



# ALARC Highlights

## Summer 2018

*USDA-Agricultural Research Service*  
*Arid-Land Agricultural Research Center*  
*Maricopa, Arizona*

### *In this issue*

**Featured Accomplishment**

**Other Accomplishments**

**Awards and Recognition**

**Current Grants**

**ALARC in the News**

**Employee Engagement**

**Events and Outreach**

**Recent Publications**



## FEATURED ACCOMPLISHMENT

### **Increasing knowledge of the basic biology of a pest insect to enhance control strategies**

The widespread adoption of Bt cotton and an effective pink bollworm eradication program have led to a welcome reduction in the use of broad spectrum insecticides and enhanced biological control of pests like the sweetpotato whitefly. However, this change in control strategies has led to the increasing prominence of *Lygus* bug, which is now considered the major yield limited pest of cotton in the western U.S. In the mid-southern US, insecticide-resistant populations of *Lygus lineolaris* have caused havoc, while in the western cotton belt, the primary culprit has been *L. hesperus* (Figure 1). While *L. hesperus* are now being managed largely with selective insecticides, there is still a need for alternative approaches that can provide highly targeted control as part of an integrated pest management (IPM) program. Some of these new avenues include pheromonal manipulation, gene knockdown, and more precisely timed insecticide applications to maximize impact. All of these new approaches depend upon a thorough knowledge of the basic biology of this pest, something that has not been the focus of past research. The current situation is rapidly improving as ARS researchers have focused considerable resources to understand and undermine this pest and its close relatives.

Reproductive biology is an area of study that is often fruitful in identifying potential novel control approaches for insects. Producing offspring is a complex process that often provides

numerous opportunities for interference. For the past several years, scientists at the Arid-Land Agricultural Research Center (ALARC) in Maricopa, Arizona have undertaken an extensive examination of the factors that regulate reproductive behaviour and physiology in *L. hesperus*. They have had a number of promising breakthroughs in three key areas of reproductive biology: sexual maturation, chemical communication, and post-mating responses.



**Figure 1. The western tarnished plant bug, *Lygus hesperus* is a major pest of cotton and other economically important crops throughout the American southwest,**

## Sexual Maturation

Before *Lygus* can start having offspring, they come to a crossroads where they have to determine whether to develop normally or enter into a reproductively inactive state that enhances their chances of surviving hostile environmental conditions. Research at ALARC has shown that this decision occurs during the fourth larval instar, and that the insects respond to the amount of light that they receive. Short daylengths cause *Lygus* to enter into a state of diapause; they develop into adults but rather than investing resources into producing eggs, they build up large stores of fat on which they can survive when food becomes scarce. When days grow longer, the insects break diapause and quickly begin activating their reproductive organs in preparation for reproduction. We have identified a variety of traits that differentiate diapause from the normal state, several of which are readily observed making field assays easier (Figure 2). We are currently using diapause and normal morphs to identify the hormonal processes and genes that regulate reproductive development.

## Chemical Communication

After molting to adulthood, female *Lygus* bugs become reproductively mature in 5-7 days under normal environmental conditions. We have found that diet and temperature can significantly impact this rate; warmer temperatures and better quality food reducing the time needed, while the process



**Figure 2. Body color can vary in *Lygus* bugs depending on whether they have developed normally or entered into a reproductive diapause. The female on the left is reproductively mature and has a typical bright green coloration. The female on the right has entered into diapause, building up a considerable store of yellow/white fat that is visible just below the semi-translucent cuticle.**

is elongated with poorer diets and cooler climates. Around the same time that females begin to develop their first eggs, we notice that they become increasingly attractive to males. This attraction can occur at a distance, suggesting that the females are emitting a pheromone, a chemical message that convey her status as a mature female. We have identified this sex pheromone that is able to attract males from a distance, providing the potential for developing a trap lure to reduce the male population. We have also found that females

are unattractive to males for several days after they mate (Figure 3). Careful investigation revealed that males transfer an anti-aphrodisiac pheromone into the female along with their sperm. We identified the chemical and showed that females slowly externalized it, greatly reducing the likelihood that they will be courted by males. Application of the anti-aphrodisiac on virgin females also render them unattractive. We are currently assessing the potential application of this chemical as a crop spray to restrict mating in *Lygus* without negatively impacting beneficial predators that are unlikely to respond to this species-specific odor. We also have identified, for the first time in any organism, an anti-anti-aphrodisiac. This is a compound secreted by females to counteract the male-produced anti-aphrodisiac. Currently, we are working to identify the chemical receptors in the antennae that allow these pheromones to be perceived.



**Figure 3. A male *Lygus* bug typically uses his antennae to smell a female, assessing her reproductive maturity and mating status (left). If everything is to his liking her will court the female. If the wrong pheromones are present, the male quickly moves his antennae back from the female, ducks down, then beats a hasty retreat (right).**

## Post-Mating Responses

In addition to becoming unattractive to males, females go through some important behavioural changes after they mate (Figure 4). We have found that for several days after copulating females dramatically increase the rate at which they lay eggs and they lose interest in remating. The changes are caused by chemical components of male semen. As these compounds become depleted the female's behaviour reverts to her normal pre-mating state. We have found that one of the active components is a signalling molecule, juvenile hormone, which has been shown to play a key role in regulating ovarian activity and reproductive behavior in numerous insects. By manipulating this hormone in females we can change the rate at which they lay eggs and cause a reduction in their sexual receptivity. We have also found that the hormone causes changes in the levels of brain neurotransmitters which probably mediate the behavioral shifts observed after mating. Targeting the production of or receptors to this hormone would radically alter *Lygus* reproduction on several levels.

## Summary

Collectively, the results of these many studies provide both new avenues of research and ample opportunity to develop novel and highly targeted control approaches for *Lygus* bugs. Continued work, especially with the underlying genetics of the regulatory architecture of reproduction, will further facilitate these endeavors. Many of the results have also been shown to hold true for the sister species *L. lineolaris*, and may be generally applicable to all species within the genus.

**Contact:** [Colin.Brent@ars.usda.gov](mailto:Colin.Brent@ars.usda.gov)



## Articles related to sexual maturation

Spurgeon, D.W. 2017. Instar- and stage-specific photoperiodic diapause response of *Lygus hesperus* (Hemiptera: Miridae). *Journal of Insect Science*. 17(6):125. ([PDF](#))

Spurgeon, D.W., Brent, C.S. 2015. Diapause response to photoperiod in an Arizona population of *Lygus hesperus* (Hemiptera: Miridae). *Journal of Entomological Science* 50(3): 238-247. ([PDF](#))

Brent, C.S., Klok, C.J., Naranjo, S.E. 2013. Effect of diapause status and gender on activity, metabolism and starvation resistance in the plant bug *Lygus hesperus* Knight. *Entomologia Experimentalis et Applicata* 148: 152-160. ([PDF](#))

Brent, C.S. 2012. Classification of diapause status by color phenotype in *Lygus hesperus*. *Journal of Insect Science* 12: 136. ([PDF](#))

Brent, C.S., Spurgeon, D.W. 2011. Diapause response of laboratory reared and native *Lygus hesperus* Knight (Hemiptera: Miridae). *Environmental Entomology* 40: 455-461. ([PDF](#))

Spurgeon, D.W., Brent, C.S. 2010. Morphological characters of diapause in *Lygus hesperus* Knight (Hemiptera: Miridae). *Journal of Entomological Science* 45: 303-316. ([PDF](#))

## Articles related to chemical communication

Brent, C.S., Byers, J.A., Levi-Zada, A. 2017. An insect anti-antiaphrodisiac. *eLife* 6: e24063. ([PDF](#))

Byers, J.A., Fefer, D., Levi-Zada, A. 2013. Sex pheromone component ratios and mating isolation among three *Lygus* plant bug species of North America. *Naturwissenschaften* 100:1115-1123. ([PDF](#))

Brent, C.S., Byers, J.A. 2011. Female attractiveness modulated by a male-derived antiaphrodisiac pheromone in a plant bug. *Animal Behaviour* 82: 937-943. ([PDF](#))

## Articles related to post-mating responses

Brent, C.S., Miyasaki, K., Vuong, C., Miranda, B., Steele, B., Brent, K.G., Nath, R. 2016. Regulatory roles of biogenic amines and juvenile hormone in the reproductive behavior of the western tarnished plant bug (*Lygus hesperus*). *Journal of Comparative Physiology B* 186(2): 169-179. ([PDF](#))

Hull, J.J., Brent, C.S. 2014. Identification and characterization of a sex peptide receptor-like transcript from the western tarnished plant bug, *Lygus hesperus*. *Insect Molecular Biology* 23: 301-319. ([PDF](#))

Brent, C.S., Hull, J.J. 2014. Characterization of male-derived factors inhibiting female sexual receptivity in *Lygus hesperus*. *Journal of Insect Physiology* 60: 104-110. ([PDF](#))

Brent, C.S., Fasnacht, M.P., Judd, T.M. 2011. Post-mating enhancement of fecundity in female *Lygus hesperus*. *Physiological Entomology* 36: 141-148. ([PDF](#))

Brent, C.S. 2010. Reproductive refractoriness in the western tarnished plant bug (Hemiptera: Miridae). *Annals of the Entomological Society of America* 102: 300-306. ([PDF](#))

Brent, C.S. 2010. Reproduction of the Western Tarnished Plant Bug, *Lygus hesperus*, in relation to age, gonadal activity and mating status. *Journal of Insect Physiology* 56: 28-34. ([PDF](#))



**Figure 4. The female *L. hesperus* undergoes numerous behavioural and physiological changes subsequent to mating.**

# OTHER ACCOMPLISHMENTS

**Patterns of endosymbiont infection in populations of whitefly and their parasitoids.** Populations of whitefly, a major pest insect and a vector of viral plant diseases, are difficult to control, but their numbers and impact may be influenced by the symbiotic microorganisms living within them. An ARS scientist from ALARC and researchers at Çukorova



University in Adana, Turkey, showed that multiple populations of whiteflies and parasitoids from Arizona and Turkey showed differences in the composition of the symbiotic species. These differences may, in part, explain regional variation

in whitefly sex ratios, which can impact the growth and spread of populations. Results may provide a novel avenue for manipulating the population dynamics of whitefly to mitigate their negative impacts on agriculture. (Steve Castle, retired)

**Transgenic crops do not affect important insect parasitoids.** Transgenic crops expressing *Bacillus thuringiensis* (Bt) toxins are cultivated on millions of hectares globally, but concerns remain about the risks these crops may pose to non-target organisms like insect parasitoids that supply important ecological services. An ALARC scientist, researchers at Cornell University, ARS in Ames, Iowa, and Agroscope in Zurich, Switzerland, showed that the development and reproduction of two species of parasitic wasps were not affected by ingestion of caterpillar hosts that had fed on diets incorporating Bt cotton leaves. The caterpillars were resistant to Bt proteins in the plant, eliminating host quality issues and allowing the direct effects of Bt proteins to be assessed under realistic exposure scenarios. Results are valuable to governmental authorities responsible for regulating transgenic crops, scientists concerned with developing integrated pest management strategies for pest control, and a general public concerned about the environmental effects of biotechnology. (Contact: Steve.Naranjo@ars.usda.gov)

**Improved management of sweetpotato whitefly in cotton.** While it is known that biological control by native arthropod predators is critical to effective control of sweetpotato whiteflies in cotton, current Integrated Pest Management (IPM) is based only on the scouting of pest abundance. An ALARC scientist collaborated with researchers at the University of Arizona, to develop, test and implement economic thresholds that use predator-pest ratios for making pest control decisions in IPM. Results were presented to pest control advisors and growers through extension programs and were validated in grower fields in Arizona and Mexico. The new biological control based thresholds greatly improved decision-making, advancing spray decisions about 10 percent of the time (too little biological control) and deferring sprays nearly 60 percent of the time (adequate biological control). The findings promote the development of improved economic threshold models and reduce the cost and risk for growers managing whitefly. (Contact: Steve.Naranjo@ars.usda.gov)



**Improving model-based estimates of crop temperature.** Estimating the potential impact of heat stress on crop performance requires accurate values of the actual temperature of the crop. Depending on weather conditions and crop water status, the upper foliage of a crop may be several degrees cooler or warmer than the air above the plants. To assess potential for mid-day heat stress, many crop growth models assume that the foliage (canopy) temperature is simply equal to the daily maximum air temperature. To support tests of nine wheat models that use more complex methods to estimate canopy temperature, ALARC scientists organized two large datasets from Maricopa and a 1984 to 1986 five-location study. ALARC scientists also assisted a scientist at the University of Bonn in analysis and interpretation of the model comparisons. The tests showed that estimating the stability of air movement over the canopy greatly improved the accuracy of canopy temperature prediction. This finding will improve how canopy temperature is modeled, ultimately improving estimations of heat stress that will strengthen management and policy decisions by stakeholders including producers. (Contact: Jeffrey.White@ars.usda.gov)

**Characterization of leaf waxes in the oilseed crop *Camelina sativa*.** The leaf cuticle contains a waxy protective layer that has low permeability to water, which directly affects the rate of leaf water loss and thus the susceptibility of plants to drought conditions. In collaboration with scientists at West Virginia University, ALARC researchers, characterized the leaf waxes from seventeen *Camelina* species. The various plant lines exhibited a wide range of wax contents, which revealed significant variation for this trait. This work lays the foundation for future breeding

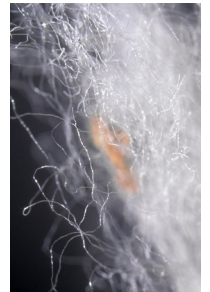


efforts that aim to increase camelina wax with the end-goal of improving drought tolerance of the crop. (Contact Hussein.Abdel-Haleem@ars.usda.gov)

**Improved irrigation scheduling via crop growth and water use simulations.** Improved irrigation scheduling methods are needed to conserve limited water resources in the western United States. One option is to enhance computer-based algorithms that calculate daily crop water use based

on local soil and weather conditions. During two cotton growing seasons in 2014 and 2015, ALARC researchers tested the recommendations of two irrigation scheduling algorithms: a new technique that computed both crop growth and water use and an existing technique that computed only crop water use. As verified through field experimentation, the research demonstrated that the newer scheduling method could meet or exceed the performance of the existing scheduling approach, which highlighted an advantage of including calculations of crop growth and development in the irrigation scheduling algorithm. Improved accounting and management of agricultural water use in the western U.S. depends on the availability of improved irrigation scheduling algorithms. (Contact: Kelly.Thorp@ars.usda.gov)

**Characterization of cotton fiber cuticular wax.** Textile mills demand high quality cotton fiber to ensure efficient production while still delivering superior products to the consumer. Cotton fiber quality is affected by many variables, which necessitates the identification of important fiber characteristics for breeding programs. Scientists at ALARC, in collaboration with Cornell and West Virginia University, investigated the content and composition of cotton fiber cuticular wax from seven upland cotton varieties grown under water deficit. Nine of the 41 identified compounds were significantly affected by the water treatment while fiber length and uniformity were highly correlated with primary alcohols, aldehydes, and free fatty acids. These findings suggest that the associated biosynthetic pathways are contributing to the phenotypic variability of these two important fiber quality traits. Thus, the biochemical pathways associated with cuticular fiber wax are candidates for metabolic engineering via molecular breeding approaches. The work is of interest to other scientists focused on improving fiber quality and new molecular breeding techniques (Contact: Alison.Thompson@ars.usda.gov)



**Irrigation scheduling for guayule.** In recent years, U.S. tire companies have invested significantly in development and commercialization of guayule in the arid US Southwest to supplement natural rubber supplies from Asia. To make guayule both profitable and sustainable in the area, improved irrigation management and crop water use efficiency are needed. ARS scientists at ALARC developed irrigation scheduling guidelines for achieving economic guayule rubber yields with reduced water use. This research, which modernizes limited information provided over 30 years ago, is already improving the guayule production efforts of the US tire industry. (Contact: Doug.Hunsaker@ars.usda.gov)



**Hydraulic analysis of surface irrigation systems.** Simulation models are increasingly used to develop, design, and provide operational recommendations for improving the hydraulic performance of irrigation systems. A continuing challenge to the effective use of these tools is the determination of infiltration and hydraulic resistance parameters for a particular field. An ALARC scientist developed a new parameter estimation component that is integrated into the WinSRFR software (Windows version of surface irrigation simulator) package developed by ARS. In contrast with previously avail-



able estimation tools, this component can be adapted to different data configurations provided by the user. Furthermore, it can be used in combination with different infiltration and hydraulic resistance models employed by WinSRFR. This work has improved accuracy of the resulting estimates. Version 5 of the software will be made available later this year. (Contact: Eduardo.Bautista@ars.usda.gov)

**Septic systems are a source for micropollutants in shallow groundwater.** Approximately 25% of households in the United States use septic systems for treatment and disposal of sewage. Effluent discharged from septic systems can be an important source of micropollutants in the environment. The fate and transport of 20 micropollutants, including human excretion markers, hormones, pharmaceuticals and personal care products, and their transformation

products were measured from three different septic systems. Reduction of micropollutants were similar among septic systems and ranged from 8% to more than 99% with concentrations ranging from <0.3 to 32,000 ng/L reaching shallow groundwater. However, risk assessment showed that the risk to human health due to drinking the groundwater is negligible. (Contact: Clinton.Williams@ars.usda.gov)



## RECENT PROFESSIONAL AWARDS AND RECOGNITION

**Dr. Jeff Fabrick** is the recipient of the 2018 Physiology, Biochemistry and Toxicology Award from the Entomological Society of America – Pacific Branch. Dr. Fabrick is recognized



for his outstanding and high impact research on numerous insect species and in a broad diversity of topics including biochemistry, molecular biology, toxicology, genomics, genetics, physiology, and resistance management. His current focus is on deciphering the molecular genetics and biochemical mechanisms of resistance to *Bacillus thuringiensis* (Bt) crops and identifying and understanding the roles of potential target genes essential for insect survival. Dr. Fabrick will be honored at the annual meeting of the Pacific Branch-ESA in Reno this June.

**Drs. Eduardo Bautista, Doug Hunsaker, Kelly Thorp and Mr. James Schlegel** received the Best Paper Award from the Journal of Irrigation and Drainage Engineering entitled "Approximate Furrow Infiltration Model for Time-Variable Ponding Depth" (PDF). The team will be honored at an Awards Luncheon at the World Environmental and Water Resources Congress in Minneapolis this June.

**Dr. Kelly Thorp** was recognized as an Outstanding Associate Editor for the Natural Resources and Environmental Systems section of the Transactions of the American Society of Agricultural and Biological Engineers (ASABE).

**Drs. Kelly Thorp, Doug Hunsaker and Kevin Bronson** were recognized with the 2018 ASABE Superior Paper Award for their work "Cotton Irrigation Scheduling Using a Crop Growth Model and FAO-56 Methods: Field and Simulation Studies" (PDF). The team will be honored at the General Session Recognition Program at the ASABE Annual Meeting in Detroit, Michigan this July.

**Drs. Jeff White and Kelly Thorp** were named 2017 *Crop Science* Outstanding Reviewers for their excellent service as a manuscript reviewers over many years. They received Certificates of Appreciation for their service and were featured in *Crop Science of America* News.

**Paige Francis** had his photograph (below) displayed on the January/February 2018 pages of *Resource* – a magazine on engineering and technology for a sustainable world published by the American Society of Agricultural and Biological Engineers (see page 26 of [Link](#)).



# CURRENT GRANT AWARDS (\*NEW)

- \*Improving Cotton Ecosystem Services with a Desert-adapted Crop, Arizona Cotton Growers Association (PI **James Hagler**) 2018
- \*Use of Small Interfering Ribonucleic Acid (RNA) to Knock Down Gene Function in *Lygus hesperus*, Cotton Incorporated (PI **Colin Brent**, Co-PIs **Jeff Fabrick**, **Joe Hull**) 2018
- \*Bumble Bee Foraging and Colony Dynamics in Agricultural Landscape, USDA-NIFA (PI James Strange, CO-PIs Knute Gundersen, Rufus Isaacs, **James Hagler**, Brynja Kohler) 2017-2020
- \*Empowering producers to effectively integrate chemical and biological controls through research and outreach on selective chemistries and impacts on natural enemies, Western Region SARE, USDA-NIFA (PI Isadora Bordini, CO-PIs Peter Ellsworth, **Steve Naranjo**, Al Fournier) 2018-2019
- \*Enhancing IPM by integration of chemical and biological controls through assessment of selectivity of chemistries and function of biocontrol, Western IPM Center Grant Program, USDA-NIFA (PI Isadora Bordini, CO-PIs Peter Ellsworth, **Steve Naranjo**, Al Fournier) 2018-2019
- \*Improving insect management strategies in Arizona Cotton, Arizona Cotton Growers Association. (PI Peter Ellsworth, CO-PI **Steve Naranjo**) 2018
- \*Designing and evaluating sustainable cotton systems with reduced pest and pesticide risks, Cotton Incorporated. (PI Peter Ellsworth, CO-PIs **Steve Naranjo**, Al Fournier) 2018
- \*Applying Proximal Sensing to Enhance Upland Cotton Yield Trials, Cotton Incorporated (PI **Alison Thompson**) 2018
- \*Utilizing Genes from the Soybean Germplasm Collection to Mitigate Drought Stress, United Soybean Board (PI, Larry Purcell, CO-PIs **Hussein Abdel-Haleem**, Felix Fritschi, Jason Gillman, James Smith, Jeff Ray) 2018-2022
- \*Improving Nitrogen Fertilizer Management in Subsurface Drip-Irrigated Cotton, International Plant Nutrition Institute (PI **Kevin Bronson**) 2018
- \*High-Throughput Phenotyping Using Portable LIDAR, Cotton Incorporated (PI **Andy French** with Co-PIs Michael Gore, Alison Thompson) 2018
- \*Improving Nitrogen Fertilizer Management and Fate of Nitrogen in Subsurface Drip-Irrigated Cotton, Cotton Incorporated (PI **Kevin Bronson**) 2018
- \*Evaluation and Improvement of Crop Simulation Models to Meet the Data Needs of Modern Cotton Production Systems, Cotton Incorporated (PI **Kelly Thorp**) 2018
- \*Securing Water for and from Agriculture through Effective Community & Stakeholder Engagement, USDA-NIFA (PI Kathy Brasier, CO-PIs Clinton Williams, Sarah Porter, Julia Bausch et al.) 2017-2020
- Quantitative Assessments of Water and Salt Balance for Cropping Systems in Lower Colorado River Irrigation Districts, Dept. Interior, Bureau of Reclamation (PI **Andy French**, CO-PIs Charles Sanchez, Paul Brown, Dawit Zerihun, **Eduardo Bautista**, **Clinton Williams**) 2016-2019
- Sustainable Bioeconomy for Arid Regions, USDA-NIFA (PI Kimberly Ogden, Co-PIs Dennis Ray, Peter Waller, Raina Maier, Istvan Molnar, Meghan Downes, William McCloskey, Trent Teegerstrom, Omololu Idowu, Paul Gutierrez, Kulbhushan Grover, F. Omar Holguin, Catherine Brewer, Sangamesh Angadi, **Hussein Abdel-Haleem**, Colleen McMahan, David Dierig, Amy Landis, Jason Quinn, Xianglan Bai, Karl Seck) 2017-2022
- Root Genetics in the Field to Promote Drought Adaptation and Carbon Sequestration, Dept. Energy, ARPA-e Program (PI John McKay, Parker Antin, Randy Bartels, Thomas Borch, Pedro Andrade Sanchez, Francesca Cotrufo, **Andrew French**, Michael Ottman, Sangmi Palickara, Keith Paustian, Patrick Schnable, Chris Topp, Chris Turner, Matthew Wallenstein, Jianming Yu) 2017-2020.
- Eco-hydrological Modeling Using Field-based and Earth Observations to Assess H<sub>2</sub>O Use Efficiency and Support Agricultural Water Resources Management, NASA (PI Pierre Guillevic, CO-PIs Inbal Becker-Reshef, Alissa Coffin, Jan Dempewolf, **Andy French**, Jerry Hatfield, Matthew Hansen, Roberto Cesar Izaurrlade, Jaehak Jeong, Catherine Nakalembe, Brian Thomas, Eric Vermote) 2017-2019
- Monitoring Evapotranspiration, Crop Growth and Nutrient Stress over Irrigated Crops in Central Arizona, NASA (PI **Andrew French**, Co-I **Kevin Bronson**, **Kelly Thorp**, Pedro Andrade-Sanchez) 2017-2020
- Genomics and Phenomics to Identify Yield and Drought Tolerance Alleles for Improvement of Camelina as a Biofuel Crop, USDA-NIFA. (PI **John Dyer**, Co-PIs **Hussein Abdel-Haleem**, Daniel Schachtman, Yufeng Ge, Toni Kutchan, Noah Fahlgren) 2016-2019
- Energy Sorghum Reference Phenotyping System, DOE-ARPA-E (PI Todd Mockler, CO-PIs Noah Fahlgren, Erica Fishel, Stephen Kresovich, Jeremy Schmutz, Jesse Poland, Geoff Morris, William Rooney, Pedro Andrade, Mike Ottman, **Jeff White**, David LeBauer, Robert Pless, Roman Garnett) 2015-2019
- Selecting and Using Bt-Resistant Strains of Two Key Pests to Understand Resistance and Characterize Responses to Novel Toxins, CRADA Pioneer Hi-Bred International (PI **Jeff Fabrick**) 2013-2018.
- Elucidating the Cellular Machinery for Lipid Storage in Plants, DOE-BES (PI Kent Chapman, CO-PIs **John Dyer**, Robert Mullen) 2016-2019.





# ALARC IN THE NEWS

**USDA ALARC - A Gem in the Desert.** The Economic Development Department of the City of Maricopa recently highlighted ALARC as a driver of agricultural technology for the city and the region. They also noted how ALARC contributes to the community through their outreach efforts, including its involvement in the Project Puenta student intern program with Central Arizona College. [\[Link\]](#)

**Where to Grow Food Worldwide.** Scientists from ALARC participated in a meeting at the University of Florida focused on understanding how to advance computer models for predicting the most suitable places in the world to grow food crops like wheat and cassava. [\[Link\]](#)

**ALARC working on Cutting Edge Technology.** ALARC research in water conservation, plant improvement and crop protection was featured in a story by the Tri-Valley Dispatch. The story focused on ALARC's involvement in High-Throughput-Phenotyping to remotely measure characteristics of plant in enhance plant breeding efforts, development



of the guayule plant as a native source of rubber, development of new technologies for fighting insect pests and development of improved irrigation systems. [\[Link\]](#)

**Keys to Understanding Insect Reproduction.** The research of an ALARC scientist was recently featured in a blog post with Phys.org [\[Link\]](#) and podcast with the Naked Scientist [\[Link\]](#). The research focused on understanding the role of several pheromones (chemicals used by organisms to communicate with one another) that regulate when a female Lygus bug is ready and willing to mate with a male. The research may eventually lead to better ways to control pest insect populations. (see also Featured Accomplishment)

**BRDI (USDA/DOE) Grant on Guayule Comes to a Close.**

The \$6.9M consortium grant including Cooper Tire, USDA-ARS, Pan Aridis, and Cornell and Clemson Universities came to a close in mid 2017. ALARC scientists contributed critical research on direct seeding and irrigation efficiency. Over 400 prototype tires were produced and tested [\[Link\]](#)



## EMPLOYEE ENGAGEMENT

ALARC held its **Annual Thanksgiving Potluck**. This is a yearly tradition at the center, which brings together current, former, and retired employees, as well as family and friends. Everyone enjoyed wonderful food while catching up with friends and colleagues.

Dale Spurgeon is the Center's representative on the **PWA Employee Engagement Committee**. The goal of the committee is to report engagement activities that can be featured on AXON, ARS' intranet, and to generate and share employee engagement ideas that could potentially be implemented at the Location, Area or Agency level.

This year we used **Administrative Professionals Day** to celebrate and thank all ALARC employees. Everyone enjoyed a pizza party hosted by the Center's RLs.

ALARC held its 3<sup>rd</sup> Annual **Safety Poster Contest** as a fun way to highlight the importance of safety in the workplace. Employees voted to determine the winners. All the posters are hanging in the laboratory building. **Special thanks** to Brenda Singleton for organizing the contest and Mike Roybal for printing the posters.



**1st Place**

Sharette Rockholt

**2nd Place**

Melissa Stefanek



**3rd Place**

Justin Scaturro

ALARC employees remembered Gail Dahlquist, a New Crops Research Technician who touched everyone's hearts with her amazing personality. She was diagnosed with Lou Gehrig's disease, which took her way too early. During her last months after being confined to a wheelchair, she would wear very colorful socks to keep her spirits up. The tradition lives on as we "celebrate our individuality" and "zest for life" with *Crazy Sock Day* on Gail's birthday, August 1<sup>st</sup>.

# RECENT EVENTS AND OUTREACH

**June-July 2017.** ALARC scientists in all three units hosted a total of 15 students during the third year of Project Puente (Bridge), a USDA-NIFA funded program conducted in partnership with Central Arizona College (CAC), a Hispanic Serving Institute. The program gives each student an opportunity to



conduct their own research project while learning about lab safety, data entry, strategies for working in the field, and the importance of maintaining a good



laboratory notebook during the 8-week internship. The students produced scientific posters and presented them at the annual ALARC Intern Pizza Party and then again at the closing ceremony. Students earned three college-level credits while engaged in a unique learning opportunity. ALARC scientists



have been actively involved in training and mentoring under-represented students in programs like this since 2012.

**June 2017.** The EEO committee at the USDA-ARS-Arid-Land Agricultural Research Center (ALARC) in Maricopa, AZ hosted a "Silent Auction" to help raise money to support EEO activities and diversity events held during the year. The auction was a success, raising over \$150; the event would not have been possible without generous donations from ALARC employees.

**June 2017.** ALARC hosted the annual Summer Ag Institute, a group of K-12 teachers that embark on a week-long tour throughout Arizona to learn about agriculture. This adventure is designed to teach them about food and fiber production, so they can incorporate that knowledge in the classroom curriculum. This experience is a great opportunity for the teachers to see the vital role agriculture plays in rural communities and the importance of the research being conducted at our center. The group had the opportunity to tour various labs in our three research units, learning about plant breeding, genomics, molecular biology, pest management, and water conservation. They also toured the Field Scanner and our Lateral Move Sprinkler Irrigation System.



**August 2017.** Amanda Crump, the new Director of the Western IPM Center at the University of California visited ALARC to learn more about the research happening at the Center and to meet with ALARC scientists.

**August 2017.** ALARC hosted a visit by Congressman Paul Gosar (Arizona, District 4) and his staff member Penny Pew. The Center Director and Research Leaders provided a tour of the facility and discussed current research projects in all three units.

**August 2017.** Three Crop Consultants from New South Wales, Australia visited ALARC and UA scientists to learn about the successful IPM program they co-developed to manage whiteflies in southwestern US cotton.

**September 2017.** ALARC Center Director and Research Leaders met with the Chief Executive Officer and staff members from BioHumaNetics. The company was founded in 1973 and produces premium solutions for agriculture, turf, and wastewater. The company developed a proprietary process to extract organic acids, valuable minerals, and other organic components from oxidized humate, a mineral mined in the northwestern US. This extract contains the base of Micro Carbon Technology used in over 70 of their products. The group learned about the research being conducted at the Center and discussions are underway to collaborate on projects related to remote and proximal sensing, crop nutrition and pest control in crops.

**September 2017.** ALARC employees celebrated National Hispanic Month by learning about the histories, cultures, and contributions of American citizens whose ancestors who came from Spain, Mexico, the Caribbean, and Central and South America. The theme for 2017 was "Shaping the Bright Future of America." Employees enjoyed watching a video in honor of Dr. Alfredo Quinones-Hinojosa (Dr. Q), John Hopkins, on "How I became a Scientist." The observation started in 1968 as Hispanic Heritage Week under President Lyndon Johnson and was expanded by President Ronald Reagan in 1988 to cover a 30-day period September 15 — October 15. The day of September 15 is significant because it is the anniversary of independence for Latin American countries Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua. In addition, Mexico and Chile celebrate their independence days on September 16 and September 18, respectively.

**September 2017.** Cotton and soybean scientists and industry representatives from Brazil visited ALARC and UA to learn more about the successful IPM program they co-developed to manage whiteflies in southwestern US cotton.

**September 2017.** ALARC hosted an event to recognize problem-solving situations during National Disability Employment Awareness Month. The theme for 2017 was "Inclusion Drives Innovation." Americans of all abilities must have access to a safe environment in which to work. Hiring employees with diverse abilities strengthens their business, increases competition, and drives innovation. A video was presented on the Ability One Program-Employing People who are blind or have significant disabilities, as well as providing various resources to attendees of the event.



**September 2017.** ALARC scientists and technicians Alison Thompson, Andrew French, Kelly Thorp, Kevin Bronson, Matt Conley, and Dr. Pedro Andrade-Sanchez from the University of Arizona participated in the 2017 Cotton Breeders Association Tour, sponsored by Cotton Incorporated. The



group was welcomed to ALARC by the Center Director and a tour was provided that included the TERRA-REF field scanner, a demonstration of USDA's semi-autonomous phenotyping cart platforms, and field visits to ALARC's variable-rate sprinkler and subsurface drip irrigation experimental sites. The group consisted of 75 cotton breeders from US-cotton-growing states, Australia and Pakistan (*photo courtesy of Paige Francis, ALARC*).

**November 2017.** ALARC hosted an event celebrating National Native American Heritage Month. The theme for 2017 was "Serving Our Nations." National Native American Heritage Month celebrates the rich and diverse cultures, traditions, and histories, and acknowledge the important contributions of Native people. Videos were presented entitled, "Pow-wow Dancing Styles and Meaning" and SACNAS Biography of Dr. Clifton Poodry. The Heard Museum in Phoenix lent the Center display panels called, "Remembering Our Indian School Days."

**December 2017/April 2018.** ALARC convened its semi-annual Stakeholder meetings in December and April. Stakeholders learned about on-going research from ALARC scientists on topics ranging from reuse of municipal water for irrigation, furrow irrigation dynamics, targeting pest insect biology for control, and impacts of thermal stress on grain crops. During the April meeting we heard from four of our stakeholders on topics ranging from dual-crop cotton/wheat production systems, water policy, research at the Yuma Center of Excellence in Desert Ag and Americot cotton seed. The meeting provides our stakeholders a venue to offer ideas and suggestions on research direction and to maintain strong relationships between scientists and the stakeholders they serve at the local, regional, and national level. Members represent growers, industry, university and state and federal agency interests.

**December 2017.** ALARC hosted its annual visit from a group of agricultural students and faculty from the University of Chapingo, Chapingo, Mexico. The group consisted of 47 undergraduate Irrigation Engineering students, one graduate student and four faculty members. Dr. Eduardo Bautista discussed ongoing research at ALARC in the areas of irrigation modeling, surface irrigation, and remote sensing in irrigated agriculture. Tours were given of the linear move sprinkler system, phenotyping field scanner and a phenotyping tractor. This was a great opportunity for the students to meet our scientists, and see the research being conducted.

**February 2018.** In collaboration with the University of Arizona, ALARC hosted its annual science outreach event called Farm Science Day as a Signature Event of the statewide AZ SciTech Festival. This event drew about 700 visitors from Maricopa, Casa Grande and the Phoenix metro area to learn about agriculture and the science behind agriculture. Activities included an interactive insect zoo, cotton 101, auto-steer tractor-ride along, field scanner, photosynthesis, remote sensing, drones, cricket spitting, face painting, and lots more. We were joined by the AZ Farm Bureau, Phoenix Drones, Future Farmers of America, CALS Ambassadors, AZ Dept. Ag, AZ Dept Water Resources, Central Arizona College, Arizona Mobile Education, Master Gardeners and Wild at Heart.



**March 2018.** ALARC hosted an event in celebration of Women's History Month. The Center's EEO committee presented three TED talks entitled, "Billie Jean King-the battle of the sexes", "Why gender equality is good for everyone-Men included" and "Violence against Women-it's a men's issue." The theme for 2018 was "Nevertheless She Persisted: Honoring Women Who Fight All Forms of Discrimination against Women", recognizing fifteen outstanding women for their unrelenting and inspirational persistence, and for understanding that, by fighting all forms of discrimination against women and girls, they have shaped America's history and future. In a related event, Lolita Mathew and Lily Luo participated in a panel on women in science at Estrella Mountain Community College.

**April 2018.** ALARC scientists Drs. Colin Brent, Kevin Bronson and Jeff White hosted a group of African-American youth (ages 12-17) with a Saving Our Nobel Sons (S.O.N.S) program. The program is for Phoenix-area high school students of African descent, providing physical, cultural and intellectual experiences to broaden their horizons. During the group's 4 hour visit to ALARC, they were given a tour of farm fields, laboratories and greenhouses. They were shown presentations about the center's research objectives, emphasizing the importance and scope of agricultural research. The tour was finished with a talk about career opportunities in the sciences.

# RECENT JOURNAL PUBLICATIONS

## Entomology

**Brent, C.S., Byers, J.A.,** Levi-Zada, A. 2017. An insect anti-antiaphrodisiac. *eLife*. doi:10.7554/eLife.24063. ([PDF](#))

Cook, C.N., **Brent, C.S.,** Breed, M.D. 2017. Octopamine and tyramine modulate the thermoregulatory fanning response in honey bees (*Apis mellifera* L.). *Journal of Experimental Biology*. 220:1925-1930. jeb.149203 doi:10.1242/jeb.149203

Eisenring, M., Romeis, J., **Naranjo, S.E.,** Meissle, M. 2017. Multi-trophic Cry-protein flow in Bt-cotton. *Agriculture, Ecosystems and Environment*. 247:283-289. ([PDF](#))

**Fabrick, J.A., Hull, J.J.** 2017. Assessing integrity of insect RNA. *USDA-ARS Research Notes*. 5991-7903EN: 1-12. ([PDF](#))

**Fabrick, J.A., Hull, J.J.** 2017. Transient expression and cellular localization of recombinant proteins in cultured insect cells. *Journal of Visualized Experiments*. 122:e55756. ([PDF](#))

Gouge, D.H., **Hagler, J.R.,** Walker, K., Li, S., Nair, S., Bibbs, C.S., Sumner, C., Smith, K.A. 2017. Human disease causing viruses vectored by mosquitoes. *University of Arizona Cooperative Extension*. 1744:1-10. ([PDF](#))

**Hagler, J.R., Thompson, A.L., Stefanek, M.A., Machtley, S.A.** 2018. Use of body-mounted cameras to enhance data collection: an evaluation of two arthropod sampling techniques. *Journal of Insect Science*. 18(2):40;1-8. ([PDF](#))

Kang, P., Chang, K., Liu, Y., Bouska, M., Karashchuk, G., Thakore, R., Wang, W., Post, S., **Brent, C.S.,** Li, S., Tatar, M., Bai, H. 2017. *Drosophila* Kruppel homolog 1 represses lipolysis through interactions with dFOXO. *Scientific Reports*. 7:16369. ([PDF](#))

Luo, J., Li, Z., Ma, C., Zhang, Z., **Hull, J.J.,** Lei, C., Jin, S., Chen, L. 2017. Knockdown of a metathoracic scent gland desaturase enhances the production of (E)-4-oxo-2-hexenal and suppresses female sexual attraction in the plant bug, *Adelphocoris suturalis*. *Insect Molecular Biology*. 26:642-653. ([PDF](#))

**Naranjo, S.E.** 2018. Retrospective analysis of a classical biological control programme. *Journal of Applied Ecology* <https://doi.org/10.1111/1365-2664.13163>

**Naranjo, S.E.,** Ellsworth, P. 2017. Methodology for developing life tables for sessile insects in the field using the Whitefly, *Bemisia tabaci*, in cotton as a model system. *Journal of Visualized Experiments*. (129): e56150, doi:10.3791/56150 ([PDF](#))

Oliveira, R.C., Vollet-Neto, A., Oi, C.A., Van Zoweden, J.S., Nascimento, F., **Brent, C.S.,** Wenseleers, T. 2017. Hormonal pleiotropy helps maintain queen signal honesty in a highly eusocial wasp. *Scientific Reports*. 7:1654. ([PDF](#))

Prabhaker, N., **Naranjo, S.E.,** Perring, T., **Castle, S.J.** 2017. Comparative toxicities of newer and conventional insecticides against four generalist predator species. *Journal of Economic Entomology*. 110(6):2630-2636. ([PDF](#))

Rendon, D., **Hagler, J.R.,** Taylor, P., Whitehouse, M. 2018. Integrating immunomarking with ecological and behavioural approaches to assess predation of *Helicoverpa* spp. larvae by wolf spiders in cotton. *Biological Control*. 122:51-59. ([PDF](#))

**Spurgeon, D.W.,** Suh, C.P. 2017. Starvation-induced morphological responses of the boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae). *Journal of Cotton Science*. 21:275-283. ([PDF](#))

**Spurgeon, D.W.,** Suh, C.P. 2017. Temperature influences on diapause induction and survival in the boll weevil (Coleoptera: Curculionidae). *Journal of Insect Science*. 17(6):124. ([PDF](#))

**Spurgeon, D.W.** 2017. Instar- and stage-specific photoperiodic diapause response of *Lygus hesperus* (Hemiptera: Miridae). *Journal of Insect Science*. 17(6):125. ([PDF](#))

**Spurgeon, D.W., Van Ekert, E.,** Elhoff, L.K. 2017. Accuracy of *Lygus hesperus* Knight (Hemiptera: Miridae) egg counts improves with egg development. *Journal of Cotton Science*. 21:1-7. ([PDF](#))

Tian, J.C., Wang, X.P., Chen, Y., Romeis, J., **Naranjo, S.E.,** Hellmich II, R.L., Wang, P., Shelton, A.M. 2018. Bt cotton producing Cry1Ac and Cry2Ab does not harm two parasitoids, *Cotesia marginiventris* and *Copidosoma floridanum*. *Scientific Reports*. 8:307. ([PDF](#))

Vandervoet, T., Ellsworth, P.C., Carriere, Y., **Naranjo, S.E.** 2018. Quantifying conservation biological control for management of *Bemisia tabaci* in cotton. *Journal of Economic Entomology*. doi: 10.1093/jee/toy049 ([PDF](#))

Wang, L., Ma, Y., Wan, P., Liu, K., Xiao, Y., Wang, J., Cong, S., Xu, D., Wu, K., **Fabrick, J.A.,** Li, X., Tabashnik, B.E. 2018. Resistance to *Bacillus thuringiensis* linked with a cadherin transmembrane mutation affecting cellular trafficking in pink bollworm from China. *Insect Biochemistry and Molecular Biology*. 94:28-35. <https://doi.org/10.1016/j.ibmb.2018.01.004>

Zhang, H., Yu, S., Shi, Y., Yang, Y., **Fabrick, J.A.,** Wu, Y. 2017. Intra- and extracellular domains of the *Helicoverpa armigera* cadherin mediate Cry1Ac cytotoxicity. *Journal of Insect Biochemistry and Molecular Biology*. 86:41-49. <https://doi.org/10.1016/j.ibmb.2017.05.004>

## Plant Science

**Abdel-Haleem, H.A.,** Foster, M., Ray, D., **Coffelt, T.A.** 2018. Phenotypic variations, heritability and correlations in dry biomass, rubber and resin production among guayule germplasm. *Industrial Crops and Products*. 112:691-697. doi: 10.1016/j.indcrop.2017.12.072. ([PDF](#))

Hannam, C., Gidda, S.K., Humbert, S., Peng, M., Cui, Y., **Dyer, J.M.,** Rothstein, S.J., Mullen, R.T. 2017. Distinct domains within the NITROGEN LIMITATION ADAPTATION protein mediate its subcellular localization and function in the nitrate-dependent phosphate homeostasis pathway. *Botany* 96:79-96. <https://doi.org/10.1139/cjb-2017-0149>

Ilut, D.C., **Sanchez, P.L., Coffelt, T.A., Dyer, J.M.,** Jenks, M.A., Gore, M.A. 2017. A century of guayule: Comprehensive genetic characterization of the US national guayule (*Parthenium argentatum* A. Gray) germplasm collection. *Industrial Crops and Products*. 109:300-309. <https://doi.org/10.1016/j.indcrop.2017.08.029>

Kassie, B.T., **Kimball, B.A.,** Jamieson, P.D., Bowden, J.W., Sayre, K.D., Groot, J.R., **Pinter, P., La Morte, R.L., Hunsaker, D.J., Wall, G.W.,** Leavitt, S.W., **White, J.W.,** Asseng, S. 2018. Field experimental data for crop modeling of wheat growth response to nitrogen fertilizer, elevated CO<sub>2</sub>, water stress, and high temperature. *Open Data Journal for Agricultural Research*. 4:9-15. ([PDF](#))

**Kimball, B.A., Pinter, P.J., Lamorte, R.L.,** Leavitt, S.W., **Hunsaker, D.J., Wall, G.W.,** Wechsung, F., Wechsung, G., Bloom, A.J., **White, J.W.** 2017. Data from the Arizona FACE (Free-Air CO<sub>2</sub> Enrichment) experiments on wheat at ample and limiting levels of water and nitrogen. *Open Data Journal for Agricultural Research*. 3:29-38. ([PDF](#))

**Kimball, B.A., White, J.W., Wall, G.W.,** Ottman, M.J., Martre, P. 2018. Wheat response to a wide range of temperatures, as determined from the Hot Serial Cereal (HSC) experiment. *Open Data Journal for Agricultural Research* 4: 16-21. ([PDF](#))



Lamsal, A., Welch, S.M., **White, J.W., Thorp, K.R.**, Bello, N. 2018. Estimating parametric phenotypes that determine anthesis date in *Zea mays*: Challenges in combining ecophysiological models with genetics. PLoS One. <https://doi.org/10.1371/journal.pone.0195841>. (PDF)

Martre, P., **Kimball, B.A.**, Ottman, M.J., **Wall, G.W., White, J.W.** et al. 2018. The Hot Serial Cereal Experiment for modeling wheat response to temperature: field experiments and AgMIP-Wheat multi-model simulations. Open Data Journal for Agricultural Research. 4: 28-34. (PDF)

Pauli, D., **White, J.W.**, Andrade-Sanchez, P., **Conley, M.M.**, Huen, J., **Thorp, K.R., French, A.N., Hunsaker, D.J.**, Carmo-Silva, E.A., Wang, G., Gore, M.A. 2017. Investigation of the influence of leaf thickness on canopy reflectance and physiological traits in upland and Pima cotton populations. Frontiers in Crops Science and Horticulture. 8:1405. (PDF)

Pyc, M., Cai, Y., Gidda, S.K., **Yurchenko, O., Park, S.**, Kretschmar, F., Ischebeck, T., Valerius, O., Braus, G.H., Chapman, K., **Dyer, J.M.**, Mullen, R.T. 2017. Arabidopsis lipid droplet-associated protein (LDAP)-interacting protein (LDIP) influences lipid droplet size and neutral lipid homeostasis in both leaves and seeds. Plant Journal. 92:1182-1201. (PDF)

Pyc, M., Cai, Y., Greer, M.S., **Yurchenko, O.**, Chapman, K.D., **Dyer, J.M.**, Mullen, R.T. 2017. Turning over a new leaf in lipid droplet biology. Trends in Plant Science. 22:596-609. (PDF)

**Thompson, A.L., Thorp, K.R., Conley, M.**, Andrade-Sanchez, P., Heun, J.T., **Dyer, J.M. White, J.W.** 2018 Deploying a proximal sensing cart to identify drought-adaptive traits in upland cotton for high-throughput phenotyping. Front. Plant Sci. 9:507. (PDF)

**Tomasi, P., Dyer, J.M.**, Jenks, M.A., **Abdel-Haleem, H.A.** 2017. Characterization of leaf cuticular wax classes and constituents in a spring *Camelina sativa* diversity panel. Industrial Crops and Products. 112(2018):247-251. (PDF)

Wang, E., Martre, P., Assenge, S., Ewert, F., Zhao, Z., Maiorano, A., Rotter, R.P., **Kimball, B.A.**, Ottman, M.J., **Wall, G.W., White, J.W.** et al. 2017. The uncertainty of crop yield projections is reduced by improved temperature response functions. Nature Plants. 3:17102. [doi: 10.1038/nplants.2017.102](https://doi.org/10.1038/nplants.2017.102).

Weaver, J.M., **Lohrey, G.T., Tomasi, P., Dyer, J.M.**, Jenks, M.A., Feldmann, K.A. 2018. Cuticular wax variants in a population of switchgrass (*Panicum virgatum* L.). Industrial Crops and Products. 117:310-316. <https://doi.org/10.1016/j.indcrop.2018.02.081>

Webber, H., **White, J.W., Kimball, B.A.....Wall, G.W.** et al. 2018 Physical robustness of canopy temperature models for crop heat stress simulation across environments and production conditions. Field Crops Research 216: 75-88. <https://doi.org/10.1016/j.fcr.2017.11.005>

## **Water Conservation**

Adhikari, P., Ale, S., Delaune, P.B., **Thorp, K.R.**, Barnes, E.M. 2017. Simulated effects of winter wheat cover crop on the cotton production systems of the Texas rolling plains. Transactions of the ASABE. 60(6):2083-2096. <https://doi.org/10.13031/trans.12272>

**Bautista, E., Schlegel, J.L.** 2017. / transstimulation of infiltration and hydraulic resistance in furrow irrigation, with infiltration dependent on flow depth. Transactions of the ASABE. 60(6):1873-1884. (PDF)

**Bautista, E., Schlegel, J.L.** 2017. A flexible system for the estimation of infiltration and hydraulic resistance parameters in surface irrigation. Transactions of the ASABE. 60(4):1223-1234. (PDF)

Bilal, M.F., Saleem, M.F., Wahid, M.A., Shakeel, A., **French, A.N.**, Sarwar, M. 2017. Management practices to control premature senescence in Bt cotton. Journal of Plant Nutrition. <https://doi.org/10.1080/01904167.2017.1310886>

**Bronson, K.F., Hunsaker, D.J., Williams, C.F., Thorp, K.R., Rockholt, S.M.**, Del Grosso, S.J., Venterea, R.T., Barnes, E.M. 2018. Nitrogen management impacts nitrous oxide emissions under varying cotton irrigation systems in the American Desert Southwest. Journal of Environmental Quality. 47:70-78. (PDF)

**Bronson, K.F., Hunsaker, D.J., Mon, J.**, Andrade-Sanchez, P., **White, J.W., Conley, M.M., Thorp, K.R., Bautista, E.**, Barnes, E. 2018. Improving nitrogen fertilizer use efficiency in surface- and overhead sprinkler-irrigated cotton in the desert southwest. Soil Science Society of America Journal 81:1401-1412. (PDF)

Shamshiri, R.R., Jones, J.W., **Thorp, K.R.**, Ahmad, D., Man, H.C., Taheri, S. 2018. Review of optimum temperature, humidity, and vapour pressure deficit for microclimate evaluation and control in greenhouse cultivation of tomato: a review. International Agrophysics. 32(2),287-302. (PDF)

Shamshiri, R.R., Kalantari, F., Ting, K.C., **Thorp, K.R.**, Hameed, I.A., Weltzien, C., Ahmad, D., Shad, Z.M. 2018. Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban farming. International Journal of Agricultural and Biological Engineering 11(1):1-22. (PDF)

Spatier, M., Kim, S., Kucera, L., Fisher, J., Lee, C., **French, A.N.** 2017. Linking managed and natural ecosystems through evapotranspiration and NASA's upcoming ECOSTRESS mission. Earthzine. <https://earthzine.org/2017/06/14/linking-managed-and-natural-ecosystems-through-evapotranspiration-and-nasa-upcoming-ecostress-mission/>.

**Thorp, K.R., Hunsaker, D.J., Bronson, K.F.**, Andrade-Sanchez, P., Barnes, E.M. 2017. Cotton irrigation scheduling using a crop growth model and FAO-56 methods: Field and simulation studies. Transactions of the ASABE. 60(6):2023-2039. (PDF)

Yang, Y., Toor, G., Wilson, P., **Williams, C.F.** 2017. Micropollutants in groundwater from septic systems: Transformations, transport mechanisms, and human health risk assessment. Water Research 123:258-267. <https://doi.org/10.1016/j.watres.2017.06.054>

Youssef, M.A., Abdelbaki, A.M., Negm, L.M., Skaggs, R., **Thorp, K.R.**, Jaynes, D.B. 2018. DRAINMOD-simulated performance of drainage water management across the U.S. Midwest. Transactions of the ASABE. 197:54-66. <https://doi.org/10.1016/j.agwat.2017.11.012>



High Throughput Phenotyping tractor at Farm Science Day