**SAES-422 Multistate Research Activity Accomplishments Report**

Project No. and Title: W3128 “Scaling Microirrigation Technologies to Address Global Water Challenges”

Period Covered: 10-2017 to 09-2018

Date of Report: 12/22/2018

Annual Meeting Dates: December 3-5, 2018

**Participants:** Steven Evett (Steve.Evett@ARS.USDA.GOV) – USDA ARS, Bushland, Texas; Bradley Rein (BREIN@NIFA.USDA.EDU) – NIFA, USDA; Freddie Lamm (flamm@ksu.edu) – Kansas State University, Isaya Kisekka (ikisekka@ucdavis.edu) - University of California Davis; Amir Haghverdi (amirh@ucr.edu) - University of California, Riverside; Saleh Taghvaeian (saleh.taghvaeian@okstate.edu) - Oklahoma State University; Clinton Shock, Rhuanito Ferrarezi (rferrarezi@ufl.edu) - University of Florida, Pete Jacoby (jacoby@wsu.edu) - Washington State University; Ripendra Awal (riawal@pvamu.edu) – Prairie View A&M University; Howard Neibling (hneiblin@uidaho.edu) - University of Idaho; and Kenneth Shackel (kashackel@ucdavis.edu) - University of California Davis (Zoom)

**Brief Summary of Minutes of Annual Meeting:**

* The annual meeting was held on December 3, 2018, in the S-7 (Seaside level) room of Long Beach Convention & Entertainment Center in Long Beach, California. The meeting was presided by 2018 Committee Chair Dr. Rhuanito Ferrarezi.
* The venue chosen for the next meeting in 2019 was San Antonio, Texas at ASA, CSSA, and SSSA Annual Meetings on Nov 10-13, 2019. Dr. Steve Evett and Dr. Freddie Lamm will provide support with the society to not have registration fees.
* Dr. Amir Haghverdi, Assistant CE Specialist at the University of California Riverside, was elected 2019 secretary for the W3128 group. Dr. Davie Kadyampakeni and Dr. Ripendra Awal become 2019 Committee Chair and Vice-Chair, respectively.
* W3128 Project will expire on September 30, 2019. The new proposal is due in the National Information Management Support System (NIMSS) system by January 15, 2019.
* Dr. Bradley Rein (NIFA – USDA) provided NIFA updates. He briefly discussed on the background of new NIFA director Dr. J. Scott Angle and his interest in agricultural production. Dr. Rein also highlighted transition plans (building relocation, personnel challenges) of NIFA briefly. Dr. Rein informed the committee about some funding opportunities: AFRI Water for Food Production Systems (about seven awards), Sustainable Agricultural Systems, Agriculture Systems and Technology(Foundational and Applied Science Program).
* Dr. Steve Evett provided ARS updates and state reports were presented by Dr. Ripendra Awal (Texas) and Dr. Amir Haghverdi (California).
* The rest of the meeting was focused on new W4128 grant discussion and writing. All participants were able to contribute in an online document created by Dr. Rhuanito Ferrarezi for proposal writing.
* The committee organized **Special Session – W3128: USDA-National Institute of Food & Agriculture Multistate Microirrigation Research Group** on December 4 (2:00 p.m.-5:00 p.m.). The session was moderated by Dr. Danny H. Rogers, Oklahoma State University. Following eight papers were presented during the session:
	+ Evaporative Loss Differences Between Subsurface Drip Irrigation & Sprinkler Irrigation – Southern High Plains Experience  - *Steven R. Evett, USDA-ARS*
	+ Direct Root Zone Drip Irrigation to Enhance Precision Deficit Irrigation - *Pete Jacoby, Washington State University*
	+ Subsurface Drip Fertigation for Site-specific Precision Management of Cotton - *Mark Dougherty, Auburn University*
	+ Soil Moisture & Nutrient Dynamics in Root Zone of Collard Greens Produced in Different Organic Amendments & Rates - *Ripendra Awal, Prairie View A&M University*
	+ Potential for Intensification of Maize Production With Subsurface Drip Irrigation - *Freddie Ray Lamm, Kansas State University*
	+ Citrus Water Use & Soil Moisture Distribution Using Regulation Deficit Irrigation - *Davie Mayeso Kadyampakeni, University of Florida*
	+ Effect of Irrigation Methods & Plant Densities on Grapefruit Cultivated in Open Hydroponics System - *Rhuanito Soranz Ferrarezi, University of Florida Institute of Food and Agriculture Sciences Indian River Research and Education Center*
	+ Creation & Adoption of Smart Agriculture Innovations - *Clinton C. Shock, Oregon State University Malheur Experiment Station*



Participants during Special Session

**ACCOMPLISHMENTS**

**Alabama**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

Ongoing development of a method to use field soil tension monitoring in soybeans to develop crop coefficients for irrigation scheduling.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities and***

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

Compiled seven years of subsurface fertigated cotton yield data in replicated research plot study. Treatments related to timing of fertigated nitrogen. Results presented in 2018 Irrigation Association meeting and being revised for publication 2019.

**California**

**University of California Riverside (Department of Environmental Sciences)**

1. **Outputs**

Research findings were disseminated via refereed journal publications, conference proceedings, and a number of presentations at national and international meetings (see the publication section below). HYDRUS models have been updated with several new capabilities and options that have been developed for various research projects, which in turn have been published in peer-reviewed journals.

1. **Activities**In 2018, we offered two- or three-day short courses on how to use HYDRUS models at a) Czech University of Life Sciences, Prague, Czech Republic, b) Colorado School of Mines, Golden, CO, c) the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China, d) Tokyo University of Agriculture and Technology, Department of Ecoregion Science, Tokyo, Japan, e) WASCAL Headquarters, Accra, Ghana, NC. About 150 students participated in these short courses.

**Meetings attended**:

1. W-3188 Western Regional Soil Physics Group Meeting, Desert Research Institute, Las Vegas, NV, January 2-4, 2018.
2. CZO/LTER/NEON/ISMC Workshop"Using Observation Networks to Advance Earth System Understanding: State of the Art, Data-Model Integration, and Frontiers", February 13-15, 2018.
3. 6th International Conference "HYDRUS Software Applications to Subsurface Flow and Contaminant Transport Problems", University of Tokyo, Tokyo, Japan, September 20, 2018.
4. ISMC (International Soil Modelling Consortium) bi-annual meeting in Wageningen, The Netherlands, November 5-7, 2018.

**HYDRUS Teaching**:

1. A short course “Advanced modeling of water flow and contaminant transport in porous media using the HYDRUS software packages” organized by Czech University of Life Sciences, Prague, Faculty of Agrobiology, Food and Natural Resource, Prague, Czech Republic, March 19-21, 2018. Other instructor: M. Th. van Genuchten (20 participants).
2. A short course “Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, Colorado School of Mines, Golden, CO, June 25-27, 2018. Sole instructor (14 participants).
3. A short course “Modeling Water Flow and Contaminant Transport in Porous Media Using the HYDRUS and HP1 Software Packages”, Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China, July 2-4, 2018. Sole instructor (28 participants).
4. A short course “Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, Tokyo University of Agriculture and Technology, Department of Ecoregion Science, Tokyo, Japan, September 18-19, 2018. Other instructors: Dr. Hirotaka Saito (60 participants).
5. A short course “Hackathon: Modeling of Irrigation, Water Flow and Nutrient Transport in Soils (using the HYDRUS Software Packages)”, WASCAL Headquarters, Accra, Ghana, November 29-30, 2018. Other instructor: Dr. Roland Baatz (30 participants).
6. **Short-term Outcomes and Milestones**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

We continue to expand the capabilities of the HYDRUS modeling environment by developing specialized modules for more complex applications that cannot be solved using its standard versions. The standard versions of HYDRUS, as well as its specialized modules, have been used by myself, my students, and my collaborators in multiple applications described below.

1. ***The Use of Hydrus Models to Evaluate Various Irrigation and Fertigation Problems* - *Agricultural Applications***
2. **Karandish et al.** **(2018)** applied HYDRUS (2D/3D) for predicting the influence of subsurface drainage on soil water dynamics in a rainfed-canola cropping system. The simulation results demonstrated that the groundwater table management can be an effective strategy to sustain shallow aquifers in the subsurface-drained paddy fields during winter cropping.
3. **Darzi-Naftchali et al. (2018)** applied the HYDRUS (2D/3D) model to investigate the combined effects of different subsurface drainage systems and water management strategies on water balance, groundwater table, transpiration efficiency, and water use efficiency in paddy fields.
4. **Hartmann et al. (2018)** developed a root growth model and implemented it into HYDRUS. The model considers root growth to be a function of different environmental stresses. The effects of temperature in the root growth module was the first part of the newly developed HYDRUS add-on to be validated by comparing modeling results with measured rooting depths in an aeroponic experimental system with bell pepper.
5. **Karimov et al.** **(2018)** used HYDRUS-1D to evaluate whether a change in cropping pattern can produce water savings and social gains. The analysis was carried out for the Fergana Valley, Central Asia. Modeling results indicate that replacing alfalfa with winter wheat in the Fergana Valley released significant water resources, mainly by reducing productive crop transpiration when abandoning alfalfa in favor of alternative cropping systems. However, the winter wheat/fallow cropping system caused high evaporation losses from fallow land after harvesting of winter wheat. Double cropping (i.e., the cultivation of green gram as a short duration summer crop after winter wheat harvesting) reduced evaporation losses, enhanced crop output and hence food security, while generating water savings that make more water available for other productive uses.
6. **Shelia et al. (2018)** implemented the HYDRUS flow routines into the DSSAT crop modeling system. DSSAT refers to a suite of field‐scale, process‐based crop models that simulate the phenological development of crops, including detailed information about various yield components, from emergence till maturity on the basis of crop genetic properties, environmental conditions (soil, weather) and management options. While the DSSAT system thus far relied on the “tipping bucket” water balance approach to represent soil hydrologic and water redistribution processes, implementation of the HYDRUS flow routines into DSSAT allows one to use now the more process-based Richards equation to represent these processes.
7. **Phogat et al. (2018a)** evaluated soil water and salinity dynamics under sprinkler irrigated almond exposed to a varied salinity stress at different growth stages using both field experiments as well as their analysis using HYDRUS (2D/3D). This study provided a greater understanding of soil water and salinity dynamics under almond irrigated with waters of varying qualities.
8. **Phogat et al. (2018b)** used the HYDRUS-1D model to identify the future water and salinity risks to irrigated viticulture in the Murray-Darling Basin, South Australia. Water and water related salinity risks to viticulture were assessed by running the HYDRUS-1D model with 100 ensembles of downscaled daily meteorological data obtained from the Global Climate Model (GCM) for 2020–2099. The modeling output was evaluated for seasonal irrigation requirements of viticulture, root zone soil salinity at the beginning of the new season, and the average seasonal salinity for all 100 realizations for four 20-year periods. The modeling results indicate that soil salinity at the beginning of the vine season and the average seasonal salinity are crucial factors that may need special management to sustain the viticulture in this region.
9. **Kacimov et al. (2018)** revisited the Kornev’s irrigation technology and Kidder’s free boundary problems using analytical solutions and verified them using HYDRUS.
10. **Brunetti et al. (2018)** developed a hybrid Finite Volume – Finite Element (FV-FE) model that describes the coupled surface subsurface flow processes occurring during furrow irrigation and fertigation. The numerical approach combines a one-dimensional description of water flow and solute transport in an open channel with a two-dimensional description of water flow and solute transport in a subsurface soil domain, thus reducing the dimensionality of the problem and the computational cost. The modeling framework includes the widely used hydrological model, HYDRUS, which can simulate the movement of water and solutes, as well as root water and nutrient uptake in variably-saturated soils. The robustness of the proposed model was examined and confirmed by mesh and time step sensitivity analyses. The model was theoretically validated by comparison with simulations conducted with the well-established model WinSRFR and experimentally validated by comparison with field-measured data from a furrow fertigation experiment conducted in the US.
11. **Liu et al. (2019)** developed a coupled model a numerical model simulating water flow and solute transport for a furrow irrigation system, in which surface water flow and solute transport are described using the zero-inertia equation and the average cross-sectional convection-dispersion equation, respectively, while the two-dimensional Richards equation and the convection-dispersion equation are used to simulate water flow and solute transport in soils, respectively. Solutions are computed numerically using finite differences for surface water flow and finite volumes for solute transports in furrow. Subsurface water flow and solute transport equations are solved using the CHAIN\_2D code. An iterative method is used to couple computations of surface and subsurface processes. The coupled model was validated by comparing its simulation results with measured data.
12. **Karandish and Šimůnek (2018)** used the field-calibrated and validated HYDRUS (2D/3D) model to find optimal management scenarios based on the concept of the water footprint (WF), a measure of the consumptive and degradative water use. The scenarios were defined as a combination of different salinity rates (SR), irrigation level s (IL, the ratio of an actual irrigation water depth and a full irrigation water depth), nitrogen fertilization rates (NR), and two water-saving irrigation strategies, deficit irrigation (DI) and partial root-zone drying (PRD).
13. **Wongkaew et al. (2018)** used an artificial capillary barrier (CB), which consisted of two layers of gravel and coarse sand, to improve the soil water retention capacity of the root zone of sandy soil for the cultivation of Japanese spinach. The performance of a CB under specific conditions was evaluated using numerical simulations. Wangkaew et al. (2018) (i) evaluated the performance of a CB during the cultivation of Japanese spinach irrigated at different rates and (ii) investigated the effect of the irrigation schedule on root water uptake. Numerical analysis was performed using HYDRUS-1D after the soil hydraulic properties of the CB materials were determined.
14. **Saefuddin et al. (2018)** evaluated a ring-shaped emitter made from a standard rubber hose that has been developed and introduced for subsurface irrigation in Indonesia. It is a low-cost irrigation technology based on indigenous materials and skills. To build a ring-shaped emitter of the original design, a rubber hose is bent into a ring shape with a diameter of about 20 cm, and then five 5-mm holes are drilled into it at even intervals. The entire ring-shaped hose is covered with a permeable textile so that water can infiltrate in all directions around the buried emitter. The main objectives of this study thus were 1) to experimentally investigate the water movement around a buried ring-shaped emitter and 2) to numerically evaluate the effect of modifying the design of the ring-shaped emitter on soil water dynamics around the emitter. Numerical simulations were carried out using HYDRUS, one of the most complete packages for simulating variably-saturated water flow in two- or three-dimensional domains.
15. **Karandish and Šimůnek (2019)** applied the HYDRUS (2D/3D) and SALTMED models to investigate the influence of various water-saving irrigation strategies on maize water footprints. The models were first calibrated and validated based on data collected in a two-year field investigation under five water-saving irrigation treatments: full irrigation, partial root-zone drying at water deficit levels of 55% and 75%, and deficit irrigation at the same levels. While the SALTMED model performed well when simulating crop growth parameters, the HYDRUS (2D/3D) model was more accurate when simulating soil water and solute transport.
16. ***Hydrological Applications***
17. **Szymkiewicz et al. (2018)** simultaneously used the HYDRUS and SWI2 packages for MODFLOW to simulate freshwater lens recharge and the position of the salt/freshwater interface. While the HYDRUS package gives MODFLOW the capability to consider processes in the vadose zone, the SWI2 package is used to represents in a simplified way variable-density flow associated with saltwater intrusion in coastal aquifers.
18. **Beegum et al. (2018, 2019)** first updated the HYDRUS package for MODFLOW (HPM) by developing a new methodology to eliminate the error in the determination of the recharge flux at the bottom of the HPM profile and then additionally also implemented solute transport into the HPM. She then successfully tested these two new developments against fully two- or three-dimensional simulations with HYDRUS (2D/3D).
19. **Sasidharan et al. (2018a)** conducted numerical and field scale experiments to improve our understanding and ability to characterize the drywell behavior. HYDRUS (2D/3D) was modified to simulate transient head boundary conditions for the complex geometry of the Maxwell Type IV drywell. Falling-head infiltration experiments were conducted on drywells located at the National Training Center in Fort Irwin, California (CA) and a commercial complex in Torrance, CA to determine in situ soil hydraulic properties by inverse parameter optimization.
20. **Brunetti et al. (2018a)** investigated the use of different global sensitivity analysis techniques in conjunction with a mechanistic model in the numerical analysis of a permeable pavement installed at the University of Calabria. The Morris method and the variance-based E-FAST procedure were applied to investigate the influence of soil hydraulic parameters on the pavement’s behavior. The analysis revealed that the Morris method represents a reliable computationally cheap alternative to variance-based procedures for screening important factors and provides the first inspection of the model. The study was completed by a combined GSA-GLUE uncertainty analysis used to evaluate the model accuracy.
21. **Brunetti et al. (2018b)** assessed the information content of aboveground fast-neutron counts to estimate SHPs using both a synthetic modeling study and actual experimental data from the Rollesbroich catchment in Germany. For this, the forward neutron operator COSMIC was externally coupled with the hydrological model HYDRUS-1D. The coupled model was combined with the Affine Invariant Ensemble Sampler to calculate the posterior distributions of effective soil hydraulic parameters as well as the model-predictive uncertainty for different synthetic and experimental scenarios. Measured water contents at different depths and cosmic-ray neutron fluxes were used to assess estimated SHPs.
22. ***Fate and Transport of Various Substances (Carbon Nanotubes, Viruses, Explosives)***

With another member of the W3188 group, Scott Bradford we worked on three aspects of the transport of pathogens in the subsurface.

1. **Arthur et al. (2018)** used the HYDRUS-1D model that was modified to consider particle dissolution to evaluate dissolution and transport of energetic constituents from the new insensitive munitions (IM) formulations IMX-101, a mixture of NTO, NQ, and DNAN, and IMX-104, a mixture of NTO, RDX, and DNAN. NTO and DNAN are emerging contaminants associated with the development of insensitive munitions as replacements for traditional munitions. Flow interruption experiments were performed to investigate dissolution kinetics and sorption non-equilibrium between soil and solution phases.
2. **Rahmatpour et al. (2018)** investigated the transport and retention of polyvinylpyrrolidone (PVP) stabilized silver nanoparticles (AgNPs, diameter of 40 nm) under saturated and unsaturated conditions in intact columns of two calcareous sandy loam (TR) and loam (ZR) soils. The one-site kinetic attachment model in HYDRUS-1D, which accounted for time- and depth-dependent retention, was successfully used to analyze the retention of AgNPs. The results showed that the degree of saturation had little effect on the mobility of AgNPs through undisturbed soil columns. The results suggested the limited transport of AgNPs in neutral/alkaline calcareous soils under both saturated and unsaturated conditions.
3. **Adrian et al. (2018)** conducted packed column experiments to investigate the transport and blocking behavior of surfactant-and polymer-stabilized engineered silver nanoparticles (Ag-ENPs) in saturated natural aquifer media with varying content of silt and clay fraction, background solution chemistry, and flow velocity. Breakthrough curves for Ag-ENPs exhibited blocking behavior that frequently produced a delay in arrival time in comparison to a conservative tracer that was dependent on the physicochemical conditions, and then a rapid increase in the effluent concentration of Ag-ENPs. This breakthrough behavior was accurately described using one or two irreversible retention sites that accounted for Langmuirian blocking on one site.
4. **Sasidharan et al. (2018)** investigated the influence of virus type (PRD1 and FX174), temperature (flow at 4 and 20°C), a no-flow storage duration (0, 36, 46, and 70 d), and temperature cycling (flow at 20°C and storage at 4°C) on virus transport and fate in saturated sand-packed columns. The vast majority (84–99.5%) of viruses were irreversibly retained on the sand, even in the presence of deionized water and beef extract at pH = 11. A model that considered advective–dispersive transport, attachment, detachment, solid phase inactivation, and liquid phase inactivation coefficients, and a Langmuirian blocking function provided a good description of the early portion of the breakthrough curve.
5. **Liang et al. (2019)** investigated the roles of graphene oxide (GO) particle geometry, GO surface orientation, surface roughness, and nanoscale chemical heterogeneity on interaction energies, aggregation, retention, and release of GO in porous media. Calculations revealed that these factors had a large influence on the predicted interaction energy parameters.
6. ***Reviews***
7. **Jacques et al. (2018)** reviewed recent adaptations of the HPx module of HYDRUS that have significantly increased the flexibility of the software for different environmental and engineering applications. They provide an overview of the most significant changes of HPx, such as coupling transport properties to geochemical state variables, gas diffusion, transport in two and three dimensions, and the support for OpenMP that allows for parallel computing using shared memory. The authors concluded that HPx offers a unique framework to couple spatial-temporal variations in water contents, temperatures, and water fluxes, with dissolved organic matter and CO2 transport, as well as bioturbation processes.
8. **Šimůnek et al.** **(2018)** reviewed new features of the version 3 of the HYDRUS (2D/3D) computer software package. These new features include a flexible reservoir boundary condition, expanded root growth features, and many new graphical capabilities of the GUI. Mathematical descriptions of the new features are provided, as well as two examples illustrating applications of the reservoir boundary condition.
9. **Publications (articles, books, book chapters, abstracts)**

**Abstracts**:

* Šimůnek, J., The use of HYDRUS models to evaluate processes in the critical zone, The CZO/LTER/NEON/ISMC Workshop, Bolder, Co, February 13-15, 2018.
* Liang, J., W. Li, S. A. Bradford, and J. Šimůnek, Predictions of the surface runoff quality using machine learning and deep learning models, California Water & Environmental Modeling Forum, 2018 Annual Meeting, April 2-4, 2018.
* Lassabatere, L., J. Šimůnek, and R. Angulo, Influence of flow homogeneity on solute transport – a numerical investigation, *Geophysical Research Abstracts*, Vol. *20*, Abstract EGU2018-4012, Session SSS7.2/HS8.3.10 - Preferential flow and mass transfers in soils and porous fractured media, EGU General Assembly 2018, Vienna, Austria, April 8-13, 2018.
* Hartmann, A., J. Šimůnek, M. K. Aidoo, S. Seidel, and N. Lazarovitch, Implementation and application of a new HYDRUS add-on module to model the interactions between plant roots, soil properties, and water flow conditions in soils, *Geophysical Research Abstracts*, Vol. *20*, Abstract EGU2018-5942, Session HS8.3.4/SSS13.81 - Soil-Root Interactions, EGU General Assembly 2018, Vienna, Austria, April 8-13, 2018.
* Brunetti, G., J. Šimůnek, H. Dahlke, H. Bogena, R. Baatz, and H. Vereecken, On the information content of cosmic-ray neutrons in Bayesian optimization of soil hydraulic properties, *Geophysical Research Abstracts*, Vol. *20*, Abstract EGU2018-12838, Session HS2.3.1 – Innovative sensing techniques and data analysis approaches to increase hydrological process understanding, EGU General Assembly 2018, Vienna, Austria, April 8-13, 2018.
* Imran, M., A. G. Khan, Anwar-ul-Hassan, M. Iqbal, Tanveer-ul-Haq, A. Fares, and J. Šimůnek, Performance of spring and summer-sown maize under different water conservation irrigation strategies in Pakistan, 17th Congress of Soil Science, March 13-15, 2018, Faisalabad-Pakistan, 2018.
* Bradford, S. A., S. Sasidharan, J. Šimůnek, and S. Torkzaban, Managed aquifer recharge for water reclamation, recycling, and reuse, Japanese Geophysical Union, Makuhari Messe, Chiba, Japan, May 20-24, 2018.
* Hansson, L., J. Šimůnek, E. Ring, P.-E. Jansson, K. Bishop, and A. Gärdenäs, Root zone hydrology in and around wheel tracks on boreal forest clear-cuts: 2D modelling and vegetation inventory, *North American Forest Soils Conference - International Symposium on Forest Soils 2018*, Quebec, Canada, June 10-16, 2018.
* Mallants, D., and J. Šimůnek, The Use of UNSATCHEM to explore safe water quality requirements for sustainable irrigation with coal seam gas produced water, the 25th Salt Water Intrusion Meeting, Gdańsk, Poland, 17-22 June, 2018.
* Vanderborght, J., J. Šimůnek, G. Deckmyn, M. Javaux, D. Leitner, S. Painter, A. Schnepf, A. Verhoef, K. Van Looy, L. Weihermüller, M. Young, and H. Vereecken, Goals and activities of the ISMC soil development and intercomparison panel (Soil-MIP), International Union of Soil Science, Rio de Janeiro, Brazil, August 12-17, 2018.
* Bradford, S. A., H. Kim, C. Shen, S. Sasidharan, B. Headd, G. Hwang, and J. Šimůnek, Optimized delivery of nanoparticles and genetically engineered bacteria to enhance soil and groundwater remediation, Invited presentation**, The 4th International Conference on Contaminated Land, Ecological Assessment and Remediation 2018,** CLEAR2018, Hong Kong Polytechnic University, 16-18 August, Hong Kong, China, 2018.
* Mallants, D., P. Mallants, J. Šimůnek, A. Schapel, and D. Rassam, Effect of clay addition on the water balance of a sandy soil, 6th International Conference 'Hydrus Software Applications to Subsurface Flow and Contaminant Transport Problems', Tokyo, Japan, September 20, 2018.
* Šimůnek, J., H. Saito, M. Th. van Genuchten, D. Jacques, S. A. Bradford, and M. Šejna, Recent developments and applications of the HYDRUS software packages, 6th International Conference 'Hydrus Software Applications to Subsurface Flow and Contaminant Transport Problems', Tokyo, Japan, September 20, 2018.
* Bradford, S. A., H. Kim, C. Shen, S. Sasidharan, and J. Šimůnek, Optimized delivery of nanoparticles and genetically engineered bacteria to enhance soil and groundwater remediation, Invited Abstract for the InterNano International Workshop "Engineered Nanoparticles in Aquatic and Terrestrial Compartments: Fate, Effects and Analytics", September 19-21, Landau in der Pfalz, Germany, 2018.
* Shelia, V., J. Šimůnek, K. Boote, J. Anothai, and G. Hoogenbooom, Evaluation of two soil water dynamics modeling approaches for the cropping systems using DSSAT, 2018 ASA and CSSA meeting, Baltimore, MD, November 4-7, 2018.
* Bradford, S. A., and J. Šimůnek, Modeling episodic release and transport of colloids and colloid-facilitated contaminants with transients in solution chemistry and water saturation, ISMC (International Soil Modelling Consortium) meeting in Wageningen, The Netherlands, November 5-7, 2018.
* Brunetti, G., and J. Šimůnek, Lower-fidelity surrogate models for the numerical analysis of transport processes in variably-saturated porous media, ISMC (International Soil Modelling Consortium) meeting in Wageningen, The Netherlands, November 5-7, 2018.
* Pinheiro, E. A. R, Q. de Jong van Lier, L. Inforsato, and J. Šimůnek, Consistent measurement protocol of soil hydraulic properties allows process-based analyses of plant water availability, H11W-1782, 2018 AGU Fall Meeting, Washington, DC, December 10-14, 2018.

**Invited Presentations**:

* Focus presentation "*The use of HYDRUS models to evaluate processes in the critical zone*" at the CZO/LTER/NEON/ISMC Workshop"Using Observation Networks to Advance Earth System Understanding: State of the Art, Data-Model Integration, and Frontiers", Bolder, Colorado, February 13, 2018.
* Keynote presentation “Recent Developments and Applications of the HYDRUS Software Packages” at the workshop "HYDRUS Software Applications to Subsurface Flow and Contaminant Transport Problems", University of Mie, Mie, Japan, September 13, 2018.
* Keynote presentation “Recent and Current Developments and Applications of the HYDRUS Software Packages” at 6th International Conference "HYDRUS Software Applications to Subsurface Flow and Contaminant Transport Problems", University of Tokyo, Tokyo, Japan, September 20, 2018.
* Invited presentation “*Numerical Modeling of Vadose Zone Processes using HYDRUS and its Specialized Modules*”, Meiji University, Tokyo, Japan, September 26, 2018.
* Invited presentation “*Numerical Modeling of Vadose Zone Processes using HYDRUS and its Specialized Modules*”, Tokyo University of Agriculture and Technology, Fuchu, Tokyo, Japan, September 28, 2018.

**2018 Awarded and Active Grants**

2015-2020 USDA, ARS, Improved Decision Support for Management of Non-traditional Irrigation, 09/30/2015 - 09/29/2020, PI: J. Šimůnek, $225,000.

2016-2019 ANR Competitive Grants proposal #3741 *Optimizing Water Management Practices to Minimize Soil Salinity and Nitrate Leaching in California Irrigated Cropland,* PI: L. Wu; CoPIs: K. Bali, D. Haver, B. L. Sanden, and J. Šimůnek, 04/01/2016-03/31/2019, $299,613.

2016-2019 ANR Competitive Grants proposal #3771 *Improving nitrate and salinity management strategies for almond grown under micro-irrigation,* PI: P. Brown; CoPIs: M. Kandelous, J. Šimůnek, S. Grattan, S. Benes, and B. Sanden, 04/01/2016-03/31/2019, $386,112.

2016-2019 DOD, SERDP, 17 ER02-034 in response to SON Number: ERSON-17-03 Improved Understanding of the Fate and Effects of Insensitive Munitions Constituents; Proposal title "Phototransformation, Sorption, Transport, and Fate of Mixtures of NTO, DNAN, and Traditional Explosives as a Function of Climatic Conditions". A project with Dr. Katerina Dontsova at University of Arizona, Tucson, UCR share is $63,447.

2016-2019 EPA, USDA-ARS, Interagency Agreement for the project: "Research Support for Watershed and Basin Hydrology and Water Quality in the Arid and Semi-arid Southwest, USA", $200,000. UCR PI: Jiri Simunek; other funding goes to USDA-ARS Tucson and USDA-ARS Riverside.

2018-2020 USDA-NIFA, "Elucidating Colloidal Facilitated Phosphorus Migration in Soils: Through X-Ray Computed Tomography and Hydrus Modeling",
Drs. Lamba and Srivastava (Auburn University), Dr. Karthikeyan (University of Wisconsin-Madison), Dr. Jiří Šimůnek (University of California Riverside).
Total Budget: $500,00; UCR share $70,005.

**University of California Riverside (Haghverdi Water Management Group)**

**A. What was accomplished under the project objectives?**

A total of 48 research plots were established at UC ANR SCREC in Irvine, California, and are being prepared for irrigation research trial in 2019. The data collection phase will start from February/March of 2019. The irrigation system was installed in July 2018. Each plot is irrigated by 4 quarter circle (pop-up heads) sprinklers, all four controlled by a common solenoid valve for independent control of each plot. In early August 2018, an Acclima CS3500 smart irrigation controller was installed and all solenoid valves were wired to the controller. In addition, soil moisture sensors (Acclima TDT sensors) were installed at 12 plots and were connected to the irrigation controller for continuous monitoring of soil water status within the turf effective root zone throughout the experiment. The plots were covered with bermudagrass sods in August 2018. Bermudagrass was selected due to its superior resistance to heat, drought, salinity and wear compared to other commonly planted turfgrasses in California. All plots are under full irrigation now for the establishment of turfgrass and we will start the irrigation experiment in early 2019.

**B. What opportunities for training and professional development has the project provided?**

A two-day workshop was organized in 2018 at UCR consisting of hands-on training, lectures and a field tour. The workshop focused on autonomous urban irrigation management and audience were international visiting students and scholars.

**C. How have the results been disseminated to communities of interest?**

Our website (ucrwater.com) and twitter account (@ucrwater) were used as the clearinghouse to disseminate the findings of the projects in lay language for a diverse audience. The website had on average multiple hundreds page views per month and the twitter account currently has 107 followers.

**D. What do you plan to do during the next reporting period to accomplish these goals?**

Next steps of the experiment will be to collect soil samples to analyze soil hydraulic properties and soil salinity in the lab, perform an irrigation uniformity test on the plots, to finish instrumentations of the plots, identify the irrigation treatments and calibrate soil moisture sensors if needed, and collect base line infiltration data using SATURO infiltrometer (METER Group, Inc. USA). In addition, two plots with treatment extremes i.e. full irrigation and the highest deficit will be equipped with additional sensors for continues turf and soil monitoring. Pressure switches and/or flow meters will be utilized to precisely record irrigation runtimes and water application on each plot.

**E. Products**

Extension Publications:

Haghverdi, A., Wu, L., Hartin, J., Ahiablame, L. (2018) Assessing and managing soil salinity in irrigated landscapes, Parks & Rec Business Magazine.

Haghverdi, A., and W. Laosheng (2018). Accounting for Salinity Leaching in the Application of Recycled Water for Landscape Irrigation. White Paper prepared for the California WateReuse Association by the Southern California Salinity Coalition, Fountain Valley, CA.

**University of California Davis (Plant Sciences Department)**

**Accomplishments: (Objective 1)**

A novel method was developed and published describing the use of the pressure chamber to determine stem water potential (SWP) in dormant trees. A grape industry funded (AVF) project was started to develop installation and operation protocols for a novel, micro-tensiometer (MT) device developed at Cornell University, to continuously measure SWP in trees and vines. MT’s were installed in five mature grapevines, as well as one almond and one walnut tree, and some of these installations have shown good agreement with pressure-chamber measured SWP for periods of up to 4 months. Young almond tree evapotranspiration (ET) and calculated crop coefficient (Kc) was measured lysimetrically for years 1-4, and compared to the ET and Kc predicted from a recently published young peach tree model. For the first 3 years, measured ET and Kc values were substantially higher (about double) than predicted by the model, and after the first year there was a marked overestimate of the soil component of (E of ET) by the model. By the 4th (most recent) year, canopy growth had increased so that an individual tree % shaded area and Kc could not be determined, but the maximum midsummer Kc for both year 3 and 4 (about 1.2) was above the published mature (‘full canopy’) almond Kc (1.15). These results indicate that the currently accepted values for young tree Kc and ET are substantial underestimates, and also that the mature almond orchard Kc and ET are also underestimates. A multi-year almond water production function experiment was completed, finding that the yield effects of reduced irrigation have been minimal (reductions of from 5 - 25%, depending on location), despite imposing a relatively wide range of irrigation amounts (from 40-60"). A multi-year study was completed to document the long term effects on tree and root health of winter flood irrigations in almond orchards for the purpose of groundwater recharge. No negative effects of applying an additional 24" of water during the dormant season (December/January) have been observed. The 5th year of an ongoing walnut irrigation test was performed, and demonstrated that plant-based measurements (SWP) could be used to delay the first irrigation in the spring by about 1 month, with no detrimental effects on yield, and evidence was obtained that this practice may improve root health over the long term (years).

Training/Professional development:

Three MS and one PhD students were trained. Two MS and the PhD student graduated.

Dissemination of results:

Extension presentations to growers and other industry personnel have been made at the annual almond and walnut conferences, in addition to presentations at grower meetings that have been organized by extension farm advisors.

**Plans:**

The following industry supported projects will be continued: 1) Almond Winter Water Management, 2) Almond Lysimeter (ET), 3) Walnut Early Season Water Management, 4) Microtensiometer development in grapevine and other woody perennials. A new SCRI project (“Optimizing Irrigation for Sustainable Production of Almonds, Apples and Grapes“) based on the use of the microtensiometer for plant-based irrigation will be submitted.

**University of California Davis (Irrigation and Water Management Research Group)**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

**Development of a methodology for estimating of almond water status using artificial neural networks**

Stem water potential (SWP) is a commonly used method for determining plant water status in tree crops but is labor intensive. To eliminate the necessity for intensive fieldwork, artificial neural networks were designed to predict PWS using easier to measure information such as leaf temperature and microclimatic variables including ambient air temperature, relative humidity, incident radiation, and soil water content (Meyers et al., 2018). To collect these variables, leaf monitors developed by Dhillon et al. (2017) and soil water sensors were installed in an almond orchard. The sensors were interconnected through a wireless mesh network which allowed remote data access. SWP values were taken in the field at midday three times a week during the growing season. The artificial neural networks were trained using the Levenberg-Marquardt algorithm. Compared with multiple linear regression models fitting the same data, the neural networks consistently resulted in better R2 values. These results suggest that there is potential for machine learning techniques that use artificial neural networks to model the relationship between environmental conditions and plant water stress, which may be used for predicting acceptable temperature difference from target SWP Microirrigated almond orchards.

**iCrop Model –Driven Decision Support**

We have developed iCrop a novel web-based decision support tool that provides site-specific irrigation scheduling recommendations to growers to tree, vegetable and forage growers in California grower’s majority of have switched to microirrigation. iCrop uses crop simulation models to integrate the entire farming system including soil (S), weather (E, environment), genetics (G), and crop production practices (M, management; e.g., irrigation and fertility management practices). Preliminary evaluation of iCrop on corn and alfalfa has demonstrated on to improve yields and water productivity through in-season adaptive management of irrigation schedules.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

**Precision irrigation management by variety in almonds**

A significant number of almond growers in California have shifted from flood to microirrigation. Almond production in California has unique water issues, including the need for post-harvest irrigation and the presence of different almond varieties in the same orchard with shifted growth stages and water needs as a way to establish effective pollination. Traditionally, farmers have set up their microirrigation systems (double drip or micro sprinklers) to irrigate the entire orchard the same and cannot independently irrigate the different almond tree varieties within the same orchard. My research investigated how to precisely and independently irrigate different varieties without interfering with harvest activities and offset growth stages of the different varieties. We retrofitted the drip irrigation system on a commercial orchard with a wireless system that we used to remotely open and close tree rows of different varieties independently. Preliminary results from the 2018 growing season showed significant differences in yield amount three almond varieties (Non-peril, Butte and Aldrich) at the same irrigation level.

**Precision fertigation management for processing tomatoes**

Processing tomato producers in California are faced with several challenges e.g., constrained water supplies due to droughts and institutional policies like SGMA, and the Irrigated Lands Regulatory Program (regulation of nitrate leaching). To optimize profitability under limited water resources, growers need to enhance resource use efficiency through precision irrigation and fertigation. Over 80% of processing tomatoes growers in California have switched from flood to subsurface drip irrigation. In May of 2018 we established a study on a 5 acre subsurface drip irrigation field with automated fertigation and irrigation control by volume using ultrasonic flow meters and a Netafim irrigation controller. The objective of this study was to evaluate the effect of high frequency low concentration fertigation and the low frequency high concentration fertigation on yield of processing tomatoes. Preliminary results indicate that there were no significant differences between high and low frequency fertigation under full irrigation. However, under limited water, sustained deficit irrigation produced lower yields compared to regulated deficit irrigation but increased fruit quality in terms of soluble solute concentration.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

We have developed the iCrop webapp that growers can use for implementing specific irrigation scheduling for a variety of irrigation systems including microirrigation.

## B. What opportunities for training and professional development has the project provided?

I integrated a module in the irrigation systems and water management upper level undergraduate class that I teach at University of California Davis every year. The enrollment during the spring quarter of 2018 was 16 students. The students were introduced to computer aided design of microirrigation systems using the IRRICAD software.

I also trained a group of technocrats from Uzbekistan and Turkmenistan on microirrigation management and shared with them experiences from California.

## C. How have the results been disseminated to communities of interest?

We have disseminated our results through journal articles, conference presentations, posters and social media (e.g., UCDIrrigation twitter account).

## D. What do you plan to do during the next reporting period to accomplish these goals?

We plan to continue with field experiments on precision irrigation management by variety in almonds, precision fertigation management for processing tomatoes and also continue developing and testing of the iCrop decision support system.

## E. Products

**Conference Abstracts**

* Kisekka, I and J. Kim**. 2018**. iCrop in California. California soil and plant conference. 2018 California Plant and Soil Conference. Proceedings, Pg. 64. Fresno, CA Feb. 6-7 2018.
* Kelley Drechsler, Isaya Kisekka, Shrinivasa Upadhyaya. 2018. A Comprehensive Stress Index for Evaluating Plant Water Status in Almonds. *Precision Agriculture Conference*, Montreal 2018.

**Presentations**

* Managing Irrigation with Limited Water Using iCrop, Invited Speaker, United States Committee on Irrigation and Drainage Conference, Phoenix Arizona, 10/10/2018, ~1000 Attendees. 28.
* iCrop: An Integrated Decision Support Tool for Precision Irrigation Management, Presenter, UC Water faculty, Policy makers from state government, Sacramento, 10/25/2018, 250 Attendees.
* Almond Irrigation Management by Variety during Pre-Harvest and Post-Harvest Periods, Invited Speaker, Almond Board of California Conference 2018, Sacramento, 12/06/2018, >4000 Attendees.
* Precision Irrigation and Fertigation Management fo, Invited Speaker, California Tomato Research Institute, Davis CA, 11/29/2018, 100 Attendees.

**Florida**

1. **What was accomplished under the project objectives?**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

**Grapefruit production using different irrigation systems and plant density under open hydroponics**

Precise irrigation and fertigation management provide a less-limiting environment to roots while minimizing over irrigation and leaching of nutrients. This concept can improve tree growth in the presence of HLB and help optimize water and nutrient use. Higher tree density can increase fruit yield per area under high HLB pressure. We conducted a study to evaluated the efficiency of open hydroponics on ‘Ray Ruby’ grapefruit production under different irrigation systems and tree density. We tested a combination of rootstocks (Sour orange and US897), tree spacing [standard and high density staggered (HDS)], fertilization (dry granular and fertigation), and irrigation systems (drip and microjet).

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

**Round orange production using different dry granular fertilizer blends, irrigation systems and plant density**

Sweet oranges (*Citrus sinensis*) are impacted by huanglongbing (HLB), a disease associated with Candidatus *Liberibacter asiaticus*. The disease is threatening the citrus industry, with devastating effects on fruit production. Higher plant density can increase fruit yield per area under high HLB pressure, maximizing income and extending grove survival until a definite cure is found. This study evaluated the effect of tree planting density, fertilizer type and and irrigation systems on fruit yield and quality. ‘Valencia’ orange on ‘Kuharske’ citrange (*C. sinensis* × *Poncirus trifoliata*) trees were planted in Sept/2013 (2,995 trees in 1.61 ha). We tested three treatments: standard tree spacing (3.8×7 m, 357 trees/ha) + dry granular fertilizer + microsprinkler irrigation (one emitter per tree; microsprinkler 50 green nozzle, 16.7 GPH at 20 psi) (Bowsmith, Exeter, CA), high density staggered ([2.7×1.5×0.9 m]×6.1 m, 953 trees/ha) + fertigation + microsprinkler irrigation (one emitter per two trees), and high density staggered + fertigation + drip irrigation (two lines per row; Emitterline 0.58 GPH at 10 psi, 12-inch spacing) (Jain Irrigation), in a complete randomized block design with eight replications.

**Improving performance of HLB infected trees and root health under partial root zone drying**

The goal of this project is to improve the performance of HLB infected trees, soil and root health under partial root zone drying in a modified hydroponic system under greenhouse conditions. The following are the specific objectives: a) Investigate the optimum fertilization rate of HLB infected trees; b) Determine canopy development, root density and water use under partial root zone drying in hydroponic systems; c) Compare the performance of biochar and compost in ameliorating soil functions and restoring soil microbial diversity. Three N fertilizer rates include: IFAS recommendation for nonbearing trees (Obreza and Morgan, 2008), 75% of IFAS recommendation and 125% of IFAS recommendation with P and K changed proportionally to N. Each fertilization rate has a soil amendment with 1) biochar, 2) compost, and 3) no amendment (control). Two irrigation rates, 100% evapotranspiration (ET) and 75% ET will be used. This will be a 3 x 3 x 2 factorial experiment replicated 4 times in a randomized complete block design.

*O****bjective 3 Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

**Evaluation of water and nutrient use efficiency**

Irrigation systems are designed to maximize crop productivity and optimize uniform water application. The amount of water applied is usually determined by empirical methods, which are based on timers instead of the actual crop requirements. Several technologies have recently been developed looking for alternative methods to improve water management efficiency based on weather and soil sensing methods. One of the most relevant advances are the capacitance sensors, offering a great potential to estimate soil volumetric water content (VWC) and electrical conductivity. We conducted a laboratory study to evaluate the accuracy of data collected from several commercial capacitance sensors and establish a calibration equation for different soil types. Tested treatments were five sandy soils (Pineda, Riviera, Astatula, Candler and Immokalee) divided in two depths (0-30 and 30-60 cm) representing the majority of Florida soils used for citrus production.

1. **Products**

(i) Symposium and Conference Proceedings Papers (Non-Peer Reviewed)

* KADYAMPAKENI, D.M. S. STRAUSS, A. SCHUMANN. 2018. Citrus water use and root density patterns as influenced by citrus greening and regulated deficit irrigation under greenhouse conditions. Proceedings of Florida State Horticultural Society 131: (in press)
* SCHUMANN, A. W.; EBERT, T.; WALDO, L.; HOLMES, D.; MARINER, N.; TEST, G.; OSWALT, C.; FERRAREZI, R. S.; LEMES, R. 2018. Citrus Under Protective Screen. **Citrus Industry** 11/26/2018. URL: <http://citrusindustry.net/2018/11/26/research-update-citrus-under-protective-screen>.
* FERRAREZI, R. S.; SCHUMANN, A. W.; WRIGHT, A. L. 2018.Increasing yield through high-density plantings. **Citrus Industry** 11/19/2018. URL: <http://citrusindustry.net/2018/11/19/increasing-yield-through-high-density-plantings>.
* FERRAREZI, R. S. 2018. Growing citrus under enclosures. **UC Berkeley Research Snapshot** 04/28/2018. URL: <https://berkeley.box.com/shared/static/swyx5cv21fakjjmihzdigrpy0nd5u281.pdf>
* SCHUMANN, A. W.; WALDO, L.; KADYAMPAKENI, D. M.; FERRAREZI, R. S.; OSWALT, C. 2018. Using soil moisture sensors for citrus irrigation. **Citrus Industry** 10/07/2018. URL: <http://citrusindustry.net/2018/07/10/using-soil-moisture-sensors-for-citrus-irrigation>
* FERRAREZI, R. S.; WRIGHT, A. L.; MORGAN, K. T.; STANSLY, P. A.; OZORES-HAMPTON, M.; EBEL, R. C. 2018. Foliar nutrition on grapefruit and oranges to extend grove survival under huanglongbing. **Citrus Industry** 06/03/2018. URL: <http://citrusindustry.net/2018/03/06/foliar-nutrition-research-update>
* KADYAMPAKENI, D. M.; MORGAN, K. T.; MONGI, Z.; FERRAREZI, R. S.; SCHUMANN, A. W.; OBREZA, T. A. 2018. Citrus irrigation management: considerations for HLB affected trees and hurricane Irma. **Citrus Industry** 03/04/2018. URL: <http://citrusindustry.net/2018/04/03/current-considerations-citrus-irrigation-management>

(ii) Symposium and Conference Abstracts

* KADYAMPAKENI, D.M. 2018. Citrus water use and soil moisture distribution using regulation deficit irrigation. 2018 Irrigation Show & Education Conference. Long Beach/CA, United States.
* FERRAREZI, R.S.; THOMASON, K.A.; RITENOUR, M.A.; A.L. WRIGHT. 2018. High-density grapefruit production in open hydroponics system. **2018 Irrigation Show & Education Conference**. Long Beach/CA, United States.
* FERRAREZI, R. S.; BATAGLIA, O. C.; MEDINA, C. L.; FURLANI, P. R.; CARDOSO, F. P. 2018. Comprehensive study of soil physical and chemical properties under no-tillage systems in Brazil. **21st World Congress of Soil Sciences**, August 12-17, 2018. Rio de Janeiro/RJ, Brazil.
* FERRAREZI, R. S.; RITENOUR, M. A.; WRIGHT, A. L.; THOMASON, K. A. 2018. Plant density and irrigation systems for sweet orange production at the Indian River District. **2018 ASHS Annual Conference**, July 31 – August 3, 2018. Washington/DC, United States.
* LESMES-VESGA, R. A.; FERRAREZI, R. S.; ALBRECHT, U.; BOWMAN, K. 2018. Effect of propagation methods on citrus rootstock water uptake. **2018 ASHS Annual Conference**, July 31 – August 3, 2018. Washington/DC, United States.
* ZEPEDA, S. G. C.; FERRAREZI, R. S.; LESMES-VESGA, R. A.; FUTCH, S. H. 2018. Performance of capacitance sensors to monitor soil moisture in Florida sandy soils. **2018 ASHS Annual Conference**, July 31 – August 3, 2018. Washington/DC, United States.

(iii) Extension Bulletins

* KADYAMPAKENI, D.; MORGAN, K.; M. ZEKRI; FERRAREZI, R. S.; SCHUMANN, A. W.; OBREZA, T.A. 2017. Citrus irrigation management. **EDIS Publication**, UF/IFAS Extension, Soil and Water Sciences Department, #SL446. URL: <http://edis.ifas.ufl.edu/pdffiles/SS/SS66000.pdf>
* KADYAMPAKENI, D.; MORGAN, K.; M. ZEKRI; FERRAREZI, R. S.; SCHUMANN, A. W.; OBREZA, T.A. 2017. Irrigation Management of HLB-Affected Trees. **EDIS Publication**, UF/IFAS Extension, Soil and Water Sciences Department, #SL445. URL: <http://edis.ifas.ufl.edu/pdffiles/SS/SS65900.pdf>
* SCHUMANN, A. W.; SINGERMAN, A.; WRIGHT, A. L.; FERRAREZI, R. S. 2017. Citrus Under Protective Screen (CUPS) production systems. **EDIS Publication**, UF/IFAS Extension, Horticultural Sciences Department, #HS1304. URL: <http://edis.ifas.ufl.edu/hs1304>

(iv) Extension/Outreach Presentations/Posters

* 2018 Florida Citrus Show
* 2018 Agricultural Worker Safety Training Day
* 2018 Workshop on Citrus Management of HLB Affected Trees, Immokalee, FL, February 8, 2018
* 2018 Florida Citrus Expo, Fort Myers, FL, August 15-16, 2018,
* 2018 Citrus Nutrition Day, Bartow, FL, December 11, 2018
* 2018 FSHS In-Service Training, Fort Lauderdale, FL, June 12, 2018
* 2018 Horticultural Science Seminar, Gainesville, FL, October 22, 2018
* 2018 Citrus Production School, Sebring, FL, September 24-25, 2018

**Idaho**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-plant or weather-based approaches.***

A web-based water-budget irrigation scheduling program developed by Dr. Troy Peters, WSU, and a soil sensor based approach were again compared in 3 locations on Eastern Idaho farm fields irrigated by center pivot irrigation systems in 2018. At each location, one pivot used a LESA (Low Elevation Sprinkler Application) sprinkler package while the other pivot used the existing Mid-Elevation Sprinkler Application (MESA) system. Differences in water delivered to the ground resulted in a wider seasonal range of crop root zone soil water content on the Control pivots at all three sites than would normally be observed. Water applied to both the Control and LESA pivots was measured by IDWR-approved flowmeters installed before the 2018 growing season.

Four Decagon 10 HS sensors, tipping bucket rain gage and an AgSense data logger with cell phone transmission, and web-based data storage and retrieval were used under each of 6 malting barley pivots. Previous year’s work with the Ag Sense loggers used Watermark granular matrix sensors. Although sensor information was generally useful for determining if over-irrigation was occurring, abnormal or “odd” data readings occurred with sufficient frequency to limit sensor effectiveness for anything beyond overall trends and limit grower confidence in the data. Therefore, the 10HS sensors which worked well in 2017 with Onset data loggers, were used on the AgSense loggers this year. Data quality and appropriate response to wetting and drying events was good and made the information more credible and usable by the farmers.

The WSU “Irrigation Scheduler Remote” program used irrigator-selected soil and crop parameters, AgriMet daily estimated crop ET, and rainfall, and irrigator-input irrigation data to evaluate root zone available soil water and depth of irrigation water required to re-fill the root zone on a daily basis.

Soil sensors were installed at 4 depths (6, 12, 18, and 24 inches) on each site to serve as a daily soil water comparison measurement. The AgSense data from the sensors and a tipping bucket rain gage (where available) were transmitted by cell phone link to a website at 30-minute intervals. This information, formatted in a user-defined fashion, was available from any mobile device (cell phone, laptop, desktop,...) that could connect with the website. Pre and post-season soil sampling at 6-inch intervals to 5 feet (or rock) depth along with rain gage data provided directly-measured water budget information.

**PUBLICATIONS (**10/1/17 to 9/30/18):

No refereed publications this year.

**Kansas**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

In a two year irrigation scheduling study (2016-2017), measured crop water use (sum of irrigation, precipitation, and the change in ASW) compared well with the weather-based calculation on crop evapotranspiration (ETc). Available soil water (ASW) at planting and harvest varied to a much greater degree than did grain yield (≈13.4 vs. 5.4%) implying that the ASW levels were sufficient to prevent yield reductions. Results from an SDI (subsurface drip irrigation) crop intensification study with corn that was initiated in 2017 were summarized in a paper present at the Irrigation Association technical conference. In this study greater corn grain yield and crop water productivity were obtained through appropriate hybrid selection and through increasing plant density. Yield was not affected by irrigation levels from 85 to 115% of full irrigation, but water productivity was greatest at the lowest irrigation level (0.85 ET). This study will be continued in 2019.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

Drafting of revisions to several extension publications concerning subsurface drip irrigation (SDI) concerning design, management and maintenance continued in 2018. Two extension publications were completed with one presenting an overview of how SDI is being implemented in Kansas and the second publication outlining the minimum component requirements for successful systems. A study to examine potassium fertilization with SDI for corn was continued in 2018. Results from two years of a three year study comparing precision mobile drip irrigation (PMDI) with SDI for corn at KSU-NWREC has not shown grain yield or water use differences. A field study examining precision mobile drip irrigation (PMDI) where driplines are attached to a moving center pivot platform initiated in 2015 at the KSU Southwest Research-Extension Center at Garden City, Kansas was continued in 2018.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

Several presentations were made at the regional Central Plains Irrigation Conference along with two presentations at the annual international meeting of the American Society of Agricultural and Biological Engineers (ASABE) and one presentation at the Irrigation Association (IA) technical conference.

**What opportunities for training and professional development has the project provided?**

A PhD student at SWREC completed work evaluating irrigation application technologies, specifically looking at potential improvements with precision mobile drip irrigation (PMDI).

**How have the results been disseminated to communities of interest??**

Results have been presented to lay audiences at KSU field days, at a regional multistate meeting, and at three international conferences.

**What do you plan to do during the next reporting period to accomplish these goals?**

Field studies will be continued during the coming year. Presentations will be offered at regional and international meetings.

**Target audience**

Producers ranging from large, technologically savvy operations to small, part-time or hobby farming operations. Technical service providers such as USDA-NRCS working to improve irrigation and salinity management on regional, state and national scales. Community of scientists and extension specialists in Kansas and also regional, national and international colleagues, particularly for those with semi-arid summer precipitation pattern. Water managers and regulators within the state and region. Policymakers at the local (e.g., GMDs and LEMAs), state (e.g., State agencies and legislators) and national (Federal agencies and Congress) levels. Rural and community interests and foundations.

**PUBLICATIONS**

* Lamm, F. R. 2018. Potential for intensification of maize production with SDI. In: Proc. 2018 Irrigation Association Technical Conference, Dec 4-6, Long Beach, CA. 8 pp.
* Lamm, F. R. 2018. KSU results from twenty nine years of irrigation and fertigation studies using SDI. In: Proc. 30th annual Central Plains Irrigation Conference, Feb. 20-21, 2018, Colby, Kansas. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 89-105.
* Lamm, F. R., D. M. O’Brien, and D. H. Rogers. 2018. Using the K-State center pivot sprinkler and SDI economic comparison spreadsheet – 2018. In: Proc. 30th annual Central Plains Irrigation Conference, Feb. 20-21, 2018, Colby, Kansas. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 80-88.
* Lamm, F. R., D. H. Rogers, and J. Aguilar. 2018. Addressing the basic design issues of subsurface drip irrigation (SDI). In: Proc. 30th annual Central Plains Irrigation Conference, Feb. 20-21, 2018, Colby, Kansas. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 56-68.
* Lamm, F. R., D. H. Rogers, and J. Aguilar. 2018. Filtration and maintenance for SDI systems in the U.S. Great Plains. In: Proc. 30th annual Central Plains Irrigation Conference, Feb. 20-21, 2018, Colby, Kansas. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 69-79.
* Loring, S. J., F. R. Lamm, and C. J. Phene. 2018. Providing growers practical applications for microirrigation technologies. January 2018. Irrigation Today 2(3):34-35.
* Rogers, D., F. R. Lamm, and .J. Aguilar. 2018. Subsurface drip irrigation (SDI) in Kansas: An overview. KSU Coop. Ext. Irrigation Mgmt. Series, MF3408. May 2018. 4 pp.
* Rogers, D., F. R. Lamm, and .J. Aguilar. 2018. Subsurface drip irrigation (SDI) components: Minimum requirements. KSU Coop. Ext. Irrigation Mgmt. Series, MF2576. September 2018. 4 pp.

**New Mexico**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

Development and Evaluation of Soil-Based Irrigation Scheduling: We continued to calibrate the soil moisture content sensor to measure the moisture content, soil temperature, and soil salinity for water, solute and energy transport through soil. We are currently comparing Hydra, 5TE and TEROS 12. These probes are also used to schedule irrigation for the growing Pecan. A new low cost datalogger with wireless transmission capability is developed and tested.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

A field experiment in Brackish Groundwater National Desalination Research Facility is currently underway. We are growing halophytes using brackish groundwater and concentrate and also looking at soil property changes. Similar experiments are underway for Chile and Pecan.

**Milestone**

A low cost datalogger with wireless capability is developed that can substantially reduce costs of soil water content data collection.

**Publications**

Invited and Conference Presentations

* Shukla M.K. 2018. ACES Global initiatives program. NTU, Crownpoint, Oct 17.
* Shukla M.K. 2018. Sustainable management of soil water. China Agriculture University, June 2018.
* Shukla M.K. 2018. Sustainable management of soil salinity. China Agriculture University, June 2018.
* Fernandez J., M.K. and B. Stringam. 2017. Soil texture, nitrogen and irrigation water quality influence on Pecan kernel. SSSA Annual Meeting, Tampa, FL, Oct. 22-25.
* Kankarla V., A. Ben-Ali, Shukla M.K. and B. Das. 2017. Managing Abiotic Stress to grow Glycophyte and Halophyte across Water Salinity Gradient for Food Security in Arid Areas. 82nd Annual Convention, ISSS, Dec. 11-14, Kolkata.
* Kankarla V., M. K. Shukla, D. VanLeeuwen, B. J. Schutte, and G. A. Picchioni. 2018. Irrigation Water Salinity Effects on Germination and Emergence of Alfalfa, Triticale and Quinoa Species. USCID, Phoenix, AZ, Oct 16.
* Benali A., M.K. Shukla, and B. Stringam. 2018. Impacts of Irrigation with Brackish and RO Concentrate Water on Soil Thermal Properties. USCID, Phoenix, AZ, Oct 16.

**Funding**

* USDA Hatch grant
* Nakayama Chair Endowment
* WRRI-BOR Cooperation grants
* BOR S&T grant
* Cochran Grant

**Oklahoma**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

A multi-state (OK, TX, and KS) project on promoting sensor-based technologies to improve irrigation scheduling was continued during the reporting period. As part of this project, canopy temperature and soil moisture sensors were installed at the Oklahoma Panhandle Research and Extension Center near Goodwell, OK, where corn and sorghum plots receive variable levels of irrigation application using a subsurface drip irrigation (SDI) system. The goal is to investigate how these two different types of irrigation scheduling approaches interact and how they can be utilized in managing SDI systems. In addition, soil moisture probes were installed at six other locations in cooperation with local growers. Sensors were evaluated for their accuracy, sensitivity to irrigation applications, and usefulness in improving irrigation scheduling. One challenge in using sensors for irrigation scheduling under SDI is sensor placement, since water movement is not as uniform as under flood or sprinkler systems. To further investigate this challenge additional sensors were installed at different depths and distances from SDI tapes at one site near Hollis in southwest Oklahoma. Our team is going through data quality control and will soon initiate data analysis. We anticipate additional years and sites are required before any conclusions can be made on best management practices for sensor installation under SDI.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

Nothing to report.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

Dissemination of information on adoption of microirrigation systems and advanced methods of irrigation scheduling was accomplished by presenting at numerous field days, meetings, workshops, and in-service trainings.

Presentations (advisees are underlined):

* Datta S, Taghvaeian S (2018) Performance of soil moisture sensors under field conditions. ASABE Annual International Meeting. Jul. 29-Aug. 1, 2018; Detroit, MI.
* Masasi B, Taghvaeian S, Gowda P, Warren J, Marek G (2018) Simulating soil water content, evapotranspiration and yield of variably irrigated grain sorghum using AquaCrop. ASABE Annual International Meeting. Jul. 29-Aug. 1, 2018; Detroit, MI.
* Taghvaeian S (2018) Sensor technologies for improving agricultural water management. Oklahoma Water Research Advisory Board Meeting. Jul. 18, 2018; Oklahoma City, OK.
* Taghvaeian S, Datta S (2018) Evaluating the performance of soil moisture sensors for irrigation management. World Environmental & Water Resources Congress. Jun. 3-7, 2018; Minneapolis, MN.
* Taghvaeian S (2018) Irrigation studies at Oklahoma State University. Science and Data in Action Panel. The Ogallala Summit. Apr. 9-10, 2018; Garden City, KS.
* Taghvaeian S (2018) Using soil moisture sensors to improve irrigation. Oklahoma Irrigation Conference. Mar. 8, 2018; Weatherford, OK.
* Taghvaeian S (2018) Getting the most from your water: Effective irrigation. Oklahoma Farmers Market Conference and Expo. Feb. 22, 2018; Oklahoma City, OK.
* Taghvaeian S (2018) Soil moisture sensors. High Plains Irrigation Conference. Feb. 7, 2018; Amarillo, TX.
* Taghvaeian S, Datta S, Boman R (2018) Utilizing sensor technologies to evaluate and improve cotton irrigation management. Beltwide Cotton Conference. Jan. 3-5, 2018; San Antonio, TX.
* Datta S, Taghvaeian S, Stivers J, Ochsner T, Moriasi D (2017) Performance evaluation of soil moisture sensors under field conditions. 38th Annual Oklahoma Governor’s Water Conference & Research Symposium. Oct. 31-Nov. 1, 2017; Norman, OK.
* Masasi B, Taghvaeian S, Gowda P, Warren J, Marek G (2017) Assessment of the AquaCrop model for simulating soil water content, evapotranspiration and yield of grain sorghum. 38th Annual Oklahoma Governor’s Water Conference & Research Symposium. Oct. 31-Nov. 1, 2017; Norman, OK.

Educational material:

1. Taghvaeian S (2018) Comparing pivot & subsurface drip irrigation. Available at: <https://youtu.be/-ANCaJJwUXE>

**Oregon**

**Non-Technical Summary**

Broad expansion of microirrigation is needed. Unless timely action is taken, it is anticipated that water supply and water quality related crises will affect economies and resources of national and international importance. Microirrigation can reduce the waste of water to a negligible amount and reduce the transport of contaminants to surface water and groundwater. Irrigation events can be fine-tuned to spoon feed water and nutrients just in time to minimize plant water stress. Microirrigation can optimize crop production (more crop per drop) and in many cases, increase the quality of agricultural products. Successful experimental microirrigation results will be scaled up to commercial size through this project. Microirrigation information will be transferred effectively to growers through many venues.

**What was accomplished under these goals?**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

Potatoes: In 2018 we are carefully compared potato irrigation scheduling based on soil moisture sensors (soil water tension, SWT) with irrigation scheduling based on estimated crop evapotranspiration. These efforts were completed for two potato varieties grown with both sprinkler and drip irrigation. All treatment combinations were replicated 6 times. The irrigation scheduling techniques provided similar results. The potato variety ‘Clearwater Russet” produced 44 tons per acre under drip irrigation using crop evapotranspiration irrigation scheduling.

Vineyards: Soil-based measurements of soil water tension (SWT) were compared with soil water content, plant water potential, and crop evapotranspiration in drip-irrigated vineyards. The ideal amount and timing (trajectories) of water stress (as measured by soil, plant, or weather data) are being studied for various cultivars, weather patterns, and sites. In Oregon we seek to measure the trajectories of stress. Modification of the stress trajectory holds the promise of better water use efficiency, protection of water quality, optimization of product quality, and the realization of providing a better return on vineyard investment. The approach is to collect and evaluate automated data that is interpreted and provided in real time to growers.

Automation of data collection and delivery. The automated approach to collect SWT data in vineyards (above) was tested on onion, potato, quinoa, tomato, skullcap, and stevia in 2018.

Seed production of native plants In Oregon fixed irrigation schedules are being compared to soil- and weather-based scheduling for seed production from native plants. Plant species required 0 to 200 mm of supplemental irrigation per year to maximize seed yield. For a given species, yield responses to irrigation varied substantially by year. We have determined that accounting for rainfall during and prior to seed production improves the accuracy of estimating the amount of irrigation required. Species differ in the preceding time interval where precipitation needs to be counted against the irrigation requirement. In 2018 SWT measurements were also collected in a portion of the seed production plots for comparison.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site- specific characteristics and end-user capabilities.***

Delivery of herbicides. Herbicides were applied through the drip irrigation system in the hopes of achieving better control of yellow nutsedge. Outlook herbicide applied through drip irrigation was successful in helping to control yellow nutsedge. This work is designed to expand the labeled use of drip-applied Outlook herbicide to control yellow nutsedge.

Delivery of fungicides. Fungicides were applied through the drip system to try to obtain better control of root fungi. Pink root and plate rot were not significant problems in the onion fields used for the trials and the products tested were not beneficial.

Adaptation of drip irrigation for potato production Potato production is generally conducted with sprinkler irrigation. In the US drip irrigation has not been cost effective in comparison to sprinkler irrigation. We sought to change the drip irrigation configuration so that the drip irrigation system could be more efficiently utilized.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

In objective 1 above, the automatic collection, evaluation, and deliver of soil and weather data is described. The goal was to interpret and deliver results, predictions, and projections in real time to growers' smart phones and laptops based on growers' demands. Growers are gaining real time access to information from their fields for water management decision making. These emerging tools and technology for growers have the potential to simultaneously optimize economic outcomes and minimize the losses of water and nutrients.

**What opportunities for training and professional development has the project provided?**

Undergraduate students were trained in research protocols and learned about crop irrigation and management.

**How have the results been disseminated to communities of interest?**

Results were communicated to growers by means of field days, workshops, grower meetings, written, and "on-line" reports. Results were disseminated at 3 different 2018 field days, through numerous written reports and presentations for growers and the public, scientific and international presentations, and by reports published on the internet.

**What do you plan to do during the next reporting period to accomplish the goals?**

Continue to 1) perfect and compare the irrigation scheduling and fertigation methods for potato, 2) collect and deliver soil water tension data and interpretations to vineyard managers and growers of other crops to optimize drip-irrigation scheduling, 3) determine the irrigation criteria for seed production of perennial native plants where seed is needed for restoration activities and communicate the results to growers and others, 4) examine the possibility improving product effectiveness and reducing costs by injecting herbicides and fungicides through drip irrigation systems, and 5) actively disseminate results through field days, workshops, reports to growers and researchers, and web based reports on the internet.

Experiment Station Annual and Special Reports

* In Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C. Feibert, E. B. G., Rivera, A., & Saunders, L. D. 2018. Evaluation of chlorine and diatomaceous earth for control of internal decay in onion bulbs. pp. 73-79. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Felix, J. & Ishida, J. (2018). Onion response to various Outlook® herbicide rates applied through drip irrigation with and without fertilizer. OSU Agricultural Experiment Station, MES Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159. pp. 80-84.
* Felix, J. & Ishida, J. (2018). Response of red and white onion cultivars to Outlook® applied through drip irrigation. OSU Agricultural Experiment Station, MES Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159. pp. 85-91.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Kilkenny, F., & Shaw, N. L. 2018. Direct surface seeding systems for the establishment of native wildflowers in 2016 and 2017. pp. 135-142. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Kilkenny, F., & Shaw, N. L. 2018. Irrigation requirements for seed production of various native wildflower species. pp. 143-153. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Kilkenny, F., & Shaw, N. L. 2018. Native beeplant seed production in response to irrigation in a semi-arid environment. pp. 154-159. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Kilkenny, F., & Shaw, N. L. 2018. Irrigation requirements for native buckwheat seed production in a semi-arid environment. pp. 160-167. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Johnson, D. A., Bushman, B. S., Kilkenny, F., & Shaw, N. L. 2018. Prairie clover and basalt milkvetch seed production in response to irrigation. pp. 168-174. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Kilkenny, F., & Shaw, N. L. 2018. Irrigation requirements for *Lomatium* seed production. pp. 175-188. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.
* Shock, C. C., Feibert, E. B. G., Rivera, A., Saunders, L. D., Shaw, N. L., & Kilkenny, F. 2018. Irrigation requirements for seed production of five native *Penstemon* species. pp. 189-201. In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2017, Department of Crop and Soil Science Ext/CrS 159.

**Agency reports**

* Shock, C.C., Feibert, E.B.G., Rivera, A., Saunders, L.D., Shaw, N.L., & Kilkenny, F. 2018. Seed production of Great Basin native forbs. 73p. In the annual report of the Great Basin Native Plant Project, Rocky Mountain Research Station, US Forest Service, Boise, ID.

Invited presentations

* Shock, C.C., 2018. Design of field experiments. Qinghai Academy of Agricultural and Forestry Sciences, Xining, Qinghai, China, 18 July.

Abstracts and papers at international professionalmMeetings

* Shock, C.C. 2018. Creation and Adoption of Irrigation Innovations for Agriculture. The International Irrigation Show. Long Beach, CA. 4 December.

**Abstracts and papers at national professional meetings**

* Shock, C.C. 2018. Creation and adoption of smart agriculture innovations to cope with climatic uncertainty. American Society of Horticultural Science. Washington DC. 2 August.

**Abstracts and papers at regional and local meetings**

* Shock, C.C. 2018. Precision irrigation and fertigation of potato. Hermiston Farm Fair. Hermiston, OR. 28 November.
* Shock, C.C., Feibert, E.B.G., Rivera. 2018. Incomplete scale and heat enhance the infection of onion bulbs. Idaho-Malheur County Onion Growers Associations Annual Meeting, Four Rivers Cultural Center, Ontario, OR. 6 February.
* Shock, C.C., S. Reitz, J. Waite-Cusic, H. Kreeft, R.A. Roncarati, E.B.G. Feibert, J.M. Pinto, A. Rivera, L.D. Saundersand J. Klauzer. 2018. Overview of research and extension on the FSMA. Oregon Agricultural Extension Association, Ontario, OR. 17 April.
* Shock, C.C. 2018. Malheur County water quality problems, innovation, and Change. Earth Week, Treasure Valley Community College, Ontario, OR. 19 April.
* Shock, C.C., S. Reitz, J. Waite-Cusic, H. Kreeft, R.A. Roncarati, E.B.G. Feibert, J.M. Pinto, A. Rivera, L.D. Saundersand J. Klauzer. 2018. Overview of research and extension on the FSMA. Ontario, OR. Kiwanis. 2 May.

**Field days:**

* *Native Wildflower Seed Production Field Day*, (all trials under drip irrigation) Malheur Experiment Station, Oregon State University, Ontario, Oregon, 17 May 2018
* *Summer Farm Festival and Malheur Experiment Station Field Day*, Malheur Experiment Station, Oregon State University, Ontario, Oregon, 11 July 2018.
* Drone demonstrations
* Irrigation tour. Erosion control and irrigation efficiency. Comparison of sprinkler and drip irrigation for potato production. Irrigation scheduling of onion by crop evapotranspiration and by soil water tension. Permanent drip irrigation systems.
* Tour for youth. Drones, Water, Soils. and Seeds!
* A fun set of activities designed to educate young people. What is in the soil? Plants from seeds? Stream simulation. Aquifers. Siphon tubes and irrigation. Drones.
* Onion production tour. Control of onion thrips. Pink root fungicides. Response of multiple onion cultivars to the recently registered method of applying Outlook (dimethenamid-p) through drip irrigation.  Factors leading to internal rot of onion bulbs General weed control for onions.
* *Tomato Tasting*, (all trials under drip irrigation) Malheur Experiment Station, Oregon State University, Ontario, Oregon, 27 August 2018.
* *Onion Variety Day*, (all trials under drip irrigation) Malheur Experiment Station, Oregon State University, Ontario, Oregon, 28 August 2018.

**Puerto Rico**

**Addressed general objectives**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

d. Software Development and Comparison of Multiple or Combined Irrigation Scheduling Methods.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

b. Improved Efficiency of Water and Nutrients

1. **What was accomplished under the project objectives?**

The project leader continues focusing on micro irrigation management of citrus such as oranges and lemons. The information is useful for farmers located at the northern and central mountainous region of Puerto Rico. Project co-leaders will continue evaluating subsurface microirrigation systems effect on starchy crops and vegetables planted for in the south coastal plains. The estimation of broad scale ET using remote sensing techniques can be applied for the Caribbean area.

1. **What opportunities for training and professional development have the project provided?**

The project provided some funds to help carry out the research work of two graduate students, while a third student began this semester to carry out drip irrigation research.

1. **How have the results been disseminated to communities of interest?**

The research results has been disseminated to farmers and scientific community by different ways such as poster presentation, farmers fields days, scientific publications, and videos.

1. **What do you plan to do during the next reporting period to accomplish these goals?**

Fertilizer applications were continued at the avocado orchard at Isabela, using a rate of 3 and 4 pounds of N per tree. In addition, some moisture sensors damaged due to heavy rains caused by the hurricane were removed and reinstalled. The application of foliar and soil fertilizers treatments will continue as planned at the lemon orchard established in Lajas. Luis E. Rivera will repeat the evaluation of SDI in several starchy crops in the southern Puerto Rico (plantain – Maiden Variety; Taro – “Manga lila” and Tanier – “Yautia – Nazareno”). Hurricane Maria affects destroyed all plantains plants on September 2017. A new field to evaluate drip irrigation, planting density and bunch pruning was established on February 2018 in Juana Diaz Research Center. Trials on the use of one subsurface drip line (drip spacing 4”) or two lines (spacing 8”) and different plant densities on yield and quality of malanga Lila will continue during 2018 – 2019.

1. **Products**

(i) Symposium and Conference Proceedings Papers (Non-Peer Reviewed)

* Tirado Corbalá, Rebecca, Jonathan Muñoz, Elvin RománPaoli, Lyvette Trabal, Leonardo Lozada and Bryant Crespo. 2018. Continuous soil moisture monitoring of a mature avocado orchard (cv. Simmond) growing in an Oxisol for a precise irrigation scheduling. Proc. Interamer. Soc. Trop. Hort., in Press.

(ii) Symposium and Conference Abstracts - none during the period

(iii) Extension Bulletins – none during the period

(iv). Extension/Outreach Presentations/Posters

* In conjunction with an engineer, we have ventured into the use of remote sensing and drums to monitor soil water content.
* Dr. Eric Harmsen represented UPRM on the Puerto Rico Scientific Drought Committee.
* Participation in the production of an educational video about the threat to the Salinas (Southern PR) aquifer from over exploitation, lack of aquifer recharge and sea level rise. The film was produced by FEMA and the Puerto Rico Dept. of Natural Resources and Environment.
* Worked with 4 students from the Electrical and Computer Engineering Department to develop H2OCrop, a mobile application for managing irrigation in PR.

**Texas**

**USDA ARS, Bushland**

**A. Accomplishments**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

Published crop coefficients have traditionally not specified the irrigation application method used in determining them. With the increased use of subsurface drip irrigation (SDI) for field and specialty crops, it has become clear that crop coefficients determined using sprinkler/spray irrigation systems are different from those determined using SDI, and therefore are not suitable for irrigation scheduling of SDI systems. In 2013, the four large weighing lysimeters at Bushland, TX, were modified so that two of the lysimeters and their surrounding 4.4-ha fields would be irrigated using SDI, while the other two would continue to be irrigated using a ten-span lateral move system equipped for mid elevation spray application (MESA). In 2014, the SDI system on the two lysimeters so equipped was modified to clearly distinguish between irrigation and ET (Evett et al., 2018a). Two seasons of grain corn and two seasons of grain sorghum production have shown consistently smaller ET for SDI compared with MESA, ranging from 138 to 151 mm (5.4 to 5.9 inch) per corn season (Evett et al., 2018b) and from 50 to 112 mm per short-season sorghum season (Evett et al., 2018g). Future work will focus on determining crop coefficients using the dual coefficient approach and ASCE 2005 Standardized Penman-Monteith reference ET for a tall crop (alfalfa).

Since 2002, ARS has been developing an irrigation decision support system based on proximal sensing of plant and soil water stress indices. The patented (Evett et al., 2014) system applies to both static and moving irrigation systems, and it was first applied successfully to microirrigation during four years of corn and soybean rotation. This Irrigation Scheduling Supervisory Control And Data Acquisition (ISSCADA) system, patented in 2014, was licensed by Valmont Industries in 2018. The ARS team at Bushland, Texas, coordinated ISSCADA field trials with ARS and university partners in Alberta, Missouri, Mississippi, South Carolina and Texas in 2018, continuing multi-state field trials that began in 2016. The ISSCADA client-server software system was improved with the addition of soil water sensing (Andrade et al., 2018a). An artificial intelligence system was developed to predict future crop water stress index maps based on prior maps and current weather data (Andrade, 2018b). The team also developed methods for calibrating and testing commercial infrared thermometers used in irrigation scheduling (Colaizzi et al., 2018), and patented a novel computer vision qualified infrared temperature sensor that automatically improves the quality of canopy temperature data used in irrigation scheduling (O’Shaughnessy et al., 2018). The team continued cooperation with Acclima, Inc. and partners in Beltsville, MD, through two CRADAs, one to develop advanced soil water sensors based on time domain reflectometry and the second to develop a wireless node and gateway system to acquire data from sensors using the SDI-12 data transmission protocol, transmit the data using the LoRa radio protocol from node to gateway, and transmit data from gateway to the Cloud using cellular network data transmission. The team also contributed to understanding of how soil water sensor field testing can be done to assure accurate and informative test results (Schwartz et al., 2018).

ARS also investigated the Cosmic Ray Neutron Probe (CRNP) for use in scheduling irrigations by comparing CRNP data with data from spatially distributed networks of field-calibrated soil water sensors installed at depths from 0.05 to 1.00 m, with data from eight neutron probe access tubes and with ET and soil water data from a large weighing lysimeter at Bushland. The lysimeter and surrounding field are subsurface drip irrigated. Partners at the ARS location in El Reno, OK, performed a similar experiment without the lysimeter and neutron probe data. This experiment is coordinated with the International Atomic Energy Agency (IAEA), and the report to IAEA concluded that the CRNP had almost no value for irrigation management due to its insensitivity to soil water content changes at depths greater than 0.20 m (Evett et al., 2018c).

ARS at Bushland, TX, supported ARS at Beltsville, MD, in development of a wireless node and gateway system for datalogging of soil water sensor data and transmission of the data using the LoRa radio transmission scheme from nodes in the field to a gateway at the edge of the field. The inexpensive (~$150 US), solar powered node collected data from up to eight sensors using the SDI-12 wired data protocol and transmitted the data over distances exceeding 300 m to the gateway (~$150 US) where the data were stored prior to upload to a smart phone, tablet or other device equipped with Bluetooth. Both model TDR-315L and model CS655 sensors were used successfully with this system in four states in the southeast US. In 2018, a CRADA with Acclima, Inc. was instituted by ARS Beltsville with ARS Bushland support to develop a commercial version of this system that will upload the soil water sensor data to the Cloud via a cellular network. Initial reports on the system were given at the ASA-CSSA meeting in November and the Irrigation Association meeting in December, 2018 (Evett et al., 2018h).

Quality weather data are essential not only for irrigation scheduling based on crop coefficients and reference ET, but are also essential for development and testing of ET models embedded in crop growth and water use simulation models that are now begin widely tested by the multi-state and international AgMIP team. These simulation models represent the next step in delivering crop growth and yield estimates along with ET values for irrigation scheduling so that economic factors can be included in more sophisticated irrigation management schemes. The Bushland large weighing lysimeter ET data sets are widely used for model development and testing, but are not fully useful without accompanying standard weather data that are produced with the same degree of quality assurance and control as the lysimeter data. The USDA-ARS team at Bushland, Texas, developed quality assurance (QA) and QC procedures for research weather data compiling data from a grassed weather station, four large weighing lysimeters and a U.S. Weather Service station at Bushland. Application of these procedures not only produced quality 15-minute, 365-day weather data, but documented the necessity of redundant instrumentation and weather stations for data verification and gap filling (Evett et al., 2018d,e).

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

Subsurface drip irrigation tape laterals were replaced in an approximately 2.0-ha experimental field at ARS Bushland in 2017 and 2018. The original tape was installed in 2003 at varying depths (0.15, 0.22, and 0.30 m) and two spacings (0.76 and 1.52 m). The soil was the Pullman clay loam, with a dense Bt clay horizon at depths from ~30 to ~60 cm, which is characteristically very hard and difficult to work when dry. A drip tape extractor was modified and successfully used to remove the original drip tape, which otherwise would not have been possible using commercially available equipment for this soil. The modified extractor included adjustable sweep and chisel combinations that consecutively broke the hard near-surface layer directly over the buried lateral, then moved sufficient soil volume to one side, allowing retrieval and removal of the laterals. The extractor may undergo further modification and be tested at different locations (e.g., ARS, Lubbock, TX), and a patent and manufacturing partner may be pursued to make the extractor design commercially available. This may encourage greater adoption of subsurface drip irrigation in regions where heavy soils are perceived as a barrier.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

We licensed the ISSCADA irrigation decision support system to Valmont Industries in 2018. We published the first data set from the Bushland large weighing lysimeter experiments comparing SDI to MESA irrigation methods (Evett et al., 2018e). Crop water use efficiency benefits of SDI were explained to an international group of alfalfa and forage growers, scientists and engineers at the 2nd World Alfalfa Congress in Argentina (Evett et al., 2018f).

## B. What opportunities for training and professional development has the project provided?

Nothing to report.

## C. How have the results been disseminated to communities of interest?

Results have been disseminated through peer reviewed journal articles, proceedings papers, meeting presentations, field days and personal interaction with farmers, commercial institutions and the general public.

## D. What do you plan to do during the next reporting period to accomplish these goals?

We will continue field experiments described in the Accomplishments section. The artificial intelligence system for predicting future crop water stress index, soil water deplection, and crop ET maps will be integrated into the ISSCADA system. The node and gateway system for wireless soil water data transmission will also be integrated into the ISSCADA system.

## E. Products

**Symposium and Conference Proceedings Papers (Non-Peer Reviewed)**

Andrade, M.A., S.A. O’Shaughnessy, S.R. Evett and P.D. Colaizzi. 2018a. “ARSmartPivot – A decision support system for variable rate center pivot irrigation systems”, presented at the Sino-US Water Saving Technologies Meeting, Zhenjiang, China, Aug. 17, 2018.

Andrade, M.A., S.R. Evett and S.A. O'Shaughnessy. 2018b. Machine learning algorithms applied to the forecasting of crop water stress indicators. In 2018 Irrigation Association Show and Education Conference Technical Session Proc. Irrigation Association, Fairfax, VA. <https://www.irrigation.org/IA/Resources/Technical-Paper-Library.aspx>.

Evett, S.R., R.C. Schwartz and H.S. Schomberg. 2018c. Electromagnetic and nuclear soil water sensing methods: Comparisons and newer technologies. In Report of the Second Research Coordination Meeting of the Coordinated Research Project, “Nuclear Techniques for a Better Understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-ecosystems (D1.50.17)”, held in Rabat, Morocco, 16 to 20 April 2018.

Evett, S.R., S.A. O’Shaughnessy, M.A. Andrade and P.D. Colaizzi. 2018f. Technological Innovations to Improve Water Management in Alfalfa and Forage Crops. Pp. 54-58 In Proc. Second World Alfalfa Congress, Cordoba, Argentina. 11-14 November 2018. Instituto Nacional de Tecnología Agropecuaria (INTA), <http://www.worldalfalfacongress.org/>.

Evett, S.R., G.W. Marek, P.D. Colaizzi, D.K. Brauer and S.A. O’Shaughnessy. 2018g. Evaporative loss differences between SDI and sprinkler irrigation – Southern High Plains experience. In 2018 Irrigation Association Show and Education Conference Technical Session Proc. Irrigation Association, Fairfax, VA. <https://www.irrigation.org/IA/Resources/Technical-Paper-Library.aspx>.

Evett, S.R., H.S. Schomberg, A. Thompson, R.C. Schwartz, S.A. O'Shaughnessy and M.A. Adrade. 2018h. Water in the Cloud: A new system for field water monitoring with Cloud data access. In 2018 Irrigation Association Show and Education Conference Technical Session Proc. Irrigation Association, Fairfax, VA. <https://www.irrigation.org/IA/Resources/Technical-Paper-Library.aspx>.

**Symposium and Conference Abstracts**

Evett, S.R., P.D. Colaizzi, G.W. Marek, J.E. Moorhead, D.K. Brauer, K.S. Copeland and B.B. Ruthardt. 2018b. “Evaporative Losses from Sprinkler and Subsurface Drip Irrigation in a Region of Large Evaporative Demand”, presented at the 2018 Annual International Meeting of ASABE, July 29- Aug 1, 2018, Detroit, MI.

**Texas A&M AgriLife Research and Extension Service**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

Soil moisture sensors are being evaluated (compared) and are being used to monitor treatment effects in research field plots at Texas A&M AgriLife Research locations at Bushland, and Halfway, Texas. Soil moisture monitoring also was conducted at three commercial farm locations near Muleshoe, Bushland and Dalhart, Texas. On-site weather stations at all these locations (research and commercial farms) are being used for integration of ET-based irrigation scheduling tools, soil moisture monitoring, and of course on-site precipitation and other weather parameters needed to conduct and interpret the studies.

At the Halfway site, soil water sensors include AquaSpy capacitance probes (soil moisture is monitored from 1 ft. to 5 ft. depths, in 4-inch intervals); and Acclima 315L TDR sensors at 0.5 ft., 1 ft., 2 ft., and 3 ft. depths; neutron probe soil moisture measurement is being used for comparison and continuity with ongoing research trials. These sensors are located in research plots under different treatments (traditional full-season irrigation strategy *vs.* delayed seasonal irrigation strategy). All treatments are in cotton planted into terminated wheat (cover crop).

Sensors at the Bushland site include Campbell Scientific Inc. CSI650 TDT, Acclima 315L TDR, WaterMark and other sensors. An intensive evaluation of the sensors under different moisture regimes (full irrigation, moderate deficit irrigation and severe deficit irrigation); and under various installation configurations. Data collection and analysis are ongoing. Acclima 315L and SCI650 sensors, onsite weather stations and near-term weather forecast data also are being used in an automated irrigation controller under development (patent pending). Related to work on the automated controller, a wireless sensor network optimization methodology also has developed (patent pending).

Decagon GS1 sensors were installed and connected through AgSense datalogger/ telemetry systems at three commercial farms near Muleshoe, Canyon/Bushland and Dalhart, Texas. Depending upon soil depths (horizons, layers, soil depth above caliche layer) at each site, 3 or 4 sensors were placed within the top 3-4 ft. of soil (placements were either 9”, 18” and 30” depths or 6”, 12”, 24” and 36” depths, depending on soil depth). Multiple sites at each of these locations represent different crop rotations, soils, and cover crop treatments. Soil moisture and weather data (from on-site weather stations) are available via a password protected Internet website to the cooperators, research team and interested USDA-NRCS staff, with permission from the cooperators.

***Objective 2. Develop microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

In an effort to evaluate effects on cotton germination, a SDI system was installed on a 1-ha area with the field experiment beginning in 2013 and continuing for the sixth year in 2018. The factors considered are SDI lateral/row position and planting date. Included are five lateral/row position treatments: T1 - 2-m spaced laterals irrigating 1-m crop rows equidistant from the lateral (traditional), T2 - 2-m spaced laterals with two 0.75-m spaced rows equidistant from laterals and 1.25-m distances between row pairs (30-50 inch treatment), T3 - 2-m spaced laterals with 2-m crop rows directly over lateral, T4 - 2-m spaced laterals with one crop row directly over the lateral, and one crop row between laterals, and T5 - 1-m spaced laterals with 1-m rows directly over each lateral. The first planting date of each year is near 10 May with planting to occur in all lateral/row position treatments regardless of soil water condition. The second date is in the period from 14 to 35 days following the first planting with the planting date determined by the occurrence of favorable soil water conditions in the T1 treatment. Irrigation of all treatments is at approximately 70% ET, limited by an irrigation capacity of 5 mm d-1. Pre-plant irrigations of up to 125 mm are initiated 25 days prior to each approximate planting date and will continue for up to 10 days following planting or until seed germination has occurred in all treatments within a planting date. 2013, 2016, and 2017 results showed highest yield in early planted treatments of T1, T2, and T5. 2014 results showed relatively small differences in yield due to planting date or row/lateral arrangement due to higher than average season rain. 2015 harvest results were non-conclusive due to a severe hail event on August 28. Analysis of 2018 data is currently underway. This experiment will ultimately provide economic comparisons of water value (crop yield) relative to initial irrigation system cost and management.

SDI experiment was initiated in 2014 and continued through 2018 that focused on efficiencies of pre- and early-season irrigations of cotton with deficit irrigation capacities. Treatments include pre-plant irrigations of 2 and 4 inches and early growing season irrigation capacities of 0.0, 0.1, and 0.2 in/day resulting in six treatments plus "pre-plant only" check. Tests were inconclusive due to late replanting in 2014 and heavy rains and hail during the pre-plant and early season irrigation periods in 2015. Cotton was replanted to grain sorghum due to hail and wind in 2016. The results to date indicate no significant differences in yield due to irrigation treatments, therefore, water value was highest in treatments with no or limited pre-plant and early season irrigations. By applying recent field research findings and observing the frequency of challenging early season weather conditions, we hypothesize that irrigation productivity can be increased by up to 10% over typical limited irrigation capacity SDI strategies.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

The DIEM Dashboard for Irrigation Efficiency Management irrigation scheduling and management tool is being evaluated in research and commercial farm operations. DIEM integrates soil moisture (water balance), crop ET, and irrigation system efficiency and constraints to optimize irrigation management for cotton production systems. DIEM is unique in that it provides a prescription (pre-season, and updated throughout the season) to optimize limited irrigation. DIEM is a web-based tool; beta test accounts can be requested free of charge from diem.tamu.edu.

Microirrigation research updates and management recommendations are presented in a variety of “face-to-face” venues, including traditional Extension “CEU” meetings for agricultural producers, irrigation professionals, agency staff, agribusiness and other interested audiences. Examples of irrigation workshops and presentations are listed in the Educational Activities section below. Professional development events (in person and webinars) were conducted for County Extension faculty, with emphasis on the Texas High Plains, Rolling Plains and West Texas where there is most producer interest in microirrigation (especially subsurface drip irrigation). Jim Bordovsky and Dana Porter presented several invited presentations for Groundwater Conservation Districts, irrigation conferences, university classes, and other groups/venues. These and other technology transfer activities are included below.

**Educational Activities**

**Seminars, workshops similar education events**

**Central Plains Irrigation Conference, Comanche County, TX, December 12, 2017.** Topics included Aquifer and Permits; Precision Irrigation Technologies; Pivot Control Systems; Site Specific Irrigation; Variable Rate and Irrigation Scheduling Technology; Crop Water Requirements; Soil Moisture Monitoring; Salinity and Water Quality; Chemigation; Economics of Subsurface Drip Irrigation and Components of Subsurface Drip Irrigation. Audience included agricultural producers, USDA-NRCS engineering and field staff, irrigation professionals.

**High Plains Irrigation Conference, Amarillo, TX, February 15, 2018.** Topics included: Irrigation Scheduling Technologies with Center Pivot Sprinklers; Soil Moisture Sensors; EQIP Update; and other pertinent topics. Audience included agricultural producers, USDA-NRCS engineering and field staff, irrigation professionals. CEUs were offered for Irrigation Association Certified Irrigation Designers and Certified Agricultural Irrigation Specialists; Certified Crop Advisers and licensed Pesticide Applicators.

**Papers and presentations**

**Invited papers, presentations, and lectures**

* + Bordovsky, J.P. 2017. SDI research for improved row crop production in the Texas South Plains. 2017 W3128 Multi-State Micro-Irrigation Annual Meeting. Orlando, FL. Nov. 5-6, 2017.
	+ Bordovsky, J.P., 2017. Dashboard for irrigation efficiency management (DIEM). 2017 Irrigation Association Technical Conference. Orlando, FL. Nov. 6-10, 2017.
	+ Bordovsky, J.P. 2017. Leveraging rainfall with limited irrigation in non-traditional cotton rotations. Cotton Incorporated, Texas State Support Committee annual review. Lubbock, TX. Nov. 29-30, 2017.
	+ Bordovsky, J.P. 2017. Irrigation management research using site-specific systems. 2017 Central Texas Irrigation Summit. Gustine, TX. Dec. 12, 2017.
	+ Bordovsky, J.P. 2017. Dealing with manganese and iron clogging (and other SDI experiences) on the Texas High Plains. 2017 Central Texas Irrigation Summit. Gustine, TX. Dec. 12, 2017.
	+ Bordovsky, J.P. 2018. Irrigation management research (timing with deficit irrigation). 2018 Plainview Agricultural Cooperative Conference. Plainview, TX. Jan. 24, 2018.
	+ Bordovsky, J.P. 2018. Irrigation management research (timing with deficit irrigation). 2018 Llano Estacado Cotton Conference. Muleshoe, TX. Jan. 26, 2018.
	+ Bordovsky, J.P. 2018. Dashboard for irrigation efficiency management (DIEM) update. Webinar speaker. Texas A&M AgriLife Seed-Grant Conference. April 20, 2018.
	+ Bordovsky, J.P. 2018. Dashboard for irrigation efficiency management (DIEM), a portion of Irrigation Scheduling Tools for Improved Water Management & Water Use Efficiency. Webinar speaker. The Climate Learning Network in association with USDA-NIFA Ogallala Water CAP. May 10, 2018.
	+ Bordovsky, J.P. 2018. Irrigation practices and research activities in the Southern High Plains. Speaker / host. Site tour and on-farm instruction. Texas 4-H Water Ambassadors. Halfway, TX. July 27, 2018. (Presentations were livestreamed on the Texas 4-H Water Ambassadors Facebook page.)
	+ Bordovsky, J.P. 2018. Irrigation management with limited water. 66th Annual West Texas Agricultural Chemicals Institute Conference. Lubbock, TX. Sept. 11, 2018.
* Porter, Dana. 2017. Irrigation Management and Crop Water Management. Guest Lecture in course, Crop Stress Management. Texas A&M University Department of Soil and Crop Sciences. October 3, 2017.
* Porter, Dana. 2017. Irrigation Water Quality and Salinity Management. Guest Lecture in course, Crop Stress Management. (recorded presentation). Texas A&M University Department of Soil and Crop Sciences. October 5, 2017.
* Porter, Dana. 2018. Irrigation Management for Cotton Production. Oklahoma Irrigation Conference. Weatherford, OK. March 8, 2018.

**Conference or symposium proceedings: papers and posters presented**

* Bordovsky, J.P. 2017. Dashboard for irrigation efficiency management (DIEM). Proceedings of the 2017 Irrigation Association Technical Conference, Orlando, Florida, November 6-10, 2017. Available from the Irrigation Association, Fairfax, Virginia.
* Bordovsky, J.P. 2018. Increasing water productivity through advanced irrigation scheduling, Texas A&M AgriLife Research. Poster. USDA-ARS Ogallala Aquifer Program Annual Meeting. March 26, 2018. Lubbock, TX.
* Heflin, Kevin, Thomas Marek, Gary Marek, Jerry Moorhead, Dana Porter, Qingwu Xue, Robert Schwartz, Yong Chen. 2018. Evaluating Soil Moisture Sensors: Comparing Types, Installation and Performance. ASABE Paper No. 1800926. Annual International Meeting of the American Society of Agricultural and Engineers, Detroit, MI. July 29-Aug 1, 2018.
* Porter, Dana, Freddie Lamm, Jonathan Aguilar, Danny Rogers. 2018. Opportunities and Concerns for Agricultural Irrigation Technology Transfer and Education. ASABE Paper No. 1801394 Annual International Meeting of the American Society of Agricultural and Engineers, Detroit, MI. July 29-Aug 1, 2018.
* Marek, Thomas, Dana Porter, Kevin Heflin, Qingwu Xue, Gary Marek, Jerry Moorhead, and Robert Schwartz. Soil Sensor Evaluation: 2017 Update. USDA-ARS CIG Reporting/Workshop. Goodwell, OK. November 12, 2017.
* Yanxiang Yang, Lijia Sun, Jiang Hu, Dana Porter, Thomas Marek and Charles Hillyer. 2017. A Reliable Soil Moisture Sensing Methodology for Agricultural Irrigation. 16th IEEE International Conference on Ubiquitous Computing and Communication. Guangzhou, China, December 12-15, 2017.
* Porter, Dana, Dan Rogers, Thomas Marek, Paul Colaizzi, Jourdan Bell, and Jim Bordovsky. Applying OAP Outcomes to Improve Technical Standards and Continuing Education. Poster. 2018 Annual Research Planning Meeting of the Ogallala Aquifer Program. Lubbock, TX, March 27-29, 2018.
* Porter, Dana, Freddie Lamm, Thomas Marek, Susan O’Shaughnessy, Paul Colaizzi, Steve Evett, Gary Marek, Jim Bordovsky, Dan Rogers and Jonathan Aguilar. Celebrating 40 Years of Center Pivot Irrigation Research and Technology Transfer. Poster. 2018 Annual Research Planning Meeting of the Ogallala Aquifer Program. Lubbock, TX, March 27-29, 2018.

**Presentations at Extension meetings**

* Porter, Dana. 2017. Water quality and salinity management in irrigation. Central Texas Irrigation Summit. Comanche, Hamilton and Erath Counties. Gustine, TX. December 12, 2017.
* Porter, Dana. 2018. Irrigation Management for Cotton Production. Southern Mesa Crops Conference, Lamesa, TX. January 16, 2018.
* Porter, Dana. 2018. Crop Water Use. Cochran County Ag Profitability Meeting, Morton, TX. January 18, 2018.
* Porter, Dana. 2018. Advanced Irrigation Management Technologies and DIEM Demonstration. Webinars. February 6 and 13, 2018.
* Porter, Dana. 2018. Irrigation and Salinity Management for Vegetable Production. Presentation at Vegetable Production Seminar Series. Lubbock, TX, September 17, 2018.

**Field days / crop tours**

**Summer Crops / Ogallala Aquifer Program Center Pivot Irrigation Field Day, Bushland, TX, August 9, 2018.** Field stops included soil moisture sensor study (integrated comparisons of commercially available soil moisture sensors, installation orientations, and irrigation/soil moisture levels), integration of wireless soil moisture sensors into irrigation controller study, and soil moisture and related data-based irrigation management for turf and other crops. **Project relevant presentations included:**

Marek, Thomas and Dana Porter. 2018. Advanced irrigation control system with integrated inputs. Summer Crops / OAP Center Pivot Irrigation Field Day. Bushland, TX. August 9, 2018.

**Project relevant posters presented at the field day included:**

Bordovsky, J.P. 2018. Increasing Water Productivity through Advanced Irrigation Scheduling.

Porter, Dana, Dan Rogers, Jonathan Aguilar, Jourdan Bell, Thomas Marek,  Saleh Taghvaeian, Bridget Guerrero, Gary Marek, Tiffany Dowell Lashmet, Freddie Lamm, Kay Ledbetter, Prasanna Gowda, and Jim Bordovsky. .OAP Technology Transfer: Educating Stakeholders in Agricultural Water Management Issues, Technologies and BMPs.

Porter, Dana, Dan Rogers, Thomas Marek, Paul Colaizzi, Jourdan Bell, Jim Bordovksy..  Applying OAP Outcomes to Improve Technical Standards and Continuing Education.

Bordovsky, J.P. 2018. Irrigation practices and research activities in the Southern High Plains. Speaker / host. Site tour and on-farm instruction. Texas 4-H Water Ambassadors. Halfway, TX. July 27, 2018. (Presentations were livestreamed on the Texas 4-H Water Ambassadors Facebook page.)

Bordovsky, J.P. 2018. A history of sprinkler irrigation on the Texas High Plains. Summer Crops / OAP Center Pivot Irrigation Field Day. Luncheon Keynote Speaker. Conservation and Production Research Laboratory, Bushland, TX. Aug. 9, 2018.

**Book Chapter**

* Bell, Jourdan, Robert Schwartz, Kevin McInnes, Qingwu Xue, and Dana Porter. 2018. Improving Water Management in Sorghum Cultivation. (Chapter 15) in: Achieving Sustainable Cultivation of Sorghum, Volume 1. William Rooney, editor. Burleigh Dodds Science Publishing. Cambridge, UK. ISBN-13: 9781786761200.

**Fact Sheet**

* Aguilar, Jonathan, Dana Porter and Saleh Taghvaeian. 2017. Tips on Selecting a Soil Water Sensor. Technology Brief. USDA-NRCS-CIG project: 69-3A75-16- 013, “Promoting Sensor Based Technology to Improve Land and Water Resources Conservation”. Kansas State University Research and Extension.

**Video Documentary**

* Lewis, Katie, Dana Porter, Keith Sides, Kelly Kettner, Braden Gruhlkey. Video documentary of Texas Corn Producers Board and USDA-NRCS sponsored Irrigation/Sensors/Cover Crops Soil Health demonstration. Interviews describing farm operations, cover crops and rotations, soil moisture monitoring and weather station telemetry systems used on farms in this integrated study were filmed for integration into the documentary.

**Acknowledgments and Considerations**

Funding and in-kind support provided by Texas A&M AgriLife Research and Texas A&M AgriLife Extension Service; **USDA-NRCS CIG** project, “Promoting Sensor Based Technology to Improve Land and Water Resources Conservation” (Agreement Number: 69-3A75-16-013); the **USDA-NIFA Coordinated Agricultural Project**, “Sustaining Agriculture through Adaptive Management to Preserve the Ogallala Aquifer under a Changing Climate” (award number 2016-68007-25066); and the **USDA-ARS Ogallala Aquifer Program**. The Ogallala Aquifer Program (OAP) is a consortium between the USDA Agricultural Research Service, Kansas State University, Texas A&M University, Texas Tech University and West Texas A&M University. Associated projects are included in the **USDA REEport system** that supports many state and federal Hatch projects.

**Prairie View A&M University**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

**Soil Moisture and Nutrient Dynamics in the Root Zone of Collard Greens in Different Organic Amendment Types and Rates**

Understanding how organic amendment affects the soil-water-plant-atmosphere continuum has become imperative as the use of organic amendments in conventional and organic agricultural production is increasing. A study was conducted at the Prairie View A&M University Research Farm to investigate the effect of organic amendment types (Chicken manure, Cow manure, and Milorganite) and application rates (0, 168, 336, 672 kg total N ha-1) replicated three times on soil moisture and nutrient dynamics within and below the root zone of collard greens. Soil moisture sensors were installed at all 36 plots to monitor soil moisture within and below the root zone. Suction cups were used to collect soil water samples from 15 and 45 cm depths. Soil water samples were collected six times during the growing season at each plot and analyzed for different nutrients (N, P, K, Ca, Mg, Na, Fe, Mn, Zn, and Cu). The preliminary results showed that both organic amendment types and rates affect the soil moisture and nutrient dynamics. The Chicken manure treatments seemed to have the higher water contents consistently for a major portion of the growing season. However, the water contents of the Cow manure and Milorganite treatments were very comparable and relatively lower than that of the Chicken manure treatments. Most of the total Nitrogen concentration increment occurred after irrigation and rainfall. The cow manure treatments had the lowest value of total Nitrogen concentration in soil solutions collected within and below the root zone in all amendment rates.

**Developing Irrigation Scheduling Tool IrrigWise for Agricultural Crops and Urban Landscape in Texas**

Irrigation scheduling is the process of determining the correct frequency and duration/amount of irrigation for agricultural crops and urban landscape. Advances in real-time computing helped scientists to develop user-friendly irrigation scheduling tools which calculate near real-time plant water requirements based on near real-time site specific rainfall, reference evapotranspiration, soil water content, and plant growth data. The web-based irrigation scheduling tool, *IrrigWise*, allows users to establish an irrigation scheduling program for a specific crop grown on a specific location during a particular time of the year by selecting the crop of interest, the soil type, the closest operable weather station, and corresponding crop planting dates. The user has an option to modify crop and soil-related default parameters to fit the location of interest. The user can also extract soil data of the selected field based on the USDA-NRCS’ Soil Survey Geographic Database. *IrrigWise* incorporates multiple weather networks operable across Texas for rainfall and evapotranspiration data. This tool keeps track of the status of the different soil water budget components on a daily basis using user selected inputs (including irrigation amount) and near real-time weather data. The user can decide when and for how long to irrigate. The tool also incorporates forecasted weather data which provides information on the potential change in soil water content of the selected field during the next five days. *IrrigWise* will help in increasing irrigation water use efficiency in agricultural crops and urban landscape in Texas, eliminating over and under irrigation.

**Developing an Android App, *WeatherAndSoil*, for Site-Specific Soil Parameters and Forecasted Weather data**

Crop irrigation scheduling and water requirements are affected by soil hydrological properties, e.g., water holding capacity which varies according to soil type. In the other hand, irrigation scheduling is impacted by future weather patterns; thus, accurate forecasted weather data (temperature, precipitation, wind speed, etc.) are needed to predict reference evapotranspiration (ETO). In addition to their usefulness for irrigation scheduling, forecasted precipitation and ETO are needed for other uses, e.g., drought and flood predictions. There are several smart and/or web-based applications related to soil and weather; however, only a few of the Android applications are for both soil and weather information. There is still a substantial need for weather apps that provide forecasted ETO for the entire United States. Thus, the goal of this work is to develop an Android application for site-specific soil and forecasted weather data. In this new Android App, *WeatherAndSoil*, we incorporate daily forecasted weather information which includes precipitation, wind speed, maximum and minimum temperature, and ETO estimated based on Hargreaves and Samani equation. *WeatherAndSoil* also displays location-specific hourly forecasted weather data, soil type, and soil hydrologic properties. *WeatherAndSoil* App has a user-friendly interface, and it is very useful for different users especially farmers and urban residents which they can use to manage the water management of their crop and lawns.

**Assessing Potential Climate Change Impacts on Irrigation Requirements of Major Crops in the Brazos Headwaters Basin, Texas**

In order for the agricultural sector to be sustainable, farming practices and management strategies need to be informed by site-specific information regarding potential climate change impacts on irrigation requirements and water budget components of different crops. Such information would allow managers and producers to select cropping systems that ensure efficient use of water resources and crop productivity. The major challenge in understanding the link between cropping systems and climate change is the uncertainty of how the climate would change in the future and lack of understanding how different crops would respond to those changes. This study analyzed the potential impact of climate change on irrigation requirements of four major crops (cotton, corn, sorghum, and winter wheat) in the Brazos Headwaters Basin, Texas. The irrigation requirement of crops was calculated for the baseline period (1980–2010) and three projected periods: 2020s (2011–2030), 2055s (2046–2065), and 2090s (2080–2099). Daily climate predictions from 15 general circulation models (GCMs) under three greenhouse gas (GHG) emission scenarios (B1, A1B, and A2) were generated for three future periods using the Long Ashton Research Station–Weather Generator (LARS-WG) statistical downscaling model. Grid-based (55 grids at ~38 km resolution) irrigation water requirements (IRRs) and other water budget components of each crop were calculated using the Irrigation Management System (IManSys) model. Future period projection results show that evapotranspiration (ET) and IRR will increase for all crops, while precipitation is projected to decrease compared with the baseline period. On average, precipitation meets only 25–32% of the ET demand, depending on crop type. In general, projections from almost all GCMs show an increase in IRR for all crops for the three future periods under the three GHG emission scenarios. Irrigation requirement prediction uncertainty between GCMs was consistently greater in July and August for corn, cotton, and sorghum regardless of period and emission scenario. However, for winter wheat, greater uncertainties between GCMs were observed during April and May. Irrigation requirements show significant variations across spatial locations. There was no consistent spatial trend in changes of IRR for the four crops. A unit change in precipitation is projected to affect IRR differently depending on the crop type.

***Objective 2. Develop micro-irrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

See study on “Soil Moisture and Nutrient Dynamics in the Root Zone of Collard Greens in Different Organic Amendment Types and Rates” in objective 1.

**Publications**

**Symposium and Conference Abstracts**

* Awal, R.: Irrigation Scheduling Tool for Agricultural Crops and Urban Landscape in Texas Using a Mobile Web App, *Industry Day 2018*, April 12, 2018, Prairie View, TX
* Duong, J., Awal, R., Fares, A. and Habibi, H.: Developing a Web Soil Survey Data Extraction Tool and an Automatic - Irrigation System based on Soil Moisture, *Summer Student Research Symposium*, August 6, 2018, Prairie View, TX.
* Eisa, Z., Awal, R., Fares, A. and Habibi, H.: Effects of Soil Type on Irrigation Water Requirements of Different Crops at Prairie View, Texas, *Summer Student Research Symposium*, August 6, 2018, Prairie View, TX.
* Liu, Q., Awal, R., Fares, A. and Habibi, H.: Developing Android Application for Location Specific Soil and Forecasted Weather Data, *Summer Student Research Symposium*, August 6, 2018, Prairie View, TX.
* Zhang, R., Awal, R., Fares, A. and Habibi, H.: Upgrading Irrigation Water Estimator for Texas (IWET) for Multiple Users, S*ummer Student Research Symposium*, August 6, 2018, Prairie View, TX.
* Bhattarai, S., Awal, R., Fares, A. and Habibi, H.: Incorporating Weather Data from Different Weather Networks in the Irrigation Scheduling Tool: IrrigWise, *Summer Student Research Symposium*, August 6, 2018, Prairie View, TX.
* Sharma, R., Awal, R., Fares, A. and Fan, K.: Developing Irrigation Scheduling Tool IrrigWise to Increase Water Use Efficiency in Texas, *Land Grant Research Symposium,* April 18, 2018, Prairie View, TX.
* Lee, D., Awal, R., and Fares, A.: Analyzing Irrigation Water Needs for Turf Grass across Harris County, *Land Grant Research Symposium,* April 18, 2018, Prairie View, TX.

**Fundings:**

* USDA NIFA, Evans-Allen project - Impact of anthropogenic and natural changes on natural resources and the environment
* USDA NIFA, 1890 CBG project - Real-time site-specific irrigation scheduling tools for agricultural crops and urban landscape in Texas using mobile web app

**Washington**

**What was accomplished under these Objectives?**

***Objective 1. Develop robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches.***

Three field research locations have been used to collect data from treatments intended to quantify potential to sustain fruit production in vineyards during future periods of low water availability in the Yakima Valley of Washington State. This area is primarily, if not wholly dependent, on irrigation water released from winter snowpack in the Cascade Mountain range. Two of these field locations are cited in commercial wine grape vineyards with grower/producer cooperators and activities are guided by an industry advisory committee that meets quarterly with the research team conducting these experiments. Treatments involve the application of season-long deficit irrigation by deep subsurface micro-irrigation which has been labelled as DRZ (direct root-zone) owing to a newly implemented technique that applies water from a pressure compensated emitter directly into the rootzone through a pair of PVC tubes inserted from 1-3 ft. depths either side of the grape vine under water delivery rates equivalent to 60, 30, and 15 percent of the commercial irrigation rate applied as DI (surface drip irrigation). Plant water stress was measured at selected dates during three growing seasons (2015 -2018) using on-plant measurements by the pressure bomb technique and compared with remote sensing images using near-IR and multi-spectral cameras mounted on either ground or aerial platforms. Another experiment is using similar treatments and methods to determine impacts of these techniques in a Concord grape vineyard located at the WSU Irrigated Agriculture Research and Extension Center near Prosser. Data have either been published or being prepared for submission to peer reviewed journals.

***Objective 2. Develop micro-irrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities.***

Our hypothesis is that subsurface irrigation applied directly into the vine’s lower root-zone can result in both greater water use efficiency and improved fruit quality over surface applied drip irrigation. A randomized complete block design with three replications of each treatment and a split plot design to compare pulse and continuous irrigation schedules were used with season-long deficit irrigation treatments at Kiona Vineyards in the Red Mountain AVA of Washington. During 2015-2018, over 800 vines received subsurface drip irrigation applied by direct root-zone (DRZ) delivery at depths of 1, 2 or 3 feet below ground via vertically installed hard plastic tubes. Subsurface DRZ irrigation was delivered as either continuous or pulsed application and compared to surface drip irrigation application on an additional 180 vines managed to meet commercial production and quality goals. Analyses of data performed during 2017 determined that no significant differences were attributable to water savings from DRZ applied as pulse (interrupted) versus continuous (none interrupted) delivery during any given irrigation set or event. Neither were differences found in depth of deliver among depths varying from 1-3 ft. Since grapevines are known to be efficient in the use of hydraulic redistribution via the root system, this trait is the probable factor influencing this lack of treatment effect. However, differences in total water applied was found to enhance grape quality by increasing levels of BRIX, anthocyanin, and tannins while decreasing levels of titratable acidity with progressively decreasing level of water applied (increasing levels of plant water stress).

In 2017, the irrigation treatments were adjusted to increase water amounts applied as DRZ to 80, 60, and 40 percent of commercial rate applied as surface drip and installed additional treatments to directly compare surface drip and DRZ at equal rates of water application. Results from 2017 and 2018 growing seasons indicate no significant differences among grape yield among those from commercially irrigated by surface drip at 1.25 acre ft. and grape yields from DRZ subsurface micro-irrigation applied as low as 0.46 acre ft. over the growing seasons.

***Objective 3. Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.***

Our lab group is developing a web-site <https://labs.wsu.edu/jacoby/> inform our grower audience about our most current research activities and findings. Additionally, we participate in field days to engage growers with on-site applied research each growing season, present posters and oral reports of our research at annual grower meetings such as the Washington Winegrowers and the Washington Grape Society, as well as national meetings such as the Irrigation Association and American Society of Enology and Viticulture. We also prepare new articles for the popular press and work closely with reporters with local and area media outlets.

Opportunities for commercialization of the DRZ micro-irrigation technique are currently being explored.

**What opportunities for training and professional development has the project provided?**

The project has permitted the PI with the opportunity to interact with other scientists and educators conducting research on micro-irrigation. These connections will be helpful in creating multi-state teams to address issues of growers in seeking means to increase water use efficiency in irrigated agriculture.

**How have the results been disseminated to communities of interest?**

Results have been presented to commodity organizations and regional project groups in the Pacific Northwest. Presentations have also been made at conferences held by the American Society of Agricultural and Biological Engineers (ASABE), the Irrigation Association (IA), American Society of Enology and Viticulture, and the Tri-Societies (ASA, CSSA, and SSSA).

**What do you plan to do during the next reporting period to accomplish these goals?**

Field studies will be continued during the coming year (2019) and presentations will be delivered at regional and international meetings.

**Target audience**

Our primary audiences are growers of wine grapes in the Pacific Northwest. Grapevines are ideal to demonstrate the use of micro-irrigation, as grapes grow best in Mediterranean climates that are typically defined in having dry growing seasons. Similarly, deficit irrigation is typically used in vineyards to enhance the quality of grapes used to produce premium red wines. These features are ideal for evaluating new and more efficient forms of micro-irrigation, such as subsurface delivery systems. Water conservation is a topic of high interest in the western U.S. in light of competing uses of water and periodic drought events that can interrupt sustainable agriculture production that is vital to growers and the communities located within irrigated agriculture production areas.

**PUBLICATIONS**

Popular Press, Symposium, Conference Proceedings, and Abstracts

* **Jacoby, P.W.,** and X.C. Ma. 2018. Direct root-zone delivery to enhance deficit irrigation application. Ann. Meet., Irrigation Association Technical Program, Long Beach, CA. Dec. 2-6. [https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/DRZ\_Drip-Irrigation\_JACOBY.pdf]
* **Jacoby, P.W.,** and X.C. Ma. 2018. Introducing direct root-zone deficit irrigation to conserve water and enhance grape quality in the Pacific Northwest. *Crop and Soils Magazine* Sept.- Oct.: pp. 34-37, 58. doi:10.2134/cs2018.51.0510
* Ma, X.C., A.P. Smertenko, M. Keller, **P.W. Jacoby**, and K.A. Sanguinet. 2018. Enhancing crop production and water conservation through Direct Root-Zone irrigation strategy. ASA Section, Am. Soc. Agron. Ann. Meeting, Baltimore, MD. Nov. 4-7.
* **Jacoby, P.W.,** and X.C. Ma. 2018. Conserving water while increasing grape production through direct root-zone (DRZ) deficit irrigation. Ann. Meeting, Amer. Soc. Enology and Viticulture, Monterey, CA. June 18-21.
* Hawkins, G., **P.W. Jacoby**, and X.C. Ma.2018. Cabernet Sauvignon berry quality from vines irrigated through direct root-zone irrigation. Ann. Meeting, Amer. Soc. Enology and Viticulture, Monterey, CA. June 18-21.
* Ma, X.C., K.A. Sanguinet, and **P.W. Jacoby**. 2018. Performance of Cabernet Sauvignon under direct root-zone deficit irrigation. Ann. Meeting, Amer. Soc. Enology and Viticulture, Monterey, CA. June 18-21.
* Ma, X.C., **P.W. Jacoby**, and K.A. Sanguinet. 2018. Comparing effects of different irrigation rates and depths on wine grape production, grapevine growth, and root development through direct root-zone irrigation strategy. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7.
* Hawkins, G., **P.W. Jacoby**, X.C. Ma, and J.R. Thompson. 2018. Cabernet Sauvignon berry quality in vines watered through direct root zone irrigation. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7. (Third place undergraduate poster contest)

**IMPACTS**

**Alabama**

Continued interest in agricultural irrigation, off-stream storage, and precision agriculture in Alabama has raised awareness for enhanced water efficiencies in irrigation during more frequently occurring southeastern droughts. Cotton, corn, soybean, peanut and forage producers are impacted and increasingly concerned about climate changes. Subsequently, there is significant interest in adoption of microirrigation and sensor-based / weather-based irrigation management, including increasing interest in UAV technology.

**California**

**University of California Riverside**

The HYDRUS models are being constantly updated based on the basic research carried out by the W3188 group. The HYDRUS-1D model was downloaded more than ten thousand times in 2018 and over twenty five thousand HYDRUS users from all over the world registered at the HYDRUS website. We continue supporting all these HYDRUS users from USA and around the world at the HYDRUS website using various tools, such as Discussion forums, FAQ sections, and by continuously updating and expanding a library of HYDRUS projects.

 Additionally, we have added capabilities to rigorously consider processes in the soil to the very widely used modeling tools, such as MODFLOW and DSSAT. These two tools are used by thousands of users to simulate flow in the groundwater and the growth of multiple agricultural crops, respectively.
Finally, in 2018 we have offered short courses on how to use HYDRUS models at a) Czech University of Life Sciences, Prague, Czech Republic, b) Colorado School of Mines, Golden, CO, c) the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China, d) Tokyo University of Agriculture and Technology, Department of Ecoregion Science, Tokyo, Japan, e) WASCAL Headquarters, Accra, Ghana, NC. About 150 students participated in these short courses.

**University of California Davis**

My greatest impact is in the development of precision irrigation management systems for specialty crops. For example, our site specific irrigation of almonds project through retrofitting of microirrigation systems has attracted a lot of attention from the growers (printed in two grower oriented magazines) and also received funding from the almond board of California. Our work on high frequency fertigation is also expected to reduce nitrate leaching which is a serious problem in the central valley of California but also improve yields. The web based iCrop decision support system has attracted a lot of interests from growers and crop consultants and is expected to help growers optimize yields and inputs in good years (wet years) while minimizing inputs in bad years (extreme drought) to optimize overall net profitability.

**Idaho**

Lack of in-season grower willingness to input irrigation data limited the usefulness of the water budget approach. When actual soils, crop and irrigation information was entered into the WSU scheduler, results (indicating when and how much the grower should irrigate, and amount of deep percolation loss) compared well with the soil sensor method. Because the WSU scheduler is free for grower use, development of a method to integrate actual irrigation information into the scheduler (the major barrier to adoption) should significantly increase the level of grower adoption, and result in better utilization of limited irrigation water.

Because of the improved sensor soil water measurements this year, growers were more confident in trusting the results, and 1 of the 3 growers shut off the LESA pivot based on sensor data. Due to ample early-season irrigation, the pivots on the Rexburg bench site did not require irrigation until July 5. After that time, the Control pivot ran continuously and still fell behind with the soil profile drying to water stress levels below 18 inches by mid-season and all sensors indicating water stress by the end of the season. In contrast, based on sensor readings,19% less water (one less irrigation) was applied to the LESA pivot, and soil water content at all depths remained at non-stressed levels throughout the entire season. Grain yield and quality were equal on both pivots, but the use of sensors to shut off the LESA pivot when needed resulted in energy savings of 6300 kWh or a cost savings of approximately $500 per irrigation.

Use of either of these approaches will probably increase in coming years due to the requirement that water application on approximately 1 million acres of farm land irrigated from ground water sources be reduced by 10-15% in response to settlement of a long-standing lawsuit between the Surface Water Coalition and participating members of the Idaho Ground Water Appropriators, Inc. Requirements for pumping reduction along with the requirement for IDWR approved flow meter installation were mostly implemented in 2018 and will be fully implemented in 2019. Based on results of a number of Pacific Northwest irrigation scheduling studies, use of either the web-based scheduling approach or the soil water sensor approach can play a major role in meeting the requirements of the settlement.

**Kansas**

Usage of subsurface drip irrigation (SDI) continues to grow in the USA even with lower commodity prices. Interest in the technology has continued to grow internationally for a variety of crops.

Initial results from a field study with SDI has indicated that corn grain yields and crop water productivity can be increased with cropping intensification without increasing irrigation.

**New Mexico**

Saline groundwater is increasingly used for irrigation in New Mexico and salinity induced abiotic stresses and quantification of the salinity induced influences on physiology, growth, and yield of chile and Pecans are important for the sustainability of agriculture in New Mexico. The strategy of growing glycophytes and halophytes under a water salinity gradient will be useful for food security mission of USDA. These experiments and results demonstrates that continuous long-term use of brackish water can increase soil salinization and decrease chile pepper yields.

**Oregon**

The amount of drip irrigation used in Oregon and surrounding states continues to increase. The acreage drip-irrigated of onion, vineyards, and hops has been increasing dramatically, with accompanying increases in irrigation water use efficiency. Irrigation scheduling using 1) soil water monitoring using sensors and 2) the use of crop evapotranspiration estimates are partially responsible for the water savings. Declining groundwater contamination in the Treasure Valley of Oregon is related to the adoption of drip irrigation and more careful nutrient management.

**Puerto Rico**

Farmers commonly use microirrigation to produce their crops on the southern coast of Puerto Rico. Research developed in the management of microirrigation in fruits and starchy crops has been combined with the evaluation of management practices for emerging problems and new production systems. Young farmers progressively accept the use of technology such as remote sensing. This technology has been adapted to the management of microirrigation on a large-scale basis. This project has contributed with information for the Caribbean region available in the web.

**Texas**

**USDA ARS**

A decision support system for variable rate irrigation (VRI) center pivot systems has been developed by scientists at the USDA ARS Conservation & Production Research Laboratory, Bushland, TX, and beta tested since 2016 in Texas, Mississippi, Missouri, Nebraska and South Carolina. The patented system (U.S. Patent No. 8,924,031) is embodied in a client-server software system named ARSPivot and associated wireless plant canopy temperature, soil water content and weather sensors that constitute the Irrigation Scheduling Supervisory Control And Data Acquisition (ISSCADA) system. Beta testing has been accomplished in conjunction with a Cooperative Research And Development Agreement (CRADA) with Valmont Industries. Development of the plant feedback part of the system began in 1995 with infrared thermometers and a control system that logged canopy temperatures and made automatic decisions to control valves to irrigate corn and soybean using surface and subsurface drip irrigation. The system was converted to center pivot sprinkler irrigation systems beginning in 2004 and has been used successfully to automatically schedule irrigation of corn, cotton, potato, sorghum and soybean. It remains useful for microirrigation scheduling. Success is defined by obtaining yields and water use efficiencies as large as or larger than those obtained using irrigation scheduling based on weekly neutron probe readings throughout the root zone. Since the neutron probe is the most accurate system for irrigation scheduling based on soil water content, success of the ISSCADA system meets a very high bar.

Irrigation application method can impact crop water use and water use efficiency, but the mechanisms involved are incompletely understood, particularly in terms of the water and energy balances during the growing season from pre-irrigation through planting, early growth and yield development stages. Grain corn (Zea mays L.) and sorghum (Sorghum bicolor L. Moench) were grown on four large weighing lysimeters at Bushland, Texas in 2013 (corn), 2014 and 2015 (sorghum) and 2016 (corn). Two of the lysimeters and surrounding fields were irrigated by subsurface drip irrigation (SDI) and the other two were irrigated by mid elevation spray application (MESA). Crop evapotranspiration was determined using both the weighing lysimeters and by soil water balance in eight locations in each field with soil water contents measured using the neutron probe. Final biomass and yield were measured. Irrigation amounts were metered and also measured by lysimeter mass balance. Compared with MESA irrigation, using SDI saved 48 mm (based on NP for DOY 170-189, 85 based on Lys) and 53 mm of water that was lost to evaporation early in the season (1st pre-plant irrigation to 25 days after planting, DAP) in 2013 and 2014, respectively, and 59 mm (110 based on Lys) and 112 mm for the 2013 and 2014 seasons, respectively. In the wetter 2015 and 2016 seasons, using SDI saved 11 and 12 mm, respectively, through 25 DAP, and 50 and 139 mm total for the season, respectively. While sorghum, particularly short season sorghum, is not a crop ordinarily considered for SDI, it was grown successfully using SDI with yields averaging 6.48 and 7.53 Mg ha 1 in 2014 and 2015, respectively, comparable to others reported for short season sorghum at Bushland. In the relatively dry 2013 season, SDI reduced overall corn water use by 59 mm while increasing yields by 1.88 Mg ha 1 (20%) and WUE by 0.64 kg m-3 (61%) compared with MESA full irrigation. In the relatively wet 2016 season, SDI reduced corn water use by 139 mm and increased WUE significantly, but with insignificant difference in yield between SDI and MESA irrigation methods. Significant and relatively large differences in water use indicate that crop coefficients should be tailored specifically for SDI management, and that crop coefficients determined using sprinkler irrigation are likely to be too large and lead to over irrigation if used to scheduled SDI.

**Texas A&M AgriLife Research and Extension Service**

Declining quantity and quality of water resources in the region are driving adoption of efficient irrigation technology and demand for information resources. Microirrigation (mostly subsurface drip irrigation) is relatively widely used in the Texas High Plains, where affected land area is approaching an estimated 500,000 acres (increase from an estimated 20,000 acres statewide in 2000). Most of this land area is under cotton production, but agronomic seed production, declining water resources, cost-share programs and a growing winegrape industry also are contributing significantly to this growth in adoption of microirrigation and sensor-based / weather-based irrigation management.

**Washington**

Our project participation has not yet been sufficiently long to produce impacts; however, interest in subsurface micro-irrigation is high. Our research, featuring a new concept for subsurface irrigation delivery, has drawn considerable inquiry from regional growers.

During 2015, a growing season during which record setting heat and drought was recorded, we demonstrated the ability to sustain the vigor of vineyards on irrigation rates that were only 30 to 15 percent of commercial rates using traditional surface drip irrigation. Production rates were 75 to 70 percent less than that of full commercial rates of irrigation during 2015 and slightly less than those rates during the second consecutive year of season-long deficit irrigation.

During 2017, soil water content to a depth of 8.5 ft. depth was twice as high as during the previous two growing seasons. This factor, together with an extended period of cool wet weather, deferred the first irrigations to be delayed until late June. Treatment effects for our levels and types of irrigation delivery were not significantly different from full commercial rates of surface drip in terms of harvest fruit production and quality of fruit. The 2018 growing season was similar to the 2017 season.

Our multi-disciplinary team has also seen potential for using remote sensing to monitor plant water stress in vineyards. These techniques have shown potential to aid in more effective irrigation scheduling.

**PUBLICATIONS (Peer-reviewed Journal Articles)**

**California**

**University of California Riverside**

1. Karandish, F., A. Darzi-Naftchali, and J. Šimůnek, Application of HYDRUS (2D/3D) for predicting the influence of subsurface drainage on soil water dynamics in a rainfed-canola cropping system, *Irrigation and Drainage Journal*, *67*, Supplement 2, 29-39, doi: 10.1002/ird.2194, 2018.
2. Hartmann, A., J. Šimůnek, M. K. Aidoo, S. J. Seidel, and N. Lazarovitch, Implementation and application of a root growth module in HYDRUS, *Vadose Zone Journal*, *17*(1), 170040, 16 p., doi: 10.2136/vzj2017.02.0040, 2018.
3.  In May-December 2018, this **highly cited paper** received enough citations to place it in the top 1% of the academic field of Environment/Ecology based on a highly cited threshold for the field and publication year.
4. Darzi-Naftchali, A., F. Karandish, and J. Šimůnek, Numerical modeling of soil water dynamics in subsurface drained paddies with midseason drainage or alternate wetting and drying management, *Agricultural Water Management*, *197*, 67-78, doi: 10.1016/j.agwat.2017.11.017, 2018.
5. Arthur, J. D., N. W. Mark, S. Taylor, J. Šimůnek, M. L. Brusseau, and K. M. Dontsova, Dissolution and transport of insensitive munitions formulations IMX-101 and IMX-104 in saturated soil columns, *Science of Total Environment*, *624*, 758-768, doi: 10.1016/j.scitotenv.2017.11.307, 2018.
6. Šimůnek, J., M. Th. van Genuchten, and R. Kodešová, Thematic issue on HYDRUS applications to subsurface flow and contaminant transport problems, *Journal of Hydrology and Hydromechanics*, *66*(2), 129-132, doi: 10.1515/johh-2017-0060, 2018.
7. Šimůnek, J., M. Šejna, and M. Th. van Genuchten, New features of the version 3 of the HYDRUS (2D/3D) computer software package, Journal of Hydrology and Hydromechanics, *66*(2), 133-142, **doi: 10.1515/johh-2017-0050,** 2018.
8. Karimov, A. K., M. A. Hanjra, J. Šimůnek, andM. Avliyakulov, Can a change in cropping pattern produce water savings and social gains: A case study from the Fergana Valley, Central Asia, *Journal of Hydrology and Hydromechanics*, *66*(2), 189-201, **doi:** 10.1515/johh-2017-0054, 2018.
9. Jacques, D., J. Šimůnek, D. Mallants, and M. Th. van Genuchten, The HPx software for multicomponent reactive transport during variably-saturated flow: Recent developments and applications, Journal of Hydrology and Hydromechanics, *66*(2), **211-226, doi: 10.1515/johh-2017-0049,** 2018.
10. Shelia, V., J. Šimůnek, K. Boote, and G. Hoogenbooom, Coupled DSSAT and HYDRUS-1D for simulations of soil water dynamics in the soil-plant-atmosphere system, *Journal of Hydrology and Hydromechanics*, *66*(2), 232-245, doi: 10.1515/johh-2017-0055, 2018.
11. Szymkiewicz, A., A. Gumuła-Kawęcka, J. Šimůnek, B. Leterme, S. Beegum, B. Jaworska-Szulc, M. Pruszkowska-Caceres, W. Gorczewska-Langner, R. Angulo-Jaramillo, and D. Jacques, Simulation of freshwater lens recharge and salt/freshwater interfaces using the Hydrus and SWI2 packages for Modflow, *Journal of Hydrology and Hydromechanics*, *66*(2), 246-256, doi: 10.2478/johh-2018-0005, 2018.
12. Phogat, V., T. Pitt, J. W. Cox, J. Šimůnek, and M. A. Skewes, Soil water and salinity dynamics under sprinkler irrigated almond exposed to a varied salinity stress at different growth stages, *Agricultural Water Management*, *201*, 70-82, doi: 10.1016/j.agwat.2018.01.018, 2018a.
13. Phogat, V., J. W. Cox, and J. Šimůnek, Identifying the future water and salinity risks to irrigated viticulture in the Murray-Darling Basin, South Australia, *Agricultural Water Management*, *201*, 107-117, doi: 10.1016/j.agwat.2018.01.025, 2018b.
14. Rahmatpour, S., M. R. Mosaddeghi, M. Shirvani, and J. Šimůnek, Transport of silver nanoparticles in intact columns of calcareous soils: The role of flow conditions and soil texture, *Geoderma*, *322*, 89-100, doi: 10.1016/j.geoderma.2018.02.016, 2018.
15. Adrian, Y. F., U. Schneidewind, S. A. Bradford, J. Šimůnek, T. M. Fernandez-Steeger, and R. Azzam, Transport and retention of surfactant- and polymer-stabilized engineered silver nanoparticles in silicate-dominated aquifer material, *Environmental Pollution*, *236*, 195-207, doi: 10.1016/j.envpol.2018.01.011, 2018.
16. Kacimov, A., Y. Obnosov, and J. Šimůnek, Steady flow from an array of subsurface emitters: Kornev’s irrigation technology and Kidder’s free boundary problems revisited, *Transport in Porous Media*, *121*(3), 643-664, doi: 10.1007/s11242-017-0978-x, 2018.
17. Brunetti, G., J. Šimůnek, M. Turco, and P. Piro, On the use of global sensitivity analysis for the numerical analysis of permeable pavements, *Urban Water Journal*, *15*(3), 269-275, doi: 10.1080/1573062X.2018.1439975, 2018.
18. Sasidharan, S. A. Bradford, J. Šimůnek, B. DeJong, and S. R. Kraemer, Evaluating drywells for stormwater management and enhanced aquifer recharge, *Advances in Water Resources*, *116*, 167-177, doi: 10.1016/j.advwatres.2018.04.003, 2018.
19. Brunetti, G., J. Šimůnek, and E. Bautista, A hybrid finite volume-finite element model for the numerical analysis of furrow irrigation and fertigation, *Computers and Electronics in Agriculture*, *150*, 312-327, doi: 10.1016/j.compag.2018.05.013, 2018.
20. Karandish, F., and J. Šimůnek, An application of the Water Footprint concept to optimize the production of crops irrigated with saline water: Scenario assessment with HYDRUS, *Agricultural Water Management*, *208*, 67-82, 2018.
21. Wongkaew, A., H. Saito, H. Fujimaki, and J. Šimůnek, Numerical analysis of soil water dynamics in a soil column with an artificial capillary barrier growing leaf vegetables, *Soil Use and Management*, *34*, 206-215, doi: 10.1111/sum.12423, 2018.
22. Beegum, S., J. Šimůnek, A. Szymkiewicz, K. P. Sudheer, and I. M. Nambi, Updating the coupling algorithm between HYDRUS and MODFLOW in the ‘HYDRUS Package for MODFLOW’, Technical Note, *Vadose Zone Journal*, *17*(1), 180034, 8 p., doi: 10.2136/vzj2018.02.0034, 2018.
23. Sasidharan, S.,S. A. Bradford, J. Šimůnek, and S. Torkzaban, Minimizing virus transport in porous media by optimizing solid phase inactivation, *Journal of Environmental Quality*, *47*(5), 1058-1067, doi: 10.2134/jeq2018.01.0027, 2018.
24. Saefuddin, R., H. Saito, and J. Šimůnek, Experimental and numerical evaluation of a ring-shaped emitter for subsurface irrigation, *Agricultural Water Management*, *211*, 111-122, doi: 10.1016/j.agwat.2018.09.039, 2019.
25. Liang, Y., S, A. Bradford, J. Šimůnek, and E. Klumpp, Mechanism of graphene oxide aggregation, retention, and release in quartz sand, *Science of the Total Environment*, *656*, 70-79, doi: 10.1016/j.scitotenv.2018.11.258, 2019.
26. Liu, K., G. Huang, X. Xu, Y. Xiong, Q. Huang, and J. Šimůnek, A coupled model for simulating water flow and solute transport in furrow irrigation, *Agricultural Water Management*, *213*, 792-802, 2019.
27. Karandish, F., and J. Šimůnek, A comparison of the HYDRUS (2D/3D) and SALTMED models to investigate the influence of various water-saving irrigation strategies on the maize water footprint, *Agricultural Water Management*, *213*, 809-820, doi: 10.1016/j.agwat.2018.11.023, 2019.
28. Phogat, V., J. W. Cox, J. Šimůnek, and P. Hayman, Modeling water and salinity risks to viticulture under prolonged sustained deficit and saline water irrigation, *Journal of Water and Climate Change*, *9*(??), ???-???, doi: 10.2166/wcc.2018.186, (accepted May 3 2018). (<https://doi.org/10.2166/wcc.2018.186>)
29. Beegum, S., J. Šimůnek, A. Szymkiewicz, K. P. Sudheer, and I. M. Nambi, Implementation of solute transport in the vadose zone into the 'HYDRUS package for MODFLOW', *Groundwater*, 17 p., doi: 10.1111/gwat.12815, (accepted July 29 2018). (<https://doi.org/10.1111/gwat.12815>)
30. Brunetti, G., J. Šimůnek, H. Bogena, R. Baatz, J. A. Huisman, H. Dahlke, and H. Vereecken, On the information content of cosmic-ray neutrons in Bayesian optimization of soil hydraulic properties, *Vadose Zone Journal*, doi: 10.2136/vzj2018.06.0123, (accepted September 24 2018).

**University of California Davis**

1. Muhammad S, Sanden BL, Saa, S, Lampinen BD, Smart DR, Shackel KA, DeJong TM, Brown PH. 2018. Optimization of nitrogen and potassium nutrition to improve yield and yield parameters of irrigated almond (*Prunus dulcis* (Mill.) D. A. webb). Sci. Hort. 228:204-212.
2. Milliron LK, Olivos A, Saa S, Sanden BL, Shackel KA. 2018. Dormant stem water potential responds to laboratory manipulation of hydration as well as contrasting rainfall field conditions in deciduous tree crops. Biosystems Engineering 165:2-9.
3. Meyers, J., **I. Kisekka**, Shrinivasa Upadhyaya, Gabriela Michelon, Kelley Drechsler, Erin Kizer, Channing Ko-Madden. 2018. Development of an Artificial Neural Network Approach for Predicting Plant Water Status in Almonds. 2018. *Trans. ASABE. .* doi: 10.13031/trans.12970.
4. Kisekka, I., Kandelous, M. M., B. Sanden, J. W. Hopmans. 2018. Uncertainties in leaching assessment in micro-irrigated fields using water balance approach. *Agricultural Water Management*. 213(1): 107-115.

**Florida**

1. HUANG, J.-H.; XU, J.; YE, X.; LUO, T.-Y.; REN, L.-H.; FAN, G.-C.; QI, Y.-P.; LI, Q.; FERRAREZI, R. S.; CHEN, L.-S. 2018. Magnesium deficiency secondary lignification of the vascular system in *Citrus sinensis* seedlings. **Trees: Structure and Function.** Published online on Sept 21, 2018. DOI: <https://doi.org/10.1007/s00468-018-1766-0>
2. KADYAMPAKENI, D.M., MORGAN, K.T., NKEDI-KIZZA, P., SCHUMANN, A.W. AND JAWITZ, J.W., 2018. Modeling Water and Nutrient Movement in Sandy Soils Using HYDRUS-2D. Journal of Environmental Quality 47:1546–1553, doi:10.2134/jeq2018.02.0056.
3. KADYAMPAKENI, D.M., P. NKEDI-KIZZA, J.A. LEIVA, A. MUWAMBA, E. FLETCHER, AND K.T. MORGAN. 2018. Ammonium and nitrate transport during saturated and unsaturated water flow through sandy soils. Journal of Plant Nutrition and Soil Science 181(2):198–210.
4. BREWER M.T., MORGAN K.T., ZOTARELLI L., STANLEY C.D., KADYAMPAKEN D. 2018. Effect of drip irrigation and nitrogen, phosphorus and potassium application rates on tomato biomass accumulation, nutrient content, yield, and soil nutrient. Status. Journal of Horticulture 5:227. doi: 10.4172/2376-0354.1000227
5. BANDARANAYAKE W., D.M. KADYAMPAKENI, AND L.R. PARSONS. 2018. Temporal changes of soil water in sandy soils amended with pine bark and efficient blueberry irrigation. Soil Science Society of America Journal 82:413–422.

**Kansas**

1. Oker, T., Kisekka, I., A. Sheshukov, J. Aguilar, and D. Rogers. 2018. Evaluation of Maize Production under Mobile Drip Irrigation. Agricultural Water Management. 210, pp. 11-21 [doi.org/10.1016/j.agwat.2018.07.047](https://doi.org/10.1016/j.agwat.2018.07.047%22%20%5Ct%20%22_blank%22%20%5Co%20%22Persistent%20link%20using%20digital%20object%20identifier)

**New Mexico**

1. \*Yang H., T. Du, X. Mao, R. Ding, and M.K. Shukla. 2019. A comprehensive method of evaluating the impact of drought and salt stress on tomato growth and fruit quality. Ag Water Manage. 213: 116-127.
2. \*Hooks T.N., G. A. Pichionni, B. J. Schutte, M.K. Shukla, and D. Daniel. 2018. Sodium chloride effects on seed germination, growth, and evapotranspiration of Lepidium alyssoides, L. draba, and L. latifolium: traits of resistance and implications for invasiveness on saline soils. Rangeland Ecology & Management. 71:433-442.
3. \*Kellum D.S., M.K. Shukla, J. Mexal and S. Deb. 2018. Greenhouse gas emissions from pecan orchards in semi-arid southern New Mexico. Hort Sci. 53:704-709.
4. \*O. Ozturk, M.K. Shukla, B. Stringam and C. Gard. 2018. Irrigation water salinity induced changes in the evaporation, growth and ion uptake of two halophytes. J Ag. Water Manag. 195: 142-153.
5. Rahamati M et al., 2018. Development and analysis of the Soil Water Infiltration Global database. Earth System Science Data. 10:1237-1263. https://doi.org/10.5194/essd-10-1237-2018
6. Qi, Y., J. Pu, F. Yang, M. K. Shukla, and Q. Chang. 2018. Response of soil physical, chemical and microbial biomass properties to land use changes in fixed desertified land. Catena. 160: 339-344.
7. \*Triston N. Hooks, Geno A. Picchioni, Brian J. Schutte, Manoj K. Shukla, David L. Daniel, and Jamshid Ashigh.  2018.  Salinity an Environmental “Filter” Selecting for Plant Invasiveness?  Evidence from the Indigenous *Lepidium alyssoides* on Chihuahuan Desert Shrublands.  Rangeland Ecology and Management. 71: 106-114.

**Oregon**

1. Shock, C.C., E.B.G. Feibert, A. Rivera, L.D. Saunders, N.L. Shaw, and F.F. Kilkenny. 2018. Irrigation requirements for seed production of three leguminous wildflowers of the U.S. Intermountain West. HortSci 53(5):692–697. <https://doi.org/10.21273/HORTSCI12872-17>
2. Wright, D., E.B.G. Feibert, S. Reitz, C.C. Shock, and J. Waite-Cusic. 2018. Field evidence supporting conventional onion curing practices as a strategy to mitigate *Escherichia coli* contamination from irrigation water. Journal of Food Protection 81(3):369–376. doi:10.4315/0362-028X.JFP-17-231

**Puerto Rico**

1. Harmsen, E. W. and R. H. Harmsen, 2017. Agricultural water management and Puerto Rico’s food insecurity. Ethos Gubernamental Journal.
2. Acevedo, M., E. Román-Paoli, F. Román Pérez, E. Valencia, and R. Tirado Corbalá: 2018. Pineapple [Ananas comosus (L.) MERR.] yield and growth response to fertilization methods and drip irrigation management.. J of Agric. UPR. In Press.

**Texas**

**USDA ARS, Bushland**

1. Colaizzi, P.D., S.A. O'Shaughnessy, and S.R. Evett. 2018. Calibration and tests of commercial wireless infrared thermometers. Appl. Engr. Agric. 34(4): 647-658. ISSN 0883-8542 <https://doi.org/10.13031/aea.12577>.
2. Evett, S.R., G.W. Marek, P.D. Colaizzi, B.B. Ruthardt and K.S. Copeland. 2018a. A subsurface drip irrigation system for weighing lysimetry. Appl. Engineer. Agric. 34(1):213-221. <https://dx.doi.org/10.13031/aea.12597>.
3. Evett, S.R., G.W. Marek, K.S. Copeland and P.D. Colaizzi. 2018d. Quality management for research weather data - Bushland, Texas. Accepted by Agrosystems, Geosciences & Environment, Sep 7, 2018.
4. Evett, S.R., K.S. Copeland, G.W. Marek, P.D. Colaizzi and D.K. Brauer. 2018e. 2016 USDA-ARS Bushland Texas 15-minute research weather data. NAL Ag Data Commons. DOI: <http://dx.doi.org/10.15482/USDA.ADC/1482548>.
5. O'Shaughnessy, S.A., J.J. Casanova, S.R. Evett and P.D. Colaizzi. 2018. Computer vision qualified infrared temperature sensor. United States Patent No. 9,866,768 B1. Issued January 9, 2018.
6. Schwartz, R.C., S.R. Evett and R.J. Lascano. 2018. Letter to the Editor: Comments on "J. Singh et al., Performance assessment of factory and field calibrations for electromagnetic sensors in a loam soil" [Agric. Water Manage. 196 (2018) 87-98]. Agric. Water Manage. 203(2018):236-239. <https://doi.org/10.1016/j.agwat.2018.02.029>.

**Texas A&M AgriLife Research and Extension Service**

1. Schaefer, C.R., Ritchie, G.L., Bordovsky, J.P., Lewis, K. and Kelly, B. 2018. Irrigation timing and rate affect cotton boll distribution and fiber quality. Agron. J. 110(3):1-10(2018). Doi:10.2134/agronj2017.06.0360.

**Prairie View A&M University**

1. Awal, R., Fares, A., and Bayabil, H.: Assessing Potential Climate Change Impacts on Irrigation Requirements of Major Crops in the Brazos Headwaters Basin, Texas, *Water* 2018, 10(11), 1610.

**Washington**

1. Ma, X.C., K.A. Sanguinet, **P.W. Jacoby**. 2018, Performance of direct root-zone deficit irrigation on *Vitis vinifera* L. cv. Cabernet Sauvignon production in southcentral Washington. *Agric. Water Manage.* (in review).
2. Chakraborty, M., L.R. Khot, S. Sankaran, and **P.W. Jacoby**. 2018. Evaluation of mobile 3D light detection and ranging-based canopy mapping system for tree fruit crops. *Computer and Electronics in Agriculture* (in review).
3. Zuniga, C.E., A. P. Rathnayake, M. Chakraborty, S. Sankaran, **P.W. Jacoby**, and L.R. Khot. 2018. Applicability of time-of-flight-based ground and multispectral aerial imaging for grapevine canopy vigour monitoring under direct root-zone deficit irrigation. *Int’l. J. Remote Sensing.* DOI: [10.1080/01431161.2018.1500047](https://doi.org/10.1080/01431161.2018.1500047) (Impact Factor: 1.724).
4. Zuniga, C.E., L.R. Khot, S. Sankaran, and **P.W. Jacoby**. 2017. High resolution multispectral and thermal remote sensing based water stress assessment in grapevines to evaluate subsurface irrigation technique effects. *Remote Sensing* 9(9):961-976; <http://www.mdpi.com/2072-4292/9/9/961/htm> DOI: 10.3390/rs9090961. [(ISSN 2072-4292) Impact Factor 3.244].