.A., J.L. Spencer, T.R. Mabry, and E. Levine. 2004. The influence of atmospheric conditions on high elevation flight of western corn rootworm (Coleoptera: Chrysomelidae). *Environmental Entomology*, 33(3):650-656.
- Levine, E., J.L. Spencer, S.A. Isard, D.W. Onstad & M.E. Gray. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. *American Entomologist*, 48(2): 94-107.
- Mabry, T.R. and J.L. Spencer. 2003. Survival and oviposition of a western corn rootworm variant feeding on soybean. *Entomologia Experimentalis et Applicata*, 109:113-121.
- A. Isard. 2004. Western corn rootworm (Coleoptera: Chrysomelidae) behavior is affected by alternating diets of corn and soybean. *Environmental Entomology*, 33(4):860-871.
- Miller, N. J., K. S. Kim, S. T. Ratcliffe, A. Estoup, D. Bourguet, T. Guillemaud. 2006. Absence of genetic divergence between western corn rootworms resistant and susceptible to control by crop rotation. *Journal of Economic Entomology*, 99: 685-690.
- Onstad, D. W., C. A. Guse, J. L. Spencer, E. Levine, and M. Gray. 2001. Modeling the adaptation to transgenic corn by western corn rootworm (Coleoptera: Chrysomelidae). *Journal of Economic Entomology*, 94:529-540.
- Onstad, D. W., J. L. Spencer, C. A. Guse, S. A. Isard, and E. Levine. 2001. Modeling evolution of behavioral resistance by an insect to crop rotation. *Ent. Expt. Appl.* 100:195-201.
- Onstad, D. W., D. W. Crowder, S. A. Isard, E. Levine, J. L. Spencer, M. O'Neal, S. Ratcliffe, M. E. Gray, L. W. Bledsoe, C. D. Di Fonzo, B. Easley, and C. R. Edwards. 2003. Does landscape diversity slow the spread of rotation-resistant western corn rootworm (Coleoptera: Chrysomelidae)? *Environmental Entomology*, 32:992-1001.
- Onstad, D. W., D. W. Crowder, P. D. Mitchell, C. A. Guse, J. L. Spencer, E. Levine and M. E. Gray. 2003. Economics versus alleles: balancing IPM and IRM for rotation-resistant western corn rootworm (Coleoptera: Chrysomelidae). *Journal of Economic Entomology*, 96:1872-1885.
- Pierce, C.M.F. & M.E. Gray. 2006. Western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), oviposition: a variant's response to maize phenology. *Environmental Entomology*, 35(2): 423-434.
- Pierce, C.M.F. & M.E. Gray. 2006. Seasonal oviposition of a western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), variant in east central Illinois commercial maize and soybean fields. *Environmental Entomology*, 35(3): 676-683.
- Rondon, S.I., and M.E. Gray. 2003. Captures of western corn rootworm (Coleoptera: Chrysomelidae) adults with Pherocon AM and vial traps in four crops in east central Illinois. *Journal of Economic Entomology*, 96(3): 737-747.

- Rondon, S.I., and M.E. Gray. 2004. Ovarian development and ovipositional preference of the western corn rootworm (Coleoptera: Chrysomelidae) variant in east central Illinois. *Journal of Economic Entomology*, 97(2): 390-396.
- Schroeder, J.B., S.T. Ratcliffe, and M.E. Gray. 2005. Effect of four cropping systems on variant western corn rootworm (Coleoptera: Chrysomelidae) adult and egg densities and subsequent larval injury in rotated maize. *Journal of Economic Entomology*, 98(5): 1587-1593.
- Spencer, J.L., T.R. Mabry, and T. Vaughn. 2003. Use of transgenic plants to measure insect herbivore movement. *Journal of Economic Entomology*, 96(6):1738-1749.

*Following the conclusion of our research efforts, our team received the following recognition at the Funk Awards Banquet in April 2003.*

*2003 Team Award for Excellence, Western Corn Rootworm Strategic Pest Management Team, College of Agricultural, Consumer and Environmental Sciences, Mark R. Band, Michael E. Gray, Scott A. Isard, E. Levine, H.A. Lewin, L. Liu, D.W. Onstad, S.T. Ratcliffe, H.M. Robertson, and J.L. Spencer, Funk Awards Banquet, University of Illinois.*

#### **Beneficiaries:**

Producers throughout the state of Illinois and those areas of the eastern Corn Belt in which the variant western corn rootworm has established are the direct beneficiaries of this research project. The investigators of this research have defined the range of the variant western corn rootworm in Illinois and have shed considerable light on the behavioral mechanism responsible for the expansion of the ovipositional range of this species. The results from these studies have contributed significantly to the development of resistance management models used by the United States EPA in the registration of transgenic (Bt) hybrids for corn rootworms. The adoption of these transgenic hybrids for corn rootworms is expected to increase significantly during the next decade. Our models will be used repeatedly by researchers and policy makers (USDA, EPA) in the next decade as they determine the most appropriate resistance management protocols to implement. The molecular portion of this project has served to provide a starting point for continued research by scientists (US and Europe) who seek to find a genetic marker that can be traced explicitly to the variant western corn rootworm population. This finding will be of significant importance in the US and Europe because of the continuing expansion of the western corn rootworm across Europe (now in 15 European countries). If the European population of western corn rootworms is of the variant "type" – the use of crop rotation in Europe will not serve as an effective cultural management approach for this insect pest. In an environment not accepting of soil insecticides or use of transgenic crops, one wonders how European corn producers will control this potentially devastating insect pest of corn? Results from our field and molecular studies are being reviewed carefully by our European scientific colleagues.

## **Outreach:**

As a result of C-FAR funding, much has been learned and written as we pursued these intriguing ecological questions along with providing contemporary management information to producers throughout affected areas of the eastern Corn Belt. Educational programs directed at producers have included the following: 1) presentations by researchers and extension specialists at the *Illinois Crop Protection Conference* (most widely attended conference by agricultural clientele in Illinois), 2) articles published in the *Pest Management & Crop Development Bulletin* (25 annual issues delivered to 3,300 subscribers, (<http://www.ipm.uiuc.edu/bulletin/contents.php>), 3) presentations at the *Illinois Corn and Soybean Classic* Regional Meetings (regional meetings (six per year, in Illinois, estimated attendance is approximately 1,200 producers), 4) radio and video presentations in combination with staff of the College of ACES Information Technology and Communication Services, 5) publication and dissemination of informational fact sheets (> 7,000 distributed to producers), and 6) dissemination of information through the world wide web using the College of ACES IPM web site (<http://ipm.uiuc.edu>).

Many of our C-FAR funded outreach programs have been targeted at communicating the extent to which rotation-resistant populations are spreading. These efforts combined with grower acceptance of our economic thresholds we developed, have led to a more selective and judicious use of soil insecticides. ***Due to producer adoption of University of Illinois recommendations developed through C-FAR support, nearly 7.5 million acres of Illinois soybeans have been spared aerial applications of insecticides to prevent western corn rootworm oviposition.*** Many of the aerial treatments would occur within eyesight of the most widely traveled corridors (I-57 and I-55) to Chicago. The negative furor and impact of witnessing the treatment of 7.5 million acres of soybeans to prevent corn rootworm oviposition would indeed be very significant. In addition, continuing concerns of the general public (particularly in Asia and Europe) regarding the use of crop protection inputs such as pesticides and transgenic crops, make it imperative that our foreign customers believe that our exported grain is free of any potentially harmful chemical residues. Our C-FAR funded modeling program projects the continued loss of crop rotation as a cultural pest management approach for an increasingly larger area of the Corn Belt. To date, our research and outreach efforts have been seized upon by entomologists in other states as they grapple with this daunting pest management challenge.

### *Factsheets Published from C-FAR Sentinel Research:*

Hartman, G.L., S.A. Isard, T.R. Mabry, J.L. Spencer, and E. Levine. 2002 NSRL Factsheet #5.

Illinois Soybean Pathology and Entomology Research, Bean Pod Mottle Virus and Its Insect Vectors.

Isard, S.A., J.L. Spencer, T.R. Mabry, and E. Levine. 2001. NSRL Factsheet #3. Illinois Soybean Pathology and Entomology Research, Beetles in Illinois Soybean Fields.

Isard, S.A., J.L. Spencer, T.R. Mabry, and E. Levine. 2001. NSRL Factsheet #2. Illinois Soybean Pathology and Entomology Research, Rotation-Resistant Western Corn Rootworm.

## **Leveraged Funding:**

The Sentinel C-FAR Grant has been the driver behind continued private sector, University, and USDA-CSREES support for expanding our knowledge of the biology and ecology of the variant western corn rootworm.

*Total Leveraged Funds:* \$767,938.00

- 2001 Movement, mating and soybean-feeding consequences for western corn rootworm adults. Monsanto support of western corn rootworm research. (PI: J. Spencer): \$6,000.00
- 2002 Movement and mating of adult western corn rootworms. Monsanto support of western corn rootworm research. (PI: J. Spencer): \$10,000.00
- 2003 Improving western corn rootworm management in rotated corn. USDA-CSREES North Central Region IPM Grant Program. (PIs: J. Spencer, S. Isard, and E. Levine). 5/1/03-4/31/05: \$79,460.00
- 2003 Assessing the risk of resistance to Bt corn by rotation-resistant rootworms. USDA Biotech Risk Assessment. (PIs: D. Onstad, P. Mitchell, J. Spencer, C. Guse, and M. Gray). 9/1/03 - 8/31/05: \$180,000.00
- 2004 Movement and mating of adult western corn rootworms. Monsanto support of western corn rootworm research. (PI: J. Spencer): \$3,644.00
- 2004 Measuring ascent trajectories of flying western corn rootworm beetles. University of Illinois Campus Research Board. (PI: J. Spencer). 1/1/05 -12/31/05: \$5,400.00
- 2004 Measuring ascent trajectories of flying western corn rootworm beetles. University of Illinois Campus Research Board. (PI: J. Spencer). 1/1/05 -12/31/05: \$5,400.00
- 2005 Measuring local ascent and low elevation flight of western corn rootworm beetles. Illinois Natural History Survey, Special Research Funding Program. (PI: J. Spencer). March-May, 2005: \$1,020.00
- 2006 Trap, then manage: using corn rootworm behavior to reduce producer inputs and optimize resistance management for transgenic corn. USDA-NRI Program (51.2): Organismal and Population Biology of Arthropods and Nematodes (Received notification May 2006, 4-year grant). (PI: Spencer, J.L., K.L. Steffey, and M.E. Gray): \$387,000.00
- 2006 Movement of rotation-resistant western corn rootworm beetles from soybean fields to cornfields. J. Spencer, D. Onstad, and E. Levine. USDA-CSREES North Central Region IPM Grant Program. 5/06-4/09 (PI: J. Spencer): \$90,014.00

**Websites:**

We have published the results of our findings in numerous articles in the *Pest Management and Crop Development Bulletin* for many years.

<http://www.ipm.uiuc.edu/bulletin/contents.php>

[http://www.ipm.uiuc.edu/fieldcrops/insects/western\\_corn\\_rootworm/index.html](http://www.ipm.uiuc.edu/fieldcrops/insects/western_corn_rootworm/index.html)