NERA

Where the Rubber Meets the Road:

NE2001 2020 MultiState Chemical Ecology Meeting

Project No and Title: NE2001 Harnessing Chemical Ecology to Address Agricultural Pest and Pollinator Priorities

Period Covered: 01/01/2020 to 01/01/2021

Date of Report: 4/19/2021

Annual Meeting Dates: 02/08/2021-02/10/2021

Participants:

- Lynn Adler, University of Massachusetts Amherst
- Andrei Alyokhin, University of Maine
- Anurag Agrawal, Cornell
- Tom Baker, Penn State
- Yolanda Chen, University of Vermont
- Camila Filgueiras, Cornell
- Kelli Hoover, Penn State
- Rick Karban, UC Davis
- Erica Kistner Thomas, NIFA
- Greg Loeb, Cornell
- Scott McArt, Cornell
- Esther Ngumbi, University of Illinois
- Jan Nyrop, Cornell
- Cesar Rodriguez-Saona, Rutgers
- Jennifer Thaler, Cornell
- Rachel Vannette, UC Davis
- Denis Willett, Cornell
- Keyan Zhu-Salzman, Texas A&M

Brief Summary of Minutes:

The theme of this meeting was 'Where the Rubber Meets the Road', identifying ways chemical ecology as a discipline and the NE2001 group in particular can positively impact agricultural management over the next 3-5 years. Chemical Ecology is uniquely poised to positively impact pest and pollinator management across agricultural systems. While great strides in our fundamental understanding of chemical communication have been made over the past decades, putting this understanding into practice remains an ongoing priority.

To that end, the objectives of this meeting were to:

1. Discuss new research developments over the past year.
2. Identify areas where chemical ecology as discipline can have the most impact over the next 3-5 years.
3. Identify ways of collaborating to meet those goals.

On February 8, the group met to discuss research developments over the past year with individual presentations by many participants and a discussion from Dr. Kistner-Thomas from NIFA. These presentations are discussed in the Accomplishments section below.

On February 9, the group met to brainstorm and discuss objectives 2 and 3 – where chemical ecology can have the most impact and opportunities for collaboration. The goal of these conversations was to generate many ideas.

On February 10, the group met to refine ideas generated on February and develop focus areas

Specifically, the group identified:

Areas of Impact:

1) **Leverage Past Successes.** Chemical ecology as a discipline has had notable successes in improving pest management over the last few decades ranging from implementations of mating disruption, to recruitment of natural enemies, stimulation of plant defenses, push-pull systems, and other implementations of attractants and repellents. In each of these use cases, some implementations work really well and others have little impact. We see great potential in understanding why certain strategies work across systems - identifying the specific factors that lead implementation strategies to succeed and to fail – then leveraging that knowledge for prescriptive and predictive practices that succeed broadly across a wide spectrum of agricultural systems.

   Combined with this idea of leveraging past successes and understanding how these strategies succeed in specific settings is the opportunity to stack strategies to ensure success. We unanimously agree that combining chemical ecology control strategies has enormous potential for ensuring successful management and believe that there are opportunities for additive and even synergistic effects from combined strategies that could deliver substantial positive impacts of yields.

   The perceived outcome of leverage our past successes would be the ability to make these strategies more robust and anti-fragile in order to deliver results to producers across systems and vastly different environments. More work is needed to understand these factors, limitations, potential, and any additive or synergistic effects of combined strategies. We believe that substantial research progress can be made in this area over the next 3-5 years and will deliver tremendous economic benefit.

2) **Improved Pest Monitoring Ability.** The ability to detect and monitor pest populations is a critical first step in management decision making. Knowing when a pest is present and where a pest is located enables precision targeting of intervention strategies to ensure productive yields. Chemical ecology as a discipline has historically delivered in this area and continues to see potential in using new technology to enhance grower decision making. Historically, the development of pheromone-based attractant lures has had an outsize impact in the ability of producers to detect and monitor pest populations over the course of the growing season.

   The group sees great potential in building on that historical success in two ways. The first is the ability to develop and use non-pheromone-based attractants and lures both in conjunction with pheromone-based lures and independently to improve monitoring ability. Here, research is needed both in terms of developing these lures and in connecting catch with levels of economic damage. The second is the ability to use our knowledge of chemical ecology to build chemical detection systems – volatile sensors – that can detect pests and pathogens based on their volatile signatures in agricultural systems. Here research is needed to both continue developing these sensors and in identifying volatile signatures indicative of pest presence.

   The outcome of this work would be the ability of producers to rapidly detect pest presence and monitor their development over the course of the season. We anticipate that this work would allow producers to detect pests earlier than is currently possible, detect and monitor pests to an extent greater than is currently possible and connect that information to decision making frameworks and levels of economic damage in a manner that is both precise and eminently useful. We expect that research development in this area will have outsize impact over the next 3-5 years. Specifically, we see tremendous opportunity to not only improve management through reducing extant pest problems, but also drastically reduce prophylactic and non-targeted management strategies.

3) **Plant Signaling.** Breakthroughs in our understanding of plant signaling, both within and between organisms have led our group to believe that there is the potential for revolutionary advancements in our ability to leverage our understanding in development of more effective management strategies. While we see great potential in this area, we recognize that there are large gaps in our basic understanding of how these systems work and the ramifications of manipulating these systems in an agricultural environment. Research aimed at addressing these gaps is a priority and our group estimates that such research with begin to have outsize impact on a larger time-frame over the coming decades. Our group is

uniquely poised to address these challenges, however with collaborative research connecting all aspects of chemically-mediated plant-insect interactions.

Opportunities for Collaboration:

The group identified a critical opportunity for radical collaboration around leveraging past successes and evaluating them across systems. Given the diversity of systems in which we conduct research, we are uniquely positioned to conduct similar assays across environmental and cropping systems in order to arrive at an understanding at how and why certain approaches work consistently. Dr. Rodriguez-Saona has already initiated this work with a meta-analysis, landscape-wide assessment of factors influencing natural enemies, and a proposed framework for future studies.

Accomplishments

The group has continued building upon the work done in previous iterations of this project with a renewed focus on core objectives. The focus of this meeting was in developing the core areas listed above.

Additionally, the Chemical Ecology Core Facility continues its work with a number of members and looks to continue expanding. Scott McArt presented on the use of the facility and proposed plans for expansion. Other work and accomplishments over the past year include:

- The novel use of knowledge of attractive behavior to control mushroom phorid fly from Tom Baker's program.
- Advances in the behavioral manipulation of Spotted Wing Drosophila for improved applied management by Greg Loeb's program
- Work from Rick Karban's program on two of the big challenges in using volatile cues to induce plant resistance to herbivores by identifying what the biologically active cues are that plants use and understanding the selective pressures that have shaped those cues. Towards that end, we have been studying the volatile cues that are emitted by damaged sagebrush plants from populations that vary in the levels of herbivore damage that they experience. A recent paper by Kalske et al. (2019 Current Biology) predicted that populations that experience high levels of damage will converge on a limited number of cues that are perceived by most individuals while populations that experience low levels of damage will evolve diverse cues that are perceived by only kin. We tested this hypothesis using 15 populations of sagebrush in California and Nevada. Our results supported this hypothesis and provide insights into the constraints on the evolution of plant signals.
- Examination of the ability of the spotted lanternfly to sequester chemical defenses by Kelli Hoover's program.
- How Aphids respond to potatoes infected by *Dickeya* by Andrei Aloykhin's program.
- Work from Anurag Agrawal's program on squash – insect pest interactions, examining the roles of breeding history and insect pheromones as a means to enhance control of the striped cucumber beetle - *Acalymma vittatum*. Previous

work has shown that these beetles 1) have an aggregation pheromone, 2) are more attracted to zucchini and related domesticates (*Cucurbita pepo pepo*) compared to summer squash (an independent domesticate, *Cucurbita pepo ovifera*), and 3) are attracted to floral volatiles (which have been developed into commercially available lures). In our collaborative work with Michael Mazourek's plant breeding lab, we have identified that beetle aggregation is reduced on *C. p. ovifera* by a plant volatile and emigration (rather than enhanced attraction or pheromone production on C. p. pepo). Additionally, we have found that Cucurbitacins are not playing a key role in squash - *Acalymma* interactions. Our current work is examining levels of squash attack by an emerging pest, the squash bug - *Anasa tristis*. The squash bug is often associated with beetle aggregation, and we have shown that bugs are specifically attracted to (or eavesdrop on) the beetle's pheromone. This work has been replicated in NY, New Hampshire, and Maryland. Additionally, trials in multiple states indicate that the squash bug is more abundant on *C. p. ovifera* than *C. p. pepo*. Thus, the two squash domesticates have opposing resistance to these two pests. We are working to better understand how plant traits in the two domesticates and both floral and pheromone lures might be used to increase management of striped cucumber beetles and the emerging squash bug.

- Work from Denis Willett's program on developing volatile sensors for early detection of pests and pathogens with successful case studies across cropping systems.
- Improved behavioral manipulation of natural enemies with an emphasis on a systems approach to understanding by Cesar Rodriguez-Saona's program.
- An improved understanding of how sub-lethal imidacloprid exposure alters methylation in Colorado potato beetle with implications for population management.
- Work from Jennifer Thaler's group on non-lethal indirect chemically mediated predatory effects.

Despite COVID, the results of work on this project have been widely disseminated both through publications listed below and through presentations at national and international meetings by members of this project. Several post-doc, graduate, and undergraduate students have been trained through the work on this project, not just in terms of technical approaches to chemical ecology, but also in terms of asking and answering impactful questions and professional development.

Publications

Adler LS, Fowler AE, Malfi RL, Anderson PR, Coppinger LM, Deneen PM, Lopez S, Irwin RE, Farrell IW, Stevenson PC. Assessing chemical mechanisms underlying the effects of sunflower pollen on a gut pathogen in bumble bees. Journal of chemical ecology. 2020 Mar 23:1-0.

Adler LS, Irwin RE, McArt SH, Vannette RL. Floral traits affecting the transmission of beneficial and pathogenic pollinator-associated microbes. Current Opinion in Insect Science. 2020 Aug 28.

Aflitto NC, Thaler JS. Predator pheromone elicits a temporally dependent non-consumptive effect in prey. Ecological Entomology. 2020 Oct;45(5):1190-9.

Benevenuto RF, Seldal T, Moe SR, Rodriguez-Saona C, Hegland SJ. Neighborhood effects of herbivore-induced plant resistance vary along an elevational gradient. Frontiers in Ecology and Evolution. 2020 May 8;8:117.

Brevik K, Bueno EM, McKay S, Schoville SD, Chen YH. Insecticide exposure affects intergenerational patterns of DNA methylation in the Colorado potato beetle, Leptinotarsa decemlineata. Evolutionary Applications. 2020 Nov 25.

Brochu KK, van Dyke MT, Milano NJ, Petersen JD, McArt SH, Nault BA, Kessler A, Danforth BN. Pollen defenses negatively impact foraging and fitness in a generalist bee (Bombus impatiens: Apidae). Scientific reports. 2020 Feb 20;10(1):1-2.

Brzozowski LJ, Gore MA, Agrawal AA, Mazourek M. Divergence of defensive cucurbitacins in independent Cucurbita pepo domestication events leads to differences in specialist herbivore preference. Plant, Cell & Environment. 2020 Nov;43(11):2812-25.

Brzozowski LJ, Gardner J, Hoffmann MP, Kessler A, Agrawal AA, Mazourek M. Attack and aggregation of a major squash pest: Parsing the role of plant chemistry and beetle pheromones across spatial scales. Journal of Applied Ecology. 2020 Aug;57(8):1442-51.

Cha DH, Roh GH, Hesler SP, Wallingford A, Stockton DG, Park SK, Loeb GM. 2-Pentylfuran: a novel repellent of Drosophila suzukii. Pest Management Science. 2020 Nov 24.

Chen J, Webb J, Shariati K, Guo S, Montclare JK, McArt S, Ma M. Pollen-mimicking, enzyme-loaded microparticles to reduce organophosphate toxicity in managed pollinators.
Cheng WN, Zhang YD, Liu W, Li GW, Zhu-Salzman K. Molecular and functional characterization of three odorant-binding proteins from the wheat blossom midge, Sitodiplosis mosellana. Insect science. 2020 Aug;27(4):721-34.

Crowley-Gall A, Rering CR, Rudolph AB, Vannette RL, Beck JJ. Volatile microbial semiochemicals and insect perception at flowers. Current Opinion in Insect Science. 2020 Oct 20.

Grof-Tisza P, Karban R, Pan VS, Blande JD. Assessing plant-to-plant communication and induced resistance in sagebrush using the sagebrush specialist Trirhabda pilosa. Arthropod-Plant Interactions. 2020 Mar 12:1-6.

Grout TA, Koenig PA, Kapuvari JK, McArt SH. Neonicotinoid Insecticides in New York State.

Guo H, Zhang Y, Tong J, Ge P, Wang Q, Zhao Z, Zhu-Salzman K, Hogenhout SA, Ge F, Sun Y. An aphid-secreted salivary protease activates plant defense in Phloem. Current Biology. 2020 Dec 21;30(24):4826-36.

Hodgdon EA, Hallett RH, Heal JD, Swan AE, Chen YH. Synthetic pheromone exposure increases calling and reduces subsequent mating in female Contarinia nasturtii (Diptera: Cecidomyiidae). Pest Management Science. 2021 Jan;77(1):548-56.

NERA

Jones AG, Hoover K, Pearsons K, Tooker JF, Felton GW. Potential Impacts of Translocation of Neonicotinoid Insecticides to Cotton (Gossypium hirsutum (Malvales: Malvaceae)) Extrafloral Nectar on Parasitoids. Environmental entomology. 2020 Feb 17;49(1):159-68.

Karban R, Yang LH. Feeding and damage-induced volatile cues make beetles disperse and produce a more even distribution of damage for sagebrush. Journal of Animal Ecology. 2020 Sep;89(9):2056-62.

Karban R. The ecology and evolution of induced responses to herbivory and how plants perceive risk. Ecological Entomology. 2020 Feb;45(1):1-9.

Mirzaei M, Züst T, Younkin GC, Hastings AP, Alani ML, Agrawal AA, Jander G. Less Is More: A Mutation in the Chemical Defense Pathway of Erysimum cheiranthoides (Brassicaceae) Reduces Total Cardenolide Abundance but Increases Resistance to Insect Herbivores. Journal of Chemical Ecology. 2020 Dec;46(11):1131-43.

Ngumbi EN, Hanks LM, Suarez AV, Millar JG, Berenbaum MR. Factors associated with variation in cuticular hydrocarbon profiles in the navel orangeworm, Amyelois transitella (Lepidoptera: Pyralidae). Journal of chemical ecology. 2020 Jan;46(1):40-7.

Rering CC, Vannette RL, Schaeffer RN, Beck JJ. Microbial co-occurrence in floral nectar affects metabolites and attractiveness to a generalist pollinator. Journal of chemical ecology. 2020 Aug;46(8):659-67.

Rodriguez-Saona C, Urbaneja-Bernat P, Salamanca J, Garzón-Tovar V. Interactive Effects of an Herbivore-Induced Plant Volatile and Color on an Insect Community in Cranberry. Insects. 2020 Aug;11(8):524.

Rodriguez-Saona C, Alborn HT, Oehlschlager C, Calvo C, Kyryczenko-Roth V, Tewari S, Sylvia MM, Averill AL. Fine-tuning the composition of the cranberry weevil (Coleoptera: Curculionidae) aggregation pheromone. Journal of Applied Entomology. 2020 Jun;144(5):417-21.

Ugine TA, Thaler JS. Insect predator odors protect herbivore from fungal infection. Biological Control. 2020 Apr 1;143:104186.

Urbaneja-Bernat P, Waller T, Rodriguez-Saona C. Repellent, oviposition-deterrent, and insecticidal activity of the fungal pathogen Colletotrichum fioriniae on Drosophila suzukii (Diptera: Drosophilidae) in highbush blueberries. Scientific reports. 2020 Sep 2;10(1):1-9.

Uyi O, Keller JA, Johnson A, Long D, Walsh B, Hoover K. Spotted Lanternfly (Hemiptera: Fulgoridae) can complete development and reproduce without access to the preferred host, Ailanthus altissima. Environmental entomology. 2020 Oct;49(5):1185-90.

Vannette RL. The floral microbiome: Plant, pollinator, and microbial perspectives. Annual Review of Ecology, Evolution, and Systematics. 2020 Nov 2;51:363-86.

Villalona E, Ezray BD, Laveaga E, Agrawal AA, Ali JG, Hines HM. The role of toxic nectar secondary compounds in driving differential bumble bee preferences for milkweed flowers. Oecologia. 2020 Jul;193(3):619-30.

Wolfin MS, Chilson III RR, Thrall J, Liu Y, Volo S, Cha DH, Loeb GM, Linn Jr CE. Habitat cues synergize to elicit chemically mediated landing behavior in a specialist phytophagous insect, the grape berry moth. Entomologia Experimentalis et Applicata. 2020 Dec;168(12):880-9.

Wanner KW, Moore K, Wei J, Herdlicka BC, Linn CE, Baker TC. Pheromone Odorant Receptor Responses Reveal the Presence of a Cryptic, Redundant Sex Pheromone Component in the European Corn Borer, Ostrinia nubilalis. Journal of Chemical Ecology. 2020 Jul;46(7):567-80.