Soybean entomology in the North Central region:
Management and outreach for new and existing pests

Project Director: Kelley Tilmon, Ohio State University

Co-PIs:
Erin Hodgson, Matthew O'Neal (Iowa State); Brian McCornack (Kansas State); Janet Knodel, Deirdre Prischmann-Voldseth (North Dakota State); Robert Koch, Bruce Potter, George Heimpel (University of Minnesota); Punya Nachappa (Indiana University); Christian Krupke (Purdue University); Andy Michel (Ohio State); Brian Diers (University of Illinois); Deborah Finke (University of Missouri); Thomas Hunt, Robert Wright (University of Nebraska); Glen Hartman, Doris Lagos, Louis Hesler (USDA/ARS); Adam Varenhorst (South Dakota State)

Project Objectives

I. Extension and Outreach

II. Insect Monitoring and Management
1. Stink bug monitoring and management
2. Pollinator diversity and soybean yield
3. Soybean aphid insecticide resistance
4. Monitoring for aphids, thrips, and soybean vein necrosis
5. Technology development

III. Resistant Varieties and Biotypes
1. Breeding for resistant varieties
2. Aphid virulence genotyping and mapping
3. Aphid virulence management for resistant varieties
4. Economic returns on resistant varieties

IV. Biological Control

Year 2 Final Report (October 2016 through December 2017)

Summary

This report covers Year 2 in a 3-year ongoing project on management and outreach of soybean insects in the North Central region. The report contains three sections. The first section is on the scientific and extension deliverables generated in Year 2 of this project. These deliverables all contain information generated in NCSRP-funded work. The second section is a narrative of current progress. The third section is a list of the project metrics written into our proposal for Year 2, and their status.

During the reporting period we published 33 scientific journal papers, gave 33 presentations at scientific meetings, and organized 2 scientific symposia on soybean pest management. Breeding efforts produced 4 varieties now under commercial production, and 8 experimental lines under field evaluation and experimentation. There were 18 students or postdocs graduated or in training on projects related to NCSRP research. We gave 75 extension presentations to farmers and other crop professionals containing NCSRP research. We wrote 18 extension articles and published 14 extension publications. A highlight of these publications is the field guide, *Stink Bugs of the North Central Region*, a field-friendly pocket-sized booklet on stink bug identification, biology and management. 6000 free hard copies of this field guide have been distributed through universities and state checkoff organizations, and made available as a free download on SRII and other websites. Other extension deliverables include hands-on scouting exercises designed to be used at winter meetings to teach soybean management techniques. During the reporting period we earned $588,000 in additional funding related to our NCSRP-generated research, showing the power of NCSRP funding to leverage resources for soybean research. Finally, members of our group received 6 awards for NCSRP-related work during the reporting period. In a noteworthy honor, we received the International IPM Award of Excellence for an IPM team. This award will be conferred at the 9th International IPM Symposium in March, 2018.

Deliverables

Scientific Journal Publications

Ajayi-Oyetunde, OO., B. W. Diers, D. Lagos-Kutz, C. B. Hill, G. L. Hartman, U. Reuter-Carlson, and C. A. Bradley. 2016. Differential Reactions of Soybean Isolines with Combinations of Aphid Resistance Genes Rag1, Rag2, and Rag3 to Four Soybean Aphid Biotypes. Journal of Economic Entomology, 109 (3), 1431-1437. Available at https://doi.org/10.1093/jee/tow033

Asplen, M. K., J. M. Chacon, and G. E. Heimpel. 2016. Divergent sex-specific dispersal by a parasitoid wasp in the field. Entomologia Experimentalis et Applicata 159: 252-259.

Baldin, E.L.L., L. Marchi-Werle, L.E.R. Pannuti, T.M. Heng-Moss,. 2016. Evaluating categories of resistance in soybean genotypes from United States and Brazil to Aphis glycines (Hemiptera: Aphididae). Florida Entomologist 99 (3): 487-495.

Desneux, N., L. Monticelli, C. Luo, M.L, Asplen, C.M. Brady, G.E. Heimpel, K.R. Hopper, K.M. Oliver & J.A. White. 2018. Intraspecific variation in facultative symbiont infection among native and exotic pest populations: potential implications for biological control. Biological Control 116:27-35.

Hesler, L. S. and K. J. Tilmon. Infestation ratings database for soybean aphid on early-maturity wild soybean lines. Data in Brief 15:138-141.

Hesler, L. S., B. M. Van de Stroet, N. R. Schultz, E. A. Beckendorf and K. J. Tilmon. 2017. Laboratory Evaluation of Soybean Plant Introductions for Resistance to Aphis glycines (Hemiptera: Aphididae). Journal of Agricultural and Urban Entomology 33:133-141.

Hesler, L. S., E. A. Beckendorf, K. J. Tilmon, N. R. Burkard Schultz, B. M. Van De Stroet and P. A. Rozeboom. 2017. Resistance to soybean aphid in early-maturing plant introductions of soybean, 2012–2015. Arthropod Management Tests 42: 112.

Hill, C., D. Shiao, C. Fox and G. Hartman (2017). Characterization and genetics of multiple soybean aphid biotype resistance in five soybean plant introductions. Theoretical and Applied Genetics 130: 1335-1348.

Hill, C., D. Shiao, C. Fox and G. Hartman (2017). Characterization and genetics of multiple soybean aphid biotype resistance in five soybean plant introductions. Theoretical and Applied Genetics 130: 1335-1348.

Hopper, K.R., K.L. Kuhn, K. Lanier, J.H. Rhoades, K.M. Oliver, J.A. White, M.A. Asplen & G.E. Heimpel. 2018. The defensive aphid symbiont *Hamiltonella defensa* affects host quality differently for *Aphelinus glycinis* versus *Aphelinus atriplicis*. Biological Control 116: 3-9.

Kaiser M.C. & Heimpel GE. 2016. Parasitoid-induced transgenerational fecundity compensation in an aphid. Entomologia Experimentalis et Applicata 159: 197-206.

Hopper, K. R., K. Lanier, J. H. Rhoades, K. A. Hoelmer, W. G. Meikle, G. E. Heimpel, R. J. O'Neil, D. G. Voegtlin, and J. B. Wooley. 2017. Host specificity of *Aphelinus* species collected from soybean aphid in Asia. Biological Control 115: 55-73.

Jurenka R, Russell K, O'Neal, M. 2017. Phytoecdysteroids as antifeedants towards several beetles that include polyphagous and monophagous feeding guilds. Pest. Manag. Sci, 73: 1633–1637. https://doi.org/10.1002/ps.4500

Keough, S., Danielson, J., Marshal, J., Lagos-Kutz, D., Voegtlin, D., Srinivasan, R., and Nachappa, P. 2017. Factors affecting population dynamics of thrips vectors of Soybean vein necrosis virus. Environmental Entomology. In press

Koch, Robert L, Daniela T. Pezzini, Andrew P. Michel, and Thomas E. Hunt. 2017. Identification, Biology, Impacts and Management of Stink Bugs (Hemiptera: Heteroptera: Pentatomidae) of Soybean and Corn in the Midwestern United States. Journal of Integrated Pest Management, 8(1): 1-14. DOI: 10.1093/jipm/pmx004

Koch, Robert L, Robert L. Koch, Bruce D. Potter, Phillip A. Glogoza, Erin W. Hodgson, Christian H. Krupke, John F. Tooker, Christina D. DiFonzo, Andrew P. Michel, Kelley J. Tilmon, Travis J. Prochaska, Janet J. Knodel, Robert J. Wright, Thomas E. Hunt, Bryan Jensen, Adam J. Varenhorst, Brian P. McCornack, Kelly A. Estes, and Joseph L. Spencer. 2016. Biology and Economics of Recommendations for Insecticide-Based Management of Soybean Aphid. Plant Health Progress, Vol. 17: 4, 265- 269. DOI: 10.1094/PHP-RV-16-0061

Krupke, C. H., A. Alford, E. M. Cullen, E. W. Hodgson, J. J. Knodel, B. McCornack, B. D. Potter, M. I. Spigler, K. J. Tilmon, K. Welch. 2017. Assessing the value and pest management window provided by neonicotinoid seed treatments for management of soybean aphid (*Aphis glycines* Matsumura) in the Upper Midwest. Pest Management Science 73: 2184–2193.

Lagos-Kutz, D., D. Voegtlin, J. Davis, and G. Hartman. Dispersal records of the sugarcane aphid, Melanaphis sacchari (Zehntner) (Hemiptera: Aphididae), through the Midwest Suction Trap Network. Submitted December 2017. In review.

Lagos-Kutz, D., D. Dmitriev, and D. J. Voegtlin. 2018. An Interactive Key to Aphis of Midwestern United States of America. Available at http://dmitriev.speciesfile.org/key.asp?key=Aphis&lng=En&i=1&keyN=1 [2 February 2018]

Lagos-Kutz, D., D. J. Voegtlin, and G. Hartman. 2017. Identification of a new species of Aphis (Hemiptera: Aphididae) based on distinct morphology rather than DNA barcoding. Insecta Mundi. 1040. http://digitalcommons.unl.edu/insectamundi/1040

Lagos-Kutz D., C. Favret, R. Giordano, and D. J. Voegtlin. 2016. The status of the members of the Aphis asclepiadis species group (Hemiptera, Aphididae) in the United States of America. Annals of the Entomological Society of America, 109 (4), 585-594. doi: 10.1093/aesa/saw020

Lee S, Cassone BJ, Wijeratne A, Jun T-H, Michel AP. 2017. Transcriptomic dynamics in soybean near-isogenic lines differing in alleles for an aphid resistance gene, following infestation by soybean aphid biotype 2. BMC: Genomics. 18(1):47.

Lundgren, J.G., L.S. Hesler and R.L. Anderson. Preceding crop affects soybean aphid abundance and predator–prey dynamics in soybean. J. Appl. Entomol. doi:10.1111/jen.12395. 2016.

Marchi-Werle, L, E. L. L. Baldin, H. D. Fischer, T. M. Heng-Moss and T. E. Hunt 2017. Economic Injury Levels for Aphis glycines Matsumura (Hemiptera: Aphididae) on the Soybean Aphid Tolerant KS4202 Soybean (Glycine max (L.) Merrill). Journal of Economic Entomology, 110(5): 2100-2108, doi: 10.1093/jee/tox225.

Marchi-Werle, Lia, Renata Ramos Pereira, John C Reese, Tiffany Heng-Moss, Thomas Hunt. 2017. Yield Response of Tolerant and Susceptible Soybean to the Soybean Aphid. Agronomy Journal, 109 (4):1663-1669.

O'Neal ME, Varenhorst AD, Kaiser MC. 2018. Rapid evolution to host plant resistance by an invasive herbivore: soybean aphid (Aphis glycines) virulence in North America to aphid resistant cultivars. Current Opinion in Insect Science https://doi.org/10.1016/j.cois.2017.12.006

Regan, K. H., D. Ordosch, K. D. Glover, K. J. Tilmon and A. Szczepaniec. 2017. Effects of neonicotinoid insecticides on population dynamics of spider mites (Acari: Tetranychidae) and abundance of their natural enemies in soybean fields. Crop Protection 98:24-32.

Ribeiro, Matheus G P de M, Thomas E Hunt, Blair D Siegfried. 2017. Acute-contact and chronic-systemic in-vivo bioassays: regional monitoring of susceptibility to thiamethoxam in soybean aphid (Hemiptera: Aphididae) populations from the North Central United States. Journal of Economic Entomology, doi: 10.1093/jee/tox290.

Tietjen, C.L., T.E. Hunt, D.D. Snow, D. Cassada, and B.D. Siegfried. 2017. Method development for monitoring bean leaf beetle susceptibility to thiamethoxam seed treatments on soybean. Journal of Agricultural and Urban Entomology, 33: 32-43.DOI: 10.3954/1523-5475-33.1.32

Varenhorst AJ, Pritchard SR, O'Neal ME, Hodgson EW, Singh AK. 2017. Determining the Effectiveness of Three-Gene Pyramids Against Aphis glycines (Hemiptera: Aphididae) Biotypes. Journal of Economic Entomology 110 (6), 2428-2435 https://doi.org/10.1093/jee/tox230

Ward, R.A., K.S. Kim, and B.W. Diers. 2017. Yield drag associated with the soybean aphid resistance gene *Rag2* from PI 200538. Crop Sci. 57:3035-3042.

Wenger JA, Cassone B, Cassone BJ, Legeai F, Johnston JS, Bansal R, Yates AD, Coates BS, Pavinato VAC, Michel A. 2017. Whole genome sequence of the soybean aphid, Aphis glycines. Insect Biochemistry and Molecular Biology. doi: 10.1016/j.ibmb.2017.01.005.

Yates AD, Michel AP. 2018. Mechanisms of aphid adaptation to host plant resistance. Current Opinion in Insect Science. Accepted.

Scientific Presentations

Indiana Contributions

Danielson, J., Loeffler, T., Keough, S., Marshall, J., and Nachappa, P. 2017. Factors Affecting the Population Dynamics of Thrips Vectors of Soybean Vein Necrosis Virus in Indiana. Indiana Academy of Science Annual Meeting. Indianapolis, IN. March 28th.

Danielson, J., Loeffler, T., Keough, S., Marshall, J., and Nachappa, P. 2017. Factors Affecting the Population Dynamics of Thrips Vectors of Soybean Vein Necrosis Virus in Indiana. Indiana University-Purdue University Research and Creative Endeavor Symposium. March 29th.

Iowa Contributions

Rodbell, E., E. W. Hodgson, M. Liebman, and M. E. O'Neal. Effect of crop rotation on the population growth rate of soybean aphid. PI-E Student Paper Competition. 65th Annual Entomological Society of America Meeting, Denver, CO, 5 November 2017.

Dean, A., S. Pritchard, M. O'Neal, and E. Hodgson. Optimizing yield environments and soybean genetics for soybean aphid management. PI-E Student Poster Competition. 65th Annual Entomological Society of America Meeting, Denver, CO, 6 November 2017.

Rodbell, E., E. W. Hodgson, M. Liebman, and M. E. O'Neal. Effect of crop rotation on the population growth rate of soybean aphid. M.S. Student Competition. 72nd Annual North Central Branch Entomological Society of America Meeting, Indianapolis, IN, 5 June 2017.

Minnesota Contributions

Pezzini, D.T., D. Finke, T. Hunt, J. Knodel, C.H. Krupke, B. McCornack, A. Michel, C. Philips, A. Varenhorst, R. Wright and R.L. Koch. 2017, November. Influence of field and landscape factors on stink bug (Hemiptera: Pentatomidae) community in North Central soybean. Student competition 10-minute presentation. Meeting of the Entomological Society of America. Denver, CO.

Pezzini, D.T., D. Finke, T Hunt, J. Knodel, C. Krupke, B. McCornack, A. Michel, C.R. Philips, A. Varenhorst, R. Wright, and R.L. Koch. 2017, June. Spatial pattern and sequential sampling plan for stink bugs (Hemiptera: Pentatomidae) for soybean in the north central U.S. Student competition 10-minute paper. Meeting of the North Central Branch of the Entomological Society of America. Indianapolis, IN.

Kaiser, M. & G.E. Heimpel. Transgenerational fecundity compensation in the aphid Aphis craccivora in response to parasitism by two competing parasitoids. International Congress of Entomology, Orlando, FL, USA, 10/2016.

Kaser, J. & G.E. Heimpel. Parasitoid host range, establishment success, and biological control efficacy. Symposium presentation. International Congress of Entomology, Orlando, FL, USA, 10/2016.

Kaser, J., G.E. Heimpel. Evaluating classical biological control benefits and non-target risk: from models to the field. Symposium presentation. Entomological Society of America, North Central Branch meeting, Cleveland, OH, 6/2016.

Kaser, J. J. Dregni, N. Padowski, R. Koch, G.E. Heimpel. Biological control ecology: lessons from introduced soybean aphid parasitoids. Symposium presentation. Entomological Society of America, North Central Branch meeting, Cleveland, OH, 6/2016.

Heimpel, G.. Causes and consequences of fecundity stimulation in aphids as a response parasitism. Keynote address. Ecology of Aphidophaga Conference, Freising, Germany, 8/2016.

Heimpel, G.. Biological control of the soybean aphid. Symposium presentation. Workshop on linkages between soybean aphids and endangered prairie butterflies. Institute on the Environment, St. Paul MN, USA, 11/2016

Miksanek, J. & G.E. Heimpel. Parasitism rate and percent parasitism in stage-classified matrix models: an example of soybean aphid and Aphelinus certus (Hymenoptera: Aphelinidae). Annual Meeting of the North Central Branch of the Entomological Society of America, Indianapolis, IN, USA, 6/2017

Welch, K. G.E. Heimpel, K.R. Hopper, M.C. Kaiser, M.E. O'Neal. Can aphid-resistant soybean enhance early-season suppression of soybean aphids by Aphelinus wasps? Symposium at the

North Central Branch meeting of the Entomological Society of America, Indianapolis, IN, USA, 6/2017.

Heimpel, G.. Update on biological control of soybean aphid. Crop Pest Management Short Course. Minneapolis, MN, 12/2017

Nebraska Contributions

Hunt, Thomas, Erin Hodgson, and Kelley Tilmon. 2017. Soybean IPM in the Midwest? 2017 Entomological Society of America Southeastern Branch Meeting, Invited, Memphis, TN, March 12 - 15, 2017.

Ribeiro, Matheus, Blair Siegfried and Thomas Hunt. 2017. Age-Specific Susceptibility of Soybean Aphid to Thiamethoxam Using a Detached-Leaf Bioassay Method. Entomological Society of America North Central Branch Meeting, Indianapolis, Indiana, June 04, 2017.

Fanela, T. L. M. (Presenter & Author), Baldin, E. L. L., Luhr, N., Hunt, T. E., 2017. Characterization of larval movement of Spodoptera eridania (Lepidoptera: Noctuidae) in non-Bt soybean. Entomological Society of America Annual Meeting, Denver, CO, November 7, 2017.

Ohio Contributions

Pavinato, V. D Lagos-Kutz, G Hartman, C Hill, A Chirumamilla, AP Michel. September 2016. Characterization of quantitative trait loci associated with soybean aphid adaptation to resistant plants. International Congress of Entomology. Orlando, Florida.

Michel A. Soybean Aphid Adaptation to Aphid-Resistant Soybean. Dept. of Entomology, Iowa State University. Ames, IA. Oct 2017

Michel A. Soybean Aphid Adaptation to Aphid-Resistant Soybean. Dept. of Entomology, University of Nebraska-Lincoln. Lincoln, NE. Nov 2016

Guidolin A, Lagos-Kutz D, Pavinato VAC, Hartman G, Michel AP. 2017. Association mapping of virulence in soybean aphid (Aphis glycines). Entomological Society of America Annual Meeting, Denver, CO Nov 2017

Wenger JA, Michel AP, Legeai F, Bansal R, Johnston JS, Pavinato V, Yates A, Cassone B. 2016. Genome assembly of the soybean aphid (Aphis glycines) via hybrid approach. International Congress of Entomology Meeting, Orlando, FL Sep 2016

Yates AD, Bansal R, Pavinato VAC, Michel AP. 2016. Identifying changes in gene expression that may promote virulence in the soybean aphid, Aphis glycines. International Congress of Entomology Meeting, Orlando, FL Sep 2016

Pavinato VAC, Lagos-Kutz D, Hartman G, Hill CB, Chirumamilla A, Michel A. 2016. Characterization of quantitative trait loci associated with soybean aphid adaptation to resistant plants. International Congress of Entomology Meeting, Orlando, FL Sep 2016

Tilmon, K. J. 2017. Human behavior flows from three main sources: What Plato can teach us about grower pesticide choices. Entomological Society of America Southeastern Branch Meeting. Memphis, TN. March 13.

Tilmon, K. and C. Welty. 2017. Testing baited sticky cards as a sampling method for brown marmorated stink bug in soybean. Poster: Entomological Society of America Annual Meeting. Denver, Co. Novermber 7.

South Dakota Contributions

Conzemius, S., L. Hesler, A. Varenhorst and K. Tilmon. 2017. Mind your elders: Wild soybean's contribution to soybean aphid resistance. Talk: Entomological Society of America Annual Meeting. Denver, Co. Novermber 6.

Hesler, L. and K. Tilmon. 2017. Identification and confirmation of resistance against soybean aphid (Aphis glycines) in eight wild soybean lines. Poster: Entomological Society of America Annual Meeting. Denver, Co. Novermber 7.

Hesler Lab. "Cool Beans! Soybean Accessions That Limit Aphid Biotype 4 Cool Beans!" Gamma Sigma Delta Honor Society of Agriculture Poster Contest, College of Agriculture and Biological Sciences, South Dakota State University, April 3, 2017

Hesler Lab. "No choice but to Find Resistance to Soybean Aphid Biotype 4," North Central Branch Meeting, Entomological Society of America, Indianapolis, IN. June 6, 2017

Hesler Lab. "Newly Identified Resistance to Soybean Aphid (Aphis glycines) in Soybean Plant Introduction Lines," North Central Branch Meeting, Entomological Society of America, Indianapolis, IN. June 6, 2017

Plant Breeding Accomplishments

Varieties developed and released: The University of Illinois soybean breeding program has four soybean varieties under commercial production with aphid resistance genes. These varieties have either the Rag1 or Rag2 gene. During 2017, almost 10,000 units of seed of these lines were sold to farmers. In addition, three more aphid resistant lines were provided to a seed company to start seed increases of the lines. One of these lines has both Rag1 and Rag2 stacked together.

Experimental line distributed: Aphid resistant soybean lines were distributed to collaborators for 2017 field tests. These lines were developed through previous funding from NCSRP and they have all eight possible combinations of Rag1, Rag2, and Rag3 (lines range from having all three resistance genes to no resistance genes) backcrossed into a maturity group (MG) I and a MG II background. Seed of all eight lines in both backgrounds were sent to cooperators within the team for futher work.

Theses/dissertations

Ribeiro, Matheus Geraldo Pires de Mello. 2017. Baseline Susceptibility, Resistance Detection and Selection for Resistance in *Aphis glycines* (Hemiptera: Aphididae) to the Neonicotinoid Insecticide, Thiamethoxam. ETD collection for University of Nebraska - Lincoln. AAI10271836.

Russell Ward. Genetic improvement of aphid resistance, protein, and elemental composition in soybean (Brian Diers Lab)

Scientific Symposia

Hodgson Lab. Co-Organizer, World Soybean Research Conference Symposium: Insect and Weed Resistance in Soybean, September 2017 [canceled due to Hurricane Irma]

Hodgson Lab. Co-Organizer and Moderator, NCB-ESA Symposium: Resistance management, June 2017

Extension Presentations

Indiana Contributions

Krupke Lab. Brooke Dennis, MS student presented "The role of insect pollinators in enhancing Indiana soybean yields" at Indiana Soybean Summit meeting in May 2017

Iowa Contributions

Hodgson, E. W. Soybean IPM: using thresholds to manage defoliators. University of Missouri Crop Management Conference, Columbia, MO [2 sessions; 150 people] 14 December 2017

Hodgson, E. W. Setting your defoliation eye for threshold-based spraying in field crops. The Illinois, Indiana, Ohio (Tri-State) Certified Crops Advisers Annual Conference, Indianapolis, IN [2 sessions; 95 people] 12 December 2017

Lewis, D., E. W. Hodgson, and L. Jesse. Introduction to field crop insects and management in the U.S. Iowa State University Extension and Outreach, India Study Abroad Course. Ames, IA. [20 people] 7 October 2016.

Hodgson, E. W. Resistance management plan for soybean aphid. Iowa State University Field Agronomist Professional Development Workshop, Ames, IA. [22 people] 29 November 2016

Hodgson, E. W. Soybean aphid bites back: update on pyrethroid resistance. Iowa State University Extension and Outreach Integrated Crop Management Annual Conference, Ames, IA. [2 sessions; 155 people] 29 November 2017

Hodgson, E. W. IPM and economic thresholds for insects. Iowa State University Extension and Outreach Ag Chem Dealer Update, Iowa City. 21 November 2017

Hodgson, E. W. IPM and economic thresholds for insects. Iowa State University Extension and Outreach Ag Chem Dealer Update, Ames, IA 13 December 2017

Hodgson, E. W. Introduction to insect diagnostics. Syngenta Annual Spring Training, Ames, IA. [25 people] 5 April 2017

Hodgson, E. W. Introduction to insect diagnostics. Iowa State University Extension and Outreach Crop Scout School, Ames, IA. [45 people] 25 March 2017

Hodgson, E. W. Resistance management for two key field crop pests. Iowa Soybean Association Research Conference, Des Moines, IA. [15 people] 8 February 2017

Hodgson, E. W. Resistance management plans for soybean aphid. 2017 Iowa State University Extension and Outreach Crop Advantage Series Workshops.

- Sheldon, IA. [38 people] 4 January 2017
- Okoboji, IA. [22 people] 5 January 2017
- Storm Lake, IA. [6 people] 10 January 2017
- Mason City, IA. [2 sessions; 75 people] 13 January 2017
- Fort Dodge, IA. [2 sessions; 85 people] 18 January 2017
- Le Mars, IA. [6 people] 24 January 2017
- Denison, IA. [8 people] 26 January 2017

Hodgson, E. W. Resistance management update for soybean aphid and corn rootworm. Iowa State University Extension and Outreach Crop Clinic.

- Mason City, IA. [85 people] 9 December 2016
- Northwood, IA. [115 people] 9 December 2016

Hodgson, E. W. Resistance management plan for soybean aphid. Iowa State University Extension and Outreach Integrated Crop Management Annual Conference, Ames, IA. [2 sessions; 150 people] 1 December 2016

Hodgson, E. W. Resistance management update for soybean aphid and corn rootworm. Iowa State University Extension and Outreach Ag Chem Dealer Update.

- Iowa City, IA. [115 people] 22 November 2016
- Ames, IA. [80 people] 7 December 2016

Kansas Contributions

McCornack, B. 2018. myFields.info—field crop information when and where you need it! Ohio AgriBusiness Association Industry Conference, Dublin, OH. (Presenter)

McCornack, B., and C.M. Smith. 2018. An integrated approach to managing Dectes stem borer in Kansas. Kansas Soybean Expo, sponsored by the Kansas Soybean Association, Topeka, KS. (K-State Research and Extension update)

McCornack, B. 2017. Insect and ecosystem services—building resistance, resilience and recovery into the farm. In, 2017 Agriculture's Innovative Minds (AIM) Symposium. No-Till on the Plains, Salina, KS; bio: http://www.notill.org/brian-mccornack). (Symposium)

McCornack, B. 2017. Blending ecology and technology to manage pests and beneficial organisms. Department of Entomology and Plant Pathology Seminar Series, Oklahoma State University, Stillwater, OK. (Seminar)

Minnesota Contributions

Potter, Bruce. 23 meetings and more than 1700 attendees primarily in SC,SW and WC MN

Koch, R.L., K. Ostlie and Erica Nystrom. 2017, July. Identification of insects and the injury they cause in field crops. Field School for Agricultural Professionals. Institute for Agricultural Professionals, University of Minnesota Extension. St. Paul, MN (four 90-minute presentations with 25, 26, 26, and 24 attendees).

Koch, R.L. 2017, February. Emerging challenges for insect pest management in soybean. Rice and Steele Counties Crops Day, University of Minnesota Extension. Owatonna, MN (50-minute talk with 26 attendees).

Koch, R.L. 2017, February. New challenges to soybean pest management. Tri State Aerial Applicators Conference. St. Cloud, MN (50-minute talk with 300 attendees).

Koch, R.L. 2017, January. Crop insects management. Field Crop Pest Management Recertification, University of Minnesota Extension. (40-minute talk; St. Cloud: 80 attendees; Faribault: 160 attendees).

Koch, R.L. 2017, January. Managing insect pests of soybean: Insecticide-resistant aphids and other challenges. Research Updates for Agricultural Professionals. Institute for Agricultural Professionals, University of Minnesota Extension. (30-minute talk; Waseca: 60 attendees; Kasson: 76 attendees; Lamberton: 56 attendees; Morris: 55 attendees; Crookston: 65; Willmar: 60 attendees).

Ohio Contributions

Michel, A. Insect Update for 2016/2017. Pesticide Applicators Training (PAT) Recertification Field Crop Conference. Akron, OH. Feb 15

Michel, A. Agronomic Crop Insect Management for 2016/2017. 2017 Agronomy Workshop Delaware County. Waldo, OH. Feb 23.

Michel, A. Insect Update for 2016/2017. Pesticide Applicators Training (PAT) Recertification Field Crop Conference. Dayton, OH. Feb 10.

Tilmon, K. J. McFarland County extension meeting. January 4, 2017.

Tilmon, K. J. Wester Ohio Agronomy Day. January 9, 2017.

Tilmon, K. J. Sandusky Pesticide Applicator Training. January 19, 2017.

Tilmon, K. J. Putnam County Agronomy Night. January 19, 2017.

Tilmon, K. J. Ohio Top Farmers Meeting. January 28, 2017.

Tilmon, K. J. Soybean College, Willard OH. January 31, 2017.

Tilmon, K. J. Northern Ohio Crops Day. February 2, 2017.

Tilmon, K. J. Darke County Soybean College. February 7, 2017.

Tilmon, K. J. Columbus Pesticide Applicator Training. February 28, 2017.

Tilmon, K. J. Conservation Tillage Conference, Ada OH. March 7, 2017.

Tilmon, K. J. Soybean School, Zanesville OH. March 9, 2017.

Tilmon, K. J. Northwest Ohio Field Day. July 27, 2017.

Tilmon, K. J. Champaign Co. Field Day. July 31, 2017.

Tilmon, K. J. Ashland Field Day. August 4, 2017.

Tilmon, K. J. TMK Bakersville Field Day. September 6, 2017.

Tilmon, K. J. Ohio Extension Educator In-Service. December 12, 2017.

South Dakota Contributions

Hesler Lab. "Plant Resistance: A Crucial Link in Harvesting Soybeans' Full Potential," Eastern South Dakota Soil & Water Research Farm—Field Day, Eric Beckendorf, USDA-ARS, Brookings SD & Sophi Conzemius, SDSU, Brookings SD

Extension Publications

Illinois Contributions

Lagos-Kutz, D. and D. Voegtlin. 2016. Midwest Aphid Suction Trap Network. Farm Progress Reports: Vol. 2015 (1), Article 66. http://lib.dr.iastate.edu/farmprogressreports/vol2015/iss1/66

Lagos-Kutz, D. and D. Voegtlin. 2016. Midwest Aphid Suction Trap Network. Farm Progress Reports: Vol. 2015 (1), Article 66. http://lib.dr.iastate.edu/farmprogressreports/vol2015/iss1/66

Iowa Contributions

Hohenstein JD, Kaiser MC, Hodgson EW, O'Neal ME. 2017. Refuge-in- a-bag approach for sustainable management of virulent soybean aphids in the field. 2017 Northwest Research Farm Progress Report. https://lib.dr.iastate.edu/farmprogressreports/

Dean AN, Hodgson EW, and O'Neal ME. 2017. Evaluation of soybean aphid management tactics. 2017 Northwest Research Farm Progress Report. https://lib.dr.iastate.edu/farmprogressreports/

Hodgson, E. W. Resistance management plan for soybean aphid, pp. 95-96. In Proceedings: 29th Annual Iowa State University Integrated Crop Management Conference, Ames, IA, 29-30 November 2017.

Hodgson, E. W. Resistance management for soybean aphid, p. 14. In Proceedings: Iowa State University Crop Advantage Series, Ames, IA, January 2017.

Hodgson, E. W. Resistance management for soybean aphid, pp. 97-99. In Proceedings: 28th Annual Iowa State University Integrated Crop Management Conference, Ames, IA, 30 November - 1 December 2016.

Hodgson, E. W., and G. VanNostrand. 2017. 2017 Yellow Book Report of insecticide evaluation for soybean pests, 22 pp. Department of Entomology, Iowa State University, Publication 302-17.

Mueller, D., A. Sisson, L. Abendroth, E. Hodgson, L. Iles, B. Kleinke, C. McGrath, R. Pope, A. Robertson, and K. Schaefer. 2017. Field crop scouting. Iowa State University Extension and Outreach. Interactive Web Book: https://bleepblorp.pub.

Hodgson, E. W., and G. VanNostrand. 2016. 2016 Yellow Book Report of insecticide evaluation for soybean pests, 22 pp. Department of Entomology, Iowa State University, Publication 300-16.

Minnesota Contributions

Koch, R.L., D.T. Pezzini, A.P. Michel and T.E. Hunt. 2017. Identification, biology, impacts and management of stink bugs (Hemiptera: Heteroptera: Pentatomidae) of soybean and corn in the midwestern United States. Journal of Integrated Pest Management 8(1): 1-14 https://academic.oup.com/jipm/article-lookup/doi/10.1093/jipm/pmx004

Nebraska Contributions

Specht, J.E., T. Hoegemeyer, T.E. Hunt, plus 30 other co-authors. 2017. Nebraska Soybean & Corn Pocket Field Guide. Nebraska Soybean and Corn Boards and United Soybean Board.

Wright, R., J. Peterson, T. Hunt, J. Bradshaw and J. McMechan. 2017. Crop Insect Resistance Issues in Nebraska. Proceedings of the 2017 Crop Production Clinics, pp. 34-35. University of Nebraska Extension, Lincoln, NE.

McMechan, J., R. Wright and T. Hunt. 2017. Emerging and invasive pests. Proceedings of the 2017 Crop Production Clinics, pp. 40-41. University of Nebraska Extension, Lincoln, NE.

Ohio Contributions

Raudenbush, A., A. Michel and K. Tilmon. 2017. Stink bugs on soybean in the North Central region. A publication of the North Central Soybean Research Program. 6000 copies distributed.

Extension Articles

Ohio Contributions

Michel, Andy, and Kelley Tilmon. "We've been slimed -- Slugs impacting corn and soybean crops in Ohio." CORN Newsletter: 2017-16. June 6 – June 12, 2017.

Michel, Andy, and Kelley Tilmon. "Be on the Lookout for Soybean Aphids." CORN Newsletter: 2017-26. August 14 – August 21, 2017.

Michel, Andy, and Kelley Tilmon. "What's that smell? Brown marmorated stink bug headed into homes." CORN Newsletter: 2017-32. September 25 – October 2, 2017.

Tilmon, Kelley, and Andy Michel. "Slugs can't spring, but late spring is the time to watch for them". CORN Newsletter: 2017-14. May 23 – May 29, 2017.

Tilmon, Kelley, and Andy Michel. "Japanese Beetles in Corn and Soybeans." CORN Newsletter: 2017-20. July 4 – July 10, 2017.

Tilmon, Kelley, and Andy Michel. "Stink Bugs in Soybean." CORN Newsletter: 2017-24. August 1 – August 7, 2017.

Tilmon, Kelley, and Andy Michel. "Late Season Soybean Insects." CORN Newsletter: 2017-27. August 21 – - August 28, 2017.

Tilmon, Kelley, and Andy Michel. "Some Thoughts on Slugs." CORN Newsletter: 2017-33. October 3 –October 9, 2017.

Iowa Contributions

Hodgson, E. "Summary of soybean aphid efficacy evaluation for 2017. " In Integrated Crop Management News. 21 December 2017.

Hodgson, E. “Drought stress promotes spider mite injury.” In Integrated Crop Management News. 21 July 2017.

Hodgson, E. “Japanese beetle.” In Integrated Crop Management Encyclopedia Article. 21 June 2017.

Hodgson, E. “Imported longhorned weevil.” In Integrated Crop Management Encyclopedia Article. 21 June 2017.

Hodgson, E. “Thistle caterpillar.” In Integrated Crop Management Encyclopedia Article. 21 June 2017.

Hodgson, E. “Bean leaf beetle.” In Integrated Crop Management Encyclopedia Article. 21 June 2017.

Hodgson, E. “Japanese beetles emerging in southern Iowa.” In Integrated Crop Management News. 13 June 2017.

Hodgson, E. “Stalk borers moving in southern Iowa.” In Integrated Crop Management News. 26 May 2017.

Hodgson, E., and A. Sisson. “Bean leaf beetle mortality predictions.” In Integrated Crop Management News. 10 April 2017.

Hodgson, E. “Resistance management plan for soybean aphid.” In Integrated Crop Management News. 15 February 2017.

Extension – Other Accomplishments

Raudenbush, A. and K. Tilmon. 2017. Hands-on speed scouting exercise (for use in extension programs).

Raudenbush, A. and K. Tilmon. 2017. Hands-on soybean defoliation estimation exercise (for use in extension programs).

Raudenbush, A., A. Michel and K. Tilmon. 2017. Ohio State University Agronomic Crop Insects Website. https://aginsects.osu.edu/

University of Nebraska. Crop Production Clinics

University of Nebraska. Soybean Production Clinic

University of Nebraska. Soybean Management Field Days

Hodgson, E. W. Video: Threshold-based management for soybean defoliators. PSEP Program, Iowa State University. January - December 2018.

Hodgson, E. W. Video: Japanese beetle management. PSEP Program, Iowa State University. January - December 2017.

Hodgson, E. W. Video: Soybean aphid resistance management. PSEP Program, Iowa State University. January - December 2017.

Hodgson, E. W. et al. ISU Field Crop Entomology website: https://www.ent.iastate.edu/soybeanresearch/content/extension

Leveraged Grants

Hodgson, E., M. O'Neal, J. Coats and B. Coates. Extension and research to combat insecticide-resistant soybean aphids," Iowa Soybean Association, 2017 – 2020 ($291,103)

Hodgson, E. H. Evaluating Soybean Aphid Management with an Expanded Toolbox,Iowa Soybean Association, 2017-2018 ($41,268)

McCornack, B. P. ($30K) Kansas Soybean Commission. Agricultural Research Experiences for Teachers (RET)—Using Soybean as a Model System in Kansas. The entomology lessons during the institute focus on soybean aphid and research findings from NCSRP.

Smith, C.M., B. P. McCornack and R. J. Whitworth ($107K). Development of Genetic, Chemical and Population-Based Tactics to Manage Key Kansas Soybean Insect Pests.

Tilmon, K. J. and A. Michel. 10/2016-09/2017. Research and management of soybean insects. Ohio Soybean Council. ($60,000)

Tilmon, K. J. and A. Michel. 10/2017-09/2018. Research and management of soybean insects. Ohio Soybean Council. ($60,000)

Graduate Students in Training

Carlos Esquivel (Ohio State University, PhD in training)

Ashley Yates, (Ohio State University, PhD in training)

Jacob Wenger, PhD. (Ohio State University, graduated, currently Assistant Professor, Fresno State University)

Russell Ward. Completed his Ph.D. degree May, 2017. (Brian Diers Lab). Currently a corn breeder for Syngenta in South Dakota.

Jaeyeong Han. Crop Sciences. University of Illinois at U-C. Training on aphid taxonomy.

Ben Daniels. Natural Resources Environmental and Sciences. University of Illinois at U-C. Training on aphid taxonomy.

Sophia Conzemius, South Dakotat State University

Ezra Auerbach, South Dakota State University

Hodgson Lab, Iowa State University. Ashley Dean, master's degree

Jonathan Danielson, Nachappa Lab, Purdue

Blessing Ademokoya PhD. University of Nebraska.

Thiago Fanela, PhD Sandwich student from Brazil. University of Nebraska.

Tamíris Araújo, PhD Sandwich student from Brazil. University of Nebraska.

Daniela Pezzini, MS student (U of MN, Entomology, Koch lab)

Brooke Dennis, graduation date of 05/2018 (Purdue University)

Ashley N. Dean - graduate research assistant, Iowa State

Postdocs in Training

Matthew C. Kaiser, Iowa State

Jessica D. Hohenstein, Iowa State

Awards

International IPM Award of Excellence, awarded to the North Central Soybean Entomology Research and Extension Team. 9th International IPM Symposium, Baltimore MD, March 2018

Kelley Tilmon, Distinguished Achievement Award in Extension, Entomological Society of Americal North Central Branch. 2017. Based on extension programming related to NCSRP research.

Daniela Pezzini (MS student, Koch lab): 2nd Place, Student 10-minute Paper Competition, Meeting of the Entomological Society of America, Denver, CO. (2017)

Daniela Pezzini (MS student, Koch lab): Master's Student Achievement in Entomology Award, Plant-Insect Ecosystems (P-IE) Section, Entomological Society of America. (2017)

Daniela Pezzini (MS student, Koch lab): 2nd Place, M.S. Student 10-minute Paper Competition, Meeting of the North Central Branch of the Entomological Society of America, Indianapolis, IN. (2017)

Brooke Dennis won Indiana Seed Trade Association scholarship for her work with native pollinators in Indiana soybeans. (Purdue University)

.

Other Deliverables

- The USDA laboratory in Urbana keeps alive the stock of the curent described four soybean aphid biotypes, and have been shared with other researchers in Midwest.

- The Midwest Suction Trap Network (MSTN) operates in 8 states with a total of 31 locations. A representative set of archival aphid slides from aphids collected in the MSTN have been made to be deposited in the INHS Insect Collection Museum. Online 3I Interactive Key for Aphis species in the Midwest USA has been updated to easy access http://dmitriev.speciesfile.org/key.asp?key=Aphis&lng=En&i=1&keyN=1). Suction trap samples collected in 2016 and 2017 have been shared with Punya Nachappa to monitor mainly soybean thrips.

Results

I. Extension and Outreach

We gave 75 extension presentations to farmers and other crop professionals containing NCSRP research. We wrote 18 extension articles and published 14 extension publications. A highlight of these publications is the field guide, *Stink Bugs of the North Central Region*, a field-friendly pocket-sized booklet on stink bug identification, biology and management. 6000 free hard copies of this field guide have been distributed through universities and state checkoff organizations, and made available as a free download on SRII and other websites. Other extension deliverables include hands-on scouting exercises designed to be used at winter meetings to teach soybean management techniques.

II. Insect Monitoring and Management

1. Stink bug monitoring and management: This is the second year of a 3-year study. The goal is to devise management thresholds for stink bugs that are specific to the North Central Region. In 2017, Michigan was added to the project, resulting in a total of 9 states. Work continues on identifying stink bugs from summer sampling and analyzing

data. Some additional data collection will be conducted in Year 3 of the project, and final data analysis completed.

2. Pollinator diversity and soybean yield: The goal of this study is to document the diversity of pollinators present in soybean fields. Pollinators may enhance soybean yield, and soybean may serve as an important reservoir for pollinator biodiversity. Participants in ND, SD, IA, OH, MN, NE, IN, MO, WI collected pollinators in soybean fields. Bees identified from soybean to date include 5,513 individual bees representing 71 species in 17 genera and five families. This is an increase of 14 species compared to the 2014 survey. While only three states are done, the remaining six states (MO, IA, WI, MN, SD, ND) have two fields each and not as many individuals, so identification of bees is about 50% done. Syrphid flies (also important pollinators) will be identified after bees are finished. For the project to assess the diurnal activity of wild and managed bees in soybeans: Currently the EPA requires farmers to limit their application of insecticide to periods when bees are not on flowers to reduce exposure. Honey bees (and other bees) typically fly only during periods of daylight, which limits applications to dusk. Some commercial applicators have questioned whether honey bees are active throughout the entire day or if they limit their foraging to optimal periods of activity, when temperatures are not at their highest. In order to gain a better understanding of this topic we conducted a study to determine the diurnal activity of honey bees and other bees in soybean fields growing in a variety of environments along a nationwide transect, from Mississippi to South Dakota. Sampling took place once a week from R1 to R4. These data are still being processed. We are also planning how to approach this objective in Year 3 of the project, during the summer of 2018.

3. Soybean aphid insecticide resistance: The goals of this objective are to monitor for soybean aphid resistance to the insecticide thiamethoxam in the North Central Region, and to develop a DIY assay kit to test aphids for resistance to thiamethoxam insecticide. Our resistance monitoring has detected shifts in tolerance in certain soybean aphids, but the shifts are very low. We have also fine-tuned the bioassays used to monitor this resistance with various improvements. We have developed this technique to the point where it can be used as a research tool. However, we have concluded that it will not work to develop this as a "do-it-yourself" kit for ag professionals. We have tried many methods to make this user-friendly for crop consultants. However, the soybean aphid has proven too delicate for the DIY kit approach unless the end-user is trained to handle these types of insects. Too much soybean aphid injury and mortality occurs during aphid transfer. However, we have developed the methodology to the point where it is a useful research tool for trained researchers involved in resistance monitoring. Instead of further effort to develop a kit for widespread use, we are shifting our focus to aphid genetics as a component of resistance monitoring. Dr. Andrew Michel's Lab (Ohio) has been assisting with genetic typing and development of clonal lineages. One hundred-sixty clonal populations were sent to Nebraska and each population is undergoing requisite population increase needed for bioassay.

4. Monitoring for aphids, thrips, and soybean vein necrosis: Soybean vein necrosis virus is transmitted by thrips. We sampled thrips from suction traps in 6 states. We have

completed thrips survey for the 2016 growing season and begun processing the 2017 samples. There does not appear to be much thrips activity in May in most of the locations. Thrips populations start to increase in June which coincides with early vegetative stages of soybean in most Midwest states. The northern states don't seem to have high thrips numbers even in June. Thrips activity peaked in July-August in most states and begins a decline in September. Populations of thrips vectors of SVNV are high during July-August in most locations. This coincided with appearance of the disease in IN but we did not receive any SVNV samples from other states. Regarding suction trap monitoring for soybean aphid population trends: The Midwest Suction Trap Network (MSTN) operates in 8 states with a total of 31 locations. A representative set of archival aphid slides from aphids collected in the MSTN have been made to be deposited in the INHS Insect Collection Museum. Online 3I Interactive Key for Aphis species in the Midwest USA has been updated to easy access http://dmitriev.speciesfile.org/key.asp?key=Aphis&lng=En&i=1&keyN=1). Suction trap samples collected in 2016 and 2017 have been shared with Punya Nachappa to monitor mainly soybean thrips. We have decided that the best home for the MSTN data is the Center for Invasive Species & Ecosystem Health at the University of Georgia (https://www.bugwood.org/). The suction trap data files are ready to be shared as soon as we communicate with the responsible of this database system. Moreover, emphasis on extension will be focus with the data collected from the MSTN.

5. Technology development: The goal is to develop an aphid-counting app. We are currently approximately 70% done with processing images collected over the past two summers (approx. 3000 total). Currently, mobile device cameras equipped with the android operating system are able to detect more aphids on infested soybean leaflets compared to iOS-based devices when using our aphid counting software. Work on this objective will continue in Year 3 of the project.

III. Resistant Varieties and Biotypes

1. Breeding for resistant varieties: The Diers program is developing and releasing soybean varieties with aphid resistance. The backcrossing of the aphid resistance genes Rag4 and Rag6 into cultivars that already have Rag1, Rag2, and Rag3 is continuing. During the summer of 2017, we produced BC3F1 seed for Rag6 in both the MG I Titan background and the MG II LD02-4485 background. The BC3F1 seed is being planted in the greenhouse so that the fourth and final backcross can be conducted early this winter. For Rag4, we completed the backcrossing of this gene in both backgrounds and now this gene is being combined with Rag1-3. In the LD02-4485 background, crosses were made this summer between plants with Rag4 backcrossed into them and Rag1-3 backcross plants. F1 seed from these crosses will be planted in the greenhouse to develop populations segregating for all four genes. In the Titan background, populations of F2 plants segregating for Rag1-4 were grown in the field this past summer. This winter we will grow plants in a greenhouse from these populations to identify those plants with the resistance allele for all four genes. These plants will then be crossed to backcross plants with Rag6 to complete the stacking of all five genes. Breeding to develop new cultivars with Rag1, Rag2 and stacks of Rag1 and Rag2 is

continuing. Experimental lines with different combinations of these resistance genes were yield tested in 2017 and we are awaiting the completion of harvest so results from these tests can be summarized and selections made. In addition, commercial production or commercial scale seed increases are occurring for one variety with Rag1 only, four varieties with Rag2 only, and two varieties with Rag1 and Rag2 stacked together. These varieties are being sold under the Illini Brand name or are being licensed to other companies for their branding.

2. Aphid virulence genotyping and mapping: Our goal is to map aphid virulence. Genetic mapping of virulence has revealed segregation distortion among B1 and B2 reciprocal crossed. In other words, the ratio of genotypes in the F1 generation is not what was expected. Some offspring of this cross appear to be either sterile or inviable. Survivors in the F1 generation appear similar to the female genotype regardless of biotype (i.e. female drive). Reasons for this phenomena include disparate genetic divergence between biotypes 1 and 2 (which has also been observed), or drastically different bacterial symbionts (which is currently being studied). We observed high migration to buckthorn this past autumn and have made collections. These samples will be genotyped and compared to aphids already collected from 2017. Populations include Iowa, Minnesota and Ohio. Aphids from the above collections will also be screened for phenotyping on Rag varieties. Based on the segregation distortion and female drive, we are comparing and genotyping Wolbachia from the soybean aphid. Wolbachia is a bacteria that can be found within insects that often induces mating incompatibilities. If indeed crosses of B1 and B2 are infertile, then the spread of virulence may be more rapid and place more emphasis on a refuge.

3. Aphid virulence management for resistant varieties: During the 2017 growing season we completed a field study in three states (Iowa, South Dakota, and Ohio) in quarter-acre, replicated plots to measure the impact of a Refuge-in-a-Bag approach to using aphid-resistant soybeans. The purpose of this study is to find ways to maximize the longevity of aphid resistant varieties while minimizing yield loss in refuges. Data from 2017 are being analyzed. Another field season of data will be collected in Year 3 of this study. Preliminary data assessments from Iowa show that all options using the aphid resistant line, regardless of how much susceptible soybean was mixed in, had lower aphid populations than the plots with only aphid-susceptible soybeans. These data will inform modelling to determine the likely success of a Refuge-in-a-Bag resistance management plan for the soybean aphid.

4. Economic returns on resistant varieties: This is a three-summer study designed to assess the economic returns on herbicide tolerant and aphid resistant traits. We completed the second year of a field study replicated at two locations in Iowa to determine the optimal economic approach to pest management for soybean production. In 2016 and 2017, we compared four varieties that varied by aphid-resistance and herbicide-tolerance. In replicated plots, each variety was planted either early (May) or late (June) to determine if the yield potential varies. All varieties were treated with insecticide if aphid outbreaks occurred. Overall, aphid-resistant soybeans regardless of the background genetics prevented aphid outbreaks, and did not need an insecticide application. As observed in parts of Iowa and Minnesota, the insecticide applied to aphid-susceptible varieties did not provide expected control. Yield data are pending. So far, these data suggest that farmers can achieve the same yield by

reducing inputs. A third field season of experiments will be conducted in Year 3 of this study.

IV. Biological Control

We worked with researchers from 12 states in the NCSRP network, and each scouted three times over the summer of 2017. They provided information on soybean aphid pressure and the per-plant density of black (Aphelinus) parasitoid mummies in each state, and sent samples of black mummies to the Heimpel laboratory at the University of Minnesota for identification. Soybean aphid was first detected in June across the northern tier of states - North Dakota, Minnesota, Iowa, Wisconsin, and Michigan (see maps, below). By mid July there were high densities of aphids in North Dakota, Minnesota, Iowa, and Illinois, and aphids reported in South Dakota and Nebraska; Minnesota had aphid densities above the economic threshold of 250 aphids per plant. In August soybean aphid pressure above the action threshold was reported in Minnesota and Iowa, substantial aphid numbers were found throughout the region, but no aphids were reported for the entire summer in Kansas, Missouri, and Ohio. These trends compare very closely with the numbers of A. glycines captured by the Suction Trap Network, which confirmed that Kansas and Missouri had no reports of the aphid.

The parasitoid A. certus was first reported in North Dakota on June 26th, and was found in Michigan in June as well. The parasitoid was also found in Minnesota, Iowa, Illinois, and Indiana at densities between 0.6 and 2.0 parasitoids per plant by the end of summer. A pattern of the aphid and its parasitoids seems to be centered in the north and west, spreading south and east during the summer but remaining most prevalent in Minnesota and Iowa. The parasitoid, and to some extent the aphid as well, was first detected in the northwest, in the relatively small soybean acreage of North Dakota, and despite movement southward, neither the parasitoid nor the aphid were detected in the southernmost nor easternmost states.

Aphelinus certus was the dominant parasitoid in the survey although the native parasitoid Lysiphlebus testaceipes was found in Iowa, Indiana, Michigan, and Minnesota as well. The level of hyperparasitism was relatively high for Aphelinus at 21% and included species in the genera Alloxysta (Hymenoptera: Figitidae), Dendrocerus (Hymenoptera: Megaspilidae), Asaphes (Hymenoptera: Pteromalidae), and Syrphophagus (Hymenoptera: Encyrtidae).

Project Metrics

I. Extension and Outreach.

Goal: Produce at least three extension deliverables.

Outcome: Goal met, with 14 extension publications stemming from NCSRP research.

II. Insect Monitoring and Management

1. Stink bug monitoring and management

   Goals: Continued sample processing; Data analysis; Revise protocols; Identify study fields and staff

   Outcomes: all goals met

2. Pollinator diversity and soybean yield

   Goals: Species identification for sampling continues; Data analysis for sampling; Present sampling results; Contribute to extension deliverables; Hire graduate student for yield study

   Outcomes: all the goals were met except the final one, to purse a pollinator/yield study. As described in previous progress reports, we have changed this objective to focus instead on the times of day when pollinators are present in soybean.

3. Soybean aphid insecticide resistance

   Goals: Communicate results of DIY monitoring; Begin constructing protocol for chlorpyrifos and L-cyalothrin bioassay

   Outcomes: DIY monitoring has been deemed not feasible due to the fragility of the insect, and instead the technique is being adapted as a research tool for trained researchers.

4. Monitoring for aphids, thrips, and soybean vein necrosis

   Goals: Weekly trap monitoring in summer; Communicate trap data to collaborators for extension and research; Thrips sampling; Thrips sample processing begins

   Outcomes: all goals met

5. Technology development

   Goals: Refine sampling algorithm; Collect additional images from different device types; Develop node-based sampling integrated with counting algorithm

   Outcomes: The first two goals have been met. Work continues on the third goal.

III. Resistant Varieties and Biotypes

1. Breeding for resistant varieties

Goals: Analyze data from year 1; Grow backcross plants and make crosses; Test segregating populations; Yield tests

Outcomes: all goals met

2. Aphid virulence genotyping and mapping

   Goals: Determine inheritance of virulence; Genotype F1 and F2 populations; Chromosome linkage map

   Outcomes: goals have not been fully met but work on them continues

3. Aphid virulence management for resistant varieties

   Goals: Increase cultivars; Determine experimental protocol; Field experiment, year 2; Data analysis

   Outcomes: all goals have been met except data analysis of year 2 data, which is still underway

4. Economic returns on resistant varieties

   Goals: Field experiment, year 2; Data analysis

   Outcomes: the field experiment was performed in year 2; data analysis is still underway

IV. Biological Control

Goals: Coordinate parasitoid collection with collaborating states; Conduct releases of A. glycinis and A. rhamni

Outcomes: all goals met