SAES-422 Multistate Research Activity Accomplishments Report

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

W4128 "Microirrigation: A Sustainable Technology for Crop Intensification and Improved Crop Productivity"

Period Covered: 10-2018 to 09-2019
Date of Report: 12/11/2019
Annual Meeting Date: November 10, 2019

Participants: Davie Kadyampakeni (dkadyampakeni@ufl.edu) University of Florida, Ripendra Awal (riawal@pvamu.edu) – Prairie View A&M University; Freddie Lamm (flamm@ksu.edu) – Kansas State University (Zoom), Saleh Taghvaeian (saleh.taghvaeian@okstate.edu) - Oklahoma State University (Zoom); Clinton Shock (Clinton.shock@oregonstate.edu) Oregon state University; Manoj K. Shukla (shuklamk@nmsu.edu) New Mexico State University; Pete Jacoby (jacoby@wsu.edu) - Washington State University; Jirka Simunek (jsimunek@ucr.edu) University of California Riverside; Howard Neibling (hneiblin@uidaho.edu) - University of Idaho (Zoom); Kenneth Shackel (kashackel@ucdavis.edu) - University of California Davis, Dana Porter (dporter@ag.tamu.edu) Texas A & M university (Zoom); Naftali Lazarovitch (lazarovi@bgu.ac.il) BenGurion University; Bipul K. Biswas (biswasb@fvsu.edu) Fort Valley State University.

Brief Summary of Minutes of Annual Meeting:

- The annual meeting was held on November 10, 2019, in the Bordham Room C, in Grand Hyatt San Antonio, just before the start of the ASA/CSSA/SSSA Annual meetings at the Henry B. Gonzalez Convention Center. The meeting was presided by 2019 Committee Chair Dr. Davie Kadyampakeni.
- The venue chosen for the next meeting in 2020 was San Antonio, Texas at the joint Irrigation Association (IA)/American Society of Agricultural and Biological Engineers (ASABE) Annual Meetings on Nov 30-December 5, 2020. Dr. Freddie Lamm will provide support with the society to not have registration fees and Dr. Ripendra Awal will preside over that meeting. Project members were encouraged to submit manuscripts to the special issue on 'Soil Moisture Sensors' who guest editor is Dr. Saleh Taghvaeian, one of the project members.
- Dr. Ken Shackel, Professor at the University of California Davis, was elected 2020 secretary for the W4128 group. Dr. Ripendra Awal and Dr. Amir Haghverdi, become 2019 Committee Chair and Vice-Chair, respectively.

- W3128 Project expired on September 30, 2019. The new project is W4128 "Microirrigation: A Sustainable Technology for Crop Intensification and Improved Crop Productivity".
- Dr. Manoj Shukla provided updates from Dr. Steve Loring, project advisor, who could not make it to the meeting due to a conflict schedule. Dr. Shukla also presented to the group the 2017 National Water & Energy Conservation Award for USDA-NIFA Multistate Project W-3128.
- State reports were presented by Dr. Davie Kadyampakeni (University of Florida), Dr. Ripendra Awal (Prairie View A&M University, Texas); Dr. Freddie Lamm (Kansas State

University); Saleh Taghvaeian (Oklahoma State University); Clinton Shock (Oregon state University); Dr. Manoj K. Shukla (New Mexico State University); Dr. Pete Jacoby (Washington State University); Dr. Jirka Simunek (University of California Riverside); Dr. Howard Neibling (University of Idaho); Dr. Kenneth Shackel (University of California Davis), and Dr. Dana Porter (Texas A & M university, Texas);

ACCOMPLISHMENTS

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. Additionally, we have added new capabilities to HYDRUS to rigorously consider processes in the soil profiles with furrows (the Furrow module), to calculate cosmic ray neutron fluxes (the Cosmic module), and to simulate the translocation and transformation of chemicals in the soil-plant continuum (A Dynamic Plant Uptake module).

2. **Activities**

In 2019, we offered 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) Indian Institute of Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, and d) the Sede Boker Campus of the Ben Gurion University, Israel. About 100 students participated in these short courses.

Meetings attended:

1. Annual Meeting of Soil Science Society of America, San Diego, California, 9-11, 2019.
2. W-3188 Western Regional Soil Physics Group Meeting, U.S. Salinity Laboratory, Riverside, California, January 10-11, 2019.
3. W-3128 Western Regional Soil Physics Group Meeting (Scaling Microirrigation Technologies to Address the Global Water Challenge), San Antonio, Texas, November 10, 201.
4. Annual Meeting of Soil Science Society of America, San Antonio, Texas, November 10-13, 2019.

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 25-27, 2019. Sole instructor (30 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 10-12, 2019. Sole instructor (11 participants).
3. A short course “International Workshop on Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, Indian Institute of

Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, September 9-11, 2019. Sole instructor (35 participants).

4. A short course “Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, at the Sede Boker Campus of the Ben Gurion University, Israel, September 17-19, 2019. Other instructor: N. Lazarovitch (25 participants).

2. 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.

I. ***The Use of Hydrus Models to Evaluate Various Irrigation and Fertigation Problems - Agricultural Applications***

1. **Saefuddin et al. (2019)** evaluated a ring-shaped emitter made from a standard rubber hose that has been developed and introduced for subsurface irrigation in Indonesia. 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.
2. **Phogat et al. (2019)** used the HYDRUS-1D model to identify the future water and salinity risks to irrigated viticulture in the Murray-Darling Basin, South Australia. 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.
3. **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.
4. **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.
5. **Ramos et al. (2019)** evaluated current risks and possible trends in soil salinization in very high-density olive orchards grown in southern Portugal.
6. **Ponheiro et al. (2019)** carried out a process-based analysis of the role of soil hydraulic properties on crop water use efficiency for some Brazilian scenarios.
7. **Kacimov et al. (2019)** revisited the Ovsinsky’s smart mulching-tillage technology via Gardner-Warrick’s unsaturated analytical model and HYDRUS to minimise evaporation by optimal layering of the topsoil.
8. **Mokari et al. (2019)** analyzed using numerical modeling the fate of nitrate in a flood-irrigated pecan orchard.
9. **Yang et al. (2019)** carried out a comprehensive assessment of salinity leaching efficiency in three soils using the HYDRUS-1D and -2D simulations.

10. **Chen et al. (in press)** evaluated the effects of biodegradable film mulching on soil water dynamics in a drip-irrigated field.
11. **Brunetti et al. (in press)** developed A Dynamic Plant Uptake module for the HYDRUS model for modeling the translocation and transformation of chemicals in the soil-plant continuum.
12. **Phogat et al. (in press)** carried out a comprehensive assessment of management of soil chemical changes associated with irrigation of protected crops.

II. ***Hydrological Applications***
1. **Beegum et al. (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).
2. **Brunetti et al. (2019)** 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.
3. **Sasidharan et al. (2019)** carried out numerical experiments using the HYDRUS (2D/3D) software to systematically study the influence of subsurface heterogeneity on drywell infiltration. Subsurface heterogeneity was described deterministically by defining soil layers or lenses, or by generating stochastic realizations of soil hydraulic properties with selected variance and horizontal and vertical correlation lengths.
4. **Liang et al.** (**2019)** developed physics-informed data-driven models to predict surface runoff water quantity and quality in agricultural fields.
5. **Ponheiro et al. (2019)** measured a full-range of soil hydraulic properties for the purpose of predicting crop water availability using gamma-ray attenuation and inverse modeling.
6. **Hansson et al. (2019)** studied the effects of soil compaction on root-zone hydrology and vegetation in boreal forest clearcuts.
7. **Xie et al. (2019)** evaluated experimentally and numerically the nitrate subsurface transport and losses in response to its initial distributions in sloped soils.
8. **Torkzaban et al. (in press)** modeled virus transport and removal during storage and recovery in heterogeneous aquifers.
9. **Kacimov et al. (in press)** developed analytical solutions for and then studied phreatic seepage flow through an earth dam with an impeding strip.
10. **Ali et al. (in press)** developed a pH based pedotransfer function for scaling saturated hydraulic conductivity reduction.

III. ***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. **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.

2. **Zhang et al. (2019)** evaluated a co-transport of multi-walled carbon nanotubes and sodium dodecylbenzenesulfonate in chemically heterogeneous porous media.
3. **Adrian et al. (in press)** studied the transport and retention of engineered silver nanoparticles in carbonate-rich sediments in the presence and absence of soil organic matter.

IV. ***Reviews***
1. Vereecken et al. (2019) provided an overview and outlook for land surface modelling with respect to infiltration from the pedon to global grid scales.
2. Jia et al. (in press) developed a benchmark involving soil organic matter degradation under variably-saturated flow conditions for comparing reactive transport models.

3. Impact Statement

The HYDRUS models are being constantly updated based on research carried out by the W3188 group. The HYDRUS 1D model was downloaded more than ten thousand times in 2019 and over forty 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 new capabilities to rigorously consider processes in the soil profiles with furrows (the Furrow module), to calculate cosmic ray neutron fluxes (the Cosmic module) and to simulate the translocation and transformation of chemicals in the soil plant continuum (A Dynamic Plant Uptake module).

Finally, in 2019 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) Indian Institute of Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, and d) the Sede Boker Campus of the Ben Gurion university, Israel. About 100 students participated in the short courses.

4. Publications (articles, books, book chapters, abstracts)8. Liang, J., W. Li, S. A. Bradford, and J. Šimůnek, Physics-informed data-driven models to predict surface runoff water quantity and quality in agricultural fields, *Water, 11*(2), 200, 21 p., doi: 10.3390/w11020200, 2019.

Peer-reviewed Journal Articles:

1. 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.
2. 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.
3. 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, doi: 10.1016/j.agwat.2018.11.024, 2019.
4. 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.

5. Sasidharan, S., S. A. Bradford, J. Šimůnek, and S. R. Kraemer, Drywell infiltration and hydraulic properties in heterogeneous soil profiles, *Journal of Hydrology*, *570*, 598-561, doi: 10.1016/j.jhydrol.2018.12.073, 2019.

6. Phogat, V., J. W. Cox, R. S. Kookana, J. Šimůnek, T. Pitt, and N. Fleming, Optimizing the riparian zone width near a stream for controlling lateral migration of irrigation water and solutes, *Journal of Hydrology*, *570*, 37-646, doi: 10.1016/j.jhydrol.2019.01.026, 2019.

7. 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 the inverse estimation of soil hydraulic properties, *Vadose Zone Journal*, *18*, 180123, 24 p., doi: 10.2136/vzj2018.06.0123, 2019.

8. Liang, J., W. Li, S. A. Bradford, and J. Šimůnek, Physics-informed data-driven models to predict surface runoff water quantity and quality in agricultural fields, *Water*, *11*(2), 200, 21 p., doi: 10.3390/w11020200, 2019.

9. Zhang, M., S. A. Bradford, J. Šimůnek, H. Vereecken, and E. Klumpp, Co-transport of multi-walled carbon nanotubes and sodium dodecylbenzenesulfonate in chemically heterogeneous porous media, *Environmental Pollution*, *247*, 907-916, doi: 10.1016/j.envpol.2019.01.106, 2019.

10. Pinheiro, E. A. R, Q. de Jong van Lier, L. Inforsato, and J. Šimůnek, Measuring full-range soil hydraulic properties for the prediction of crop water availability using gamma-ray attenuation and inverse modeling, *Agricultural Water Management*, *216*, 294-305, doi: 10.1016/j.agwat.2019.01.029, 2019.

11. Ramos, T. B., H. Darouich, J. Šimůnek, M. C. Gonçalves, and J. C. Martins, Soil salinization in very high-density olive orchards grown in southern Portugal: Current risks and possible trends, *Agricultural Water Management*, *217*, 265-281, doi: 10.1016/j.agwat.2019.02.047, 2019.

12. Pinheiro, E. A. R, Q. de Jong van Lier, and J. Šimůnek, The role of soil hydraulic properties in crop water use efficiency: A process-based analysis for some Brazilian scenarios, *Agricultural Systems*, *173*, 364-377, doi: 10.1016/j.agsy.2019.03.019, 2019.

13. 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*, *57*(3), 392-408, doi: 10.1111/gwat.12815, 2019.

14. Kacimov, A. R., Y. V. Obnosov, and J. Šimůnek, Minimal evaporation by optimal layering of topsoil: Revisiting Ovsinsky's smart mulching-tillage technology via Gardner-Warrick's unsaturated analytical model and HYDRUS, *Water Resources Research*, *55*, 3606-3618, doi: 10.1029/2018WR024025, 2019.

15. Vereecken, H., L. Weihermüller, S. Assouline, J. Šimůnek, A. Verhoef, M. Herbst, N. Archer, B. Mohanty, C. Montzka, J. Vanderborght, G. Balsamo, M. Bechtold, A. Boone, S. Chadburn, M. Cuntz, B. Decharme, A. Ducharne, M. Ek, S. Garrigues, K. Görgen, J. Ingewersen, S. Kollet, D. M. Lawrence, Q. Li, D. Or, S. Swenson, P. de Vrese, R. Walko, Y. Wu, and Y. Xue, Infiltration from the pedon to global grid scales: An overview and outlook for land surface modelling, *Vadose Zone Journal*, *18*(1), 18019, 53 p., doi: 10.2136/vzj2018.10.0191, 2019.

16. Mokari, E., M. Shukla, J. Šimůnek, and J. L. Fernandez, Numerical modeling of nitrate in a flood-irrigated pecan orchard, *Soil Science Society of America Journal*, *83*(3), 555-564, doi: 10.2136/sssaj2018.08.0302, 2019.

17. Hansson, L., J. Šimůnek, E. Ring, K. Bishop, and A. I. Gärdenäs, Soil compaction effects on root-zone hydrology and vegetation in boreal forest clearcuts, *Soil Science Society of America Journal*, *83*(Suppl. 1), S105-S115, doi: 10.2136/sssaj2018.08.0302, 2019.

18. Yang, T., J. Šimůnek, M. Mo, B. Mccullough-Sanden, H. Shahrokhnia, S. Cherchian, and L. Wu, Assessing salinity leaching efficiency in three soils by the HYDRUS-1D and -2D simulations, *Soil & Tillage Research*, *194*, 104342, 10 p., doi: 10.1016/j.still.2019.104342, 2019.
19. Xie, M., J. Šimůnek, Z. Zhang, P. Zhang, J. Xu, and Q. Lin, Nitrate subsurface transport and losses in response to its initial distributions in sloped soils: An experimental and modeling study, *Hydrological Processes*, 15 p., doi: 10.1002/hyp.13556, 2019.
20. Jia, M., D. Jacques, F. Gérard, D. Su, K. U. Mayer, and J. Šimůnek, A benchmark for soil organic matter degradation under variably-saturated flow conditions, *Computational Geosciences*, 19 p., doi: 10.1007/s10596-019-09862-3, (in press).
21. Torkzaban, S., M. Hocking, S. A. Bradford, S. S. Tazehkand, S. Sasidharan, and J. Šimůnek, Modeling virus transport and removal during storage and recovery in heterogeneous aquifers, *Journal of Hydrology*, *578*, 124082, 11 p., doi: 10.1016/j.jhydrol.2019.124082, (in press).
22. Adrian, Y. F., U. Schneidewind, S. A. Bradford, J. Šimůnek, E. Klumpp, and R. Azzam, Transport and retention of engineered silver nanoparticles in carbonate-rich sediments in the presence and absence of soil organic matter, *Environmental Pollution*, *255*, 113124, 11 p., doi: 10.1016/j.envpol.2019.113124 (in press).
23. Chen, N., X. Li, J. Šimůnek, H. Shi, Z. Ding, and Z. Peng, Evaluating the effects of biodegradable film mulching on soil water dynamics in a drip-irrigated field, *Agricultural Water Management*, *226*, 105788, 12 p., doi: 10.1016/j.agwat.2019.105788 (in press).
24. Brunetti, G., R. Kodešová, and J. Šimůnek, Modeling the translocation and transformation of chemicals in the soil-plant continuum: A Dynamic Plant Uptake module for the HYDRUS model, *Water Resources Research*, *55*, 23 p., doi: 10.1029/2019WR025432 (in press).
25. Kacimov, A. R., N. D. Yakimov, and J. Šimůnek, Phreatic seepage flow through an earth dam with an impeding strip, *Computational Geosciences*, 19 p., doi: 10.1007/s10596-019-09879-8, (in press).
26. Phogat, V., D. Mallants, J. W. Cox, J. Šimůnek, D. P. Oliver, and J. Awad, Management of soil chemical changes associated with irrigation of protected crops, *Agricultural Water Management*, *227*, 105845, doi: 10.1016/j.agwat.2019.105845 (in press).
27. Ali, A., A. J. W. Biggs, J. Šimůnek, and J. McL. Bennett, A pH based pedotransfer function for scaling saturated hydraulic conductivity reduction: Improved estimation of hydraulic dynamics in HYDRUS, *Vadose Zone Journal*, (in press).

Abstracts:

1. Bradford, S. A., S. Sasidharan, and J. Šimůnek, Fate of pathogens during managed aquifer recharge, *SSSA Annual Meeting*, San Diego, California, January 9-11, 2019.
2. 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, Abstract ID #115594, *SSSA Annual Meeting*, San Diego, California, January 9-11, 2019.
3. Sasidharan, S., S. A. Bradford, J. Šimůnek, and S. R. Kraemer, Influence of subsurface heterogeneity on drywell recharge, *SSSA Annual Meeting*, San Diego, California, January 9-11, 2019.
4. Pinheiro, E. A. R., Q. de Jong van Lier, and J. Šimůnek, A process-based approach to analyze the role of soil hydraulic properties in crop yield, *SSSA Annual Meeting*, San Diego, California, January 9-11, 2019.

5. Filipovic, V., J. Koestel, M. Larsbo, J. Šimůnek, L. Filipovic, and Davor Romic, Water balance estimation in ameliorated soil containing rock fragments: Connecting X Ray imaging and numerical modeling, *SSSA Annual Meeting*, San Diego, California, January 9-11, 2019.
6. Mokarighahroodi, E., M. Shukla, and J. Šimůnek, Modeling water and solute fluxes in a Pecan Orchard in Mesilla Valley, *SSSA Annual Meeting*, San Diego, California, January 9-11, 2019.
7. Glass, J., J. Šimůnek, C. Stefan, Integration of time-variable scaling factors in HYDRUS to simulate the reduction of hydraulic conductivity due to clogging during managed aquifer recharge operation, 10th International Symposium on Managed Aquifer Recharge (ISMAR10), Madrid, Spain, May 20-24, 2019.
8. Brunetti, G., and J. Šimůnek, The COSMIC module for HYDRUS-1D: Modifications of the HYDRUS-1D code to simulate Cosmic-Ray Neutron fluxes, *Geophysical Research Abstracts*, Vol. *21*, Abstract EGU2019-6798, Session HS1.1.3/SSS12.9 – Innovative methods for noninvasive monitoring of hydrological processes from field to catchment scale, EGU General Assembly 2019, Vienna, Austria, April 8-12, 2019.
9. Pinheiro, E., A. R., Q. de Jong van Lier, and J. Šimůnek, Process-based crop water availability and the role of soil hydraulic properties in crop water use efficiency, *Geophysical Research Abstracts*, Vol. *21*, Abstract EGU2019-3072, Session SSS11.5, Modelling of soil functions in agricultural systems, EGU General Assembly 2019, Vienna, Austria, April 8-12, 2019.
10. Baatz, R., J. Vanderborght, A. Verhoef, J. Šimůnek, M. van der Ploeg, D. Or, T. Gezzehei, U. Wollschläger, A.M. Tarquis, S. Painter, U. Mishra, M. Young, and H. Vereecken, The International Soil Modeling Consortium: ISMC status, goals and perspectives, *Geophysical Research Abstracts*, Vol. *21*, Abstract EGU2019-18964, Session HS8.3.3/AS4.8/ CL5.21/SSS13.24, Land surface and vadose zone process modeling – local and global challenges, EGU General Assembly 2019, Vienna, Austria, April 8-12, 2019.
11. Wang, Y., K. L. Bristow, and J. Šimůnek, A numerical analysis of the effects of Sprayable Biodegradable Polymer Membrane on soil water and thermal dynamics, *Geophysical Research Abstracts*, Vol. *21*, Abstract EGU2019-19106, SSS11.5 – Modelling of soil functions in agricultural systems, EGU General Assembly 2019, Vienna, Austria, April 8-12, 2019.
12. Saefuddin, R., H. Saito, and J. Šimůnek, Sustainable subsurface irrigation with ring-shaped emitter for small-scale farms in arid region, 3rd World Irrigation Forum, ICID, Bali, Indonesia, September 1-7, 2019.
13. Beegum, S., J. Vanderborght, M. Herbst, and J. Šimůnek, Simulation of the long-term evolution of pesticide concentrations in the Zwischenscholle aquifer using the coupled soil-groundwater model MODFLOW-HYDRUS-MT3DMS, Pesticide Symposium in Pesticide Chemistry "Environmental Risk Assessment and Management", Piacenza, Italy, September, 2019.
14. Šimůnek, J., and G. Brunetti, The use and abuse of numerical models in soil physics, vadose zone hydrology, and environmental sciences, Abstract ID #118748, *SSSA Annual Meeting*, San Antonio, Texas, November 10-13, 2019.
15. Filipović, V., H. H. Gerke, D. A. Robinson, J. Šimůnek, K. L. Bristow, and B. E. Clothier**,** Can we improve agricultural (environmental) management by using novel numerical modeling approaches? Abstract 129-7, *SSSA Annual Meeting*, San Antonio, Texas, November 10-13, 2019.
16. Yang, T., J. Šimůnek, M. Mo, H. Shahrokhnia, S. Cherchian, and L. Wu, Assessing salinity leaching efficiency in three soils by the HYDRUS-1D and -2D simulations, Abstract 43-6, *SSSA Annual Meeting*, San Antonio, Texas, November 10-13, 2019.

17. Sasidharan, S., S. Bradford, J. Šimůnek, and S. Kraemer, Evaluating the efficiency of drywell for enhanced aquifer recharge, Abstract 129-1, *SSSA Annual Meeting*, San Antonio, Texas, November 10-13, 2019.
18. Bradford, S., C. Shen, S. Sasidharan, J. Šimůnek, and S. Torkzaban, Optimized delivery of nanoparticles to enhance soil and groundwater remediation, Abstract 256-4, SSSA Annual Meeting, San Antonio, Texas, November 10-13, 2019.
19. Sasidharan, S., S. Bradford, and J. Šimůnek, Emerging environmental contamination from microplastics and nanoplastics, Abstract 287-6, *SSSA Annual Meeting*, San Antonio, Texas, November 10-13, 2019
20. Sasidharan, S., S. A. Bradford, J. Šimůnek, and S. R. Kraemer, Groundwater recharge and microbial water quality from drywells, Abstract ID#499074, AGU Fall Meeting 2019.
21. Tu, K., Q. Wu, C. Chen, J. Šimůnek, and K. Zhu, An analytical solution of the seepage field for single-well circulation (SWC) ground water heat pump systems (GWHPs), Abstract ID#510905, AGU Fall Meeting 2019.
22. Baatz, R., A. M. Tarquis, A. Verhoef, S. Painter, U. Mishra, J. Šimůnek, J. Vanderborght, U. Wollschläger, D. Or, M. van der Ploeg, M. Young, T. Ghezzehei, and H. Vereecken, The International Soil Modeling Consortium (ISMC) – New opportunities for advancing data and modeling of soil systems, Abstract ID#5586876AGU Fall Meeting 2019.
23. Araujo, J. B., J. Arthur, M. L. Brusseau, J. Šimůnek, and K. Dontsova, Integrative approach to assessing fate of munitions in the environment, Abstract ID#611684, AGU Fall Meeting 2019.
24. Al-Mayahi, A., S. Al-Ismaily, A. Al-Maktoumi, H. Al-Busaidi, A. Kacimov, R. Janke, J. Bouma, and J. Šimůnek, From nature to a novel irrigation system for home gardens in arid zone countries, 2nd International Water Conference on Water Resource in Arid Areas (WRAA 2020), Sultan Qaboos University, Oman, March 16-19, 2020.

Invited Presentations:
1. none

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.
2019-2021 USDA, ARS, Improved Irrigation Water Management for Water-Scarce Regions and Salt-Affected Lands, Co-PI: Dr. Todd Skaggs, 09/30/2019 - 12/31/2021, $96,000+$120,000.

University of California Riverside (Haghverdi Water Management Group)

A. What was accomplished under the project objectives?

A turfgrass field irrigation research trial was initiated in 2019 (a total of 48 research plots) at UC ANR SCREC in Irvine, California. Irrigation uniformity test was performed on the plots following the ANSI/ASABE S626 standard method which resulted in DULH and CU values of 0.85 and 85%, respectively. Twelve soil moisture threshold-based treatments were implemented centered around the field capacity of the soil. The field capacity of the soil for each treatment was estimated as the soil moisture in the root zone approximately 12 hours after a heavy rainfall. Two moisture level limits (lower and upper) are very critical in making irrigation decisions using the controller used in this study. The smart controller will trigger irrigation if the moisture level in the root zone drops below that lower limit level. If the moisture level exceeds the upper limit, the controller shuts off the irrigation valve. The recommended level is usually field capacity set as the upper limit and the 75% of field capacity soil moisture set as the lower limit.

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 (~5 in). ES-2 sensor (Meter Inc.) was used at a common irrigation inlet for continuous monitoring of recycled water salinity. Soil samples were collected before the start of the experiment from all the plots from depths 0-24 inches with 6-inch increments, and saturated paste extract soil salinity (ECe) was measured in the UCRWATER lab. Baseline infiltration data using SATURO infiltrometer (METER Group, Inc. USA) was also collected. Fluke 971 temperature and humidity meter and Fluke 64 max Infrared thermometer (Fluke Corporation, Everett, WA) were used to measure air temperature, humidity, and turf temperature respectively. GreenSeeker handheld crop sensor (Trimble Inc., Sunnyvale, CA) was used for NDVI measurements starting June 12, 2019. Handheld data collection was done weekly close to the solar noon on non-cloudy days. The reference evapotranspiration data was collected using CIMIS weather station near the experimental site.

The average daily EC of the irrigation water starting the month of June ranged from 0.92 up to 1.41 mS/cm with an average of 1.10 mS/cm. The soil salinity ranged from 0.78 ms/cm to 1.53 ms/cm before the start of the experiment. Water applied during the season varied between 54% to 90% of the potential ET. Given the 60% ET as the full irrigation for warm-season turf, a wide range of irrigation strategies were applied ranging from over-irrigation to full and deficit irrigation scenarios.

For a warm-season turf, the NDVI value of roughly 0.60 can be considered a good threshold where turfgrass quality is acceptable. The NDVI ranged from 0.43 to 0.74 among all treatments with an average of 0.36. The data will be statistically analyzed against the irrigation treatments and will be presented in the next report.

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

A two-day workshop was organized in 2019 at UCR consisting of hands-on training, lectures and a field tour. The workshop focused on autonomous urban irrigation management and the audience was 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 of page views per month and the twitter account currently has 188 followers.

D. What do you plan to do during the next reporting period to accomplish these goals?
Soil sample and infiltration data were collected on 10/14/2019, which is considered the end of the study for the first year and are currently being analyzed in the lab. Handheld data will be collected until the bermudagrass goes dormant in the winter season. After that, plots will be maintained at optimum irrigation levels until the start of the next year-round of data collection. Statistical analysis of the collected data will be performed to understand the effect of irrigation treatments on turf quality. Thermal data collected from the handheld sensors and the installed sensors at the plots will be analyzed to develop at temperature-based water stress index. The next round of soil sample collection and infiltration data will be performed in Spring 2020 after the rainfall season to understand how rainfall will influence the soil salinity distribution in the root zone.

E. Products

Extension Publications:

Wu, L*., Haghverdi, A. (2019). Assessment of Nitrogen and Salinity in Alternative Water Sources for Urban Landscape Irrigation. Soil Science Society of America International Soils Meeting, Jan 6-9, San Diego, California (oral presentation).

University of California Davis (Plant Sciences Department)

Accomplishments: (Objective 1)

A grape industry funded (AVF) project was continued 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. A total of over 25 MT's have been installed in grapevines, almonds, walnuts, and prunes. Some installations have remained functional for over 1 year, but tests are continuing to optimize installation methodology. The fifth year of an almond lysimeter project has been completed, indicating that Kc develops more quickly than previously thought for young almond orchards. MT's were also installed in the lysimeter and a nearby non-lysimeter tree, and these plan-based sensors showed that in this soil, trees are experiencing a rapid onset of water stress at the end of a 5 to 7 day irrigation cycle, even though tree ET is being supplied. Alternative irrigation approaches will be evaluated in 2020. The use of plant-based measurements (SWP) to improve walnut tree health by delaying the first irrigation in the spring was demonstrated for the sixth consecutive year in a commercial orchard on a deep, well-drained, sandy loam soil, and for the second consecutive year on a clay-loam soil. In both locations, the results have been dramatic. The start of irrigation is delayed on the order of 1 month, compared to matching ET, and in addition, the total applied water is about less than 50% of the calculated ET need, resulting in a savings of about 20" of water annually, with only positive impacts on tree health and appearance and no impact on tree yield. Two additional grower demonstration sites were also established in almond to use the same plant-based approach. 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 was submitted.

Training/Professional development:
Two MS students were trained.

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.

Publication (s):
Hou X, Matsumoto NJ, Matthews MA, Shackel K. 2019. Calibrating Spanner psychrometers for the effects of ambient temperature: theoretical and experimental considerations. Biosystems Engineering 183:85-94.

Florida

A. Target Audience
The target audience for this work are the scientific community, local farmers and other players in the citrus industry, such as processors and crop advisors.

B. Products
I. Referred Publications
BIZARI, D. R.; FERRAREZI, R.S. 2019. Biomass loss of corn mulching under no tillage system for irrigated common bean production. Irriga.
CARVALHO, S. A.; GIRARDI, E. A.; MOURÃO FILHO, F. A. A.; FERRAREZI, R. S.; COLETTA FILHO, H. D. 2019. Advances of citrus propagation in Brazil. Brazilian Journal of Fruticulture.
FERRAREZI, R.S.; RODRIGUEZ, K.; SHARP, D. 2019. How historical trends in Florida all-citrus production correlate with devastating hurricane and freeze events. Weather. DOI: https://doi.org/10.1002/wea.3512
FERRAREZI, R. S.; BAILEY, D. 2019. Basil performance evaluation in aquaponics. HortTechnology 29(1): 1-9. DOI: https://doi.org/10.21273/HORTTECH03797-17
DALA-PAULA, B. M.; PLOTTO, A.; BAI, J.; MANTHEY, J. A.; BALDWIN, E. A.; FERRAREZI, R. S.; GLÓRIA, M. B. A. 2019. Effect of Huanglongbing or greening disease on orange juice quality, a review. Frontiers in Plant Science 9(1976): 1-19. DOI: https://doi.org/10.3389/fpls.2018.01976

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. 2019. Magnesium deficiency affects secondary lignification of the vascular system in *Citrus sinensis* seedlings. Trees: Structure and Function 33(1): 171-182. DOI: https://doi.org/10.1007/s00468-018-1766-0

II. Technical Papers (Peer Reviewed)

FERRAREZI, R. S.; SCHIRARD, P.; BOURNIQUE, D.; HODGES G.; ROSSON, B. 2019. Evaluation of potential HLB-tolerant grapefruit rootstock/scion combinations in the Indian River. **River Ramblings** March newsletter. URL: http://ircitrusleague.org/wp-content/uploads/2019/03/IRCL-NL-3-19.pdf

III. Symposium and Conference Abstracts

KELLY-BEGAZO, C.A.; FERRAREZI, R.S.; COLE, D.C.; MUNROE, L.N. 2019. Agricultural worker safety day – A time for fun and games. **National Association County Agricultural Agents (NACAA)**, 2019 Annual Conference (Abstr.). Ft. Wayne/IN, United States.

FERRAREZI, R. S.; MEADOWS, T.; STEPHENS, J.; JAMES, T.H.; ECKMAN, M.; MACAN, N. P.; GROSSER, J. W.; ALFEREZ, F.; GAST, T. 2019. Accelerated production of citrus nursery liners using automated ebb-and-flow subirrigation. **American Society of Horticultural Science**, 2019 Annual Conference (Abstr.). Las Vegas/NV, United States.

PHUYAL, D.; MEADOWS, T.; FERRAREZI, R. S.; KADYAMPAKENI, D.; MORGAN, K. 2019. Tree density and micronutrient application on grapefruit affected by Huanglongbing. **American Society of Horticultural Science**, 2019 Annual Conference (Abstr.). Las Vegas/NV, United States.

FERRAREZI, R. S.; THOMASON, K. A.; RITENOUR, M. A.; WRIGHT, A. L. 2019. High-density grapefruit production in open hydroponics system. **American Society of Horticultural Science**, 2019 Annual Conference (Abstr.). Las Vegas/NV, United States.

DEMARD, E. P.; DOKER, I.; FERRAREZI, R. S.; QURESHI, J. A. 2019. Pest and predacious mite complex of Citrus Under Protective Screens (CUPS). **Florida Entomological Society**, 2019 Annual Meeting July 21-24, 2019 (Abstr.). Jupiter/FL, United States.

DEMARD, E. P.; FERRAREZI, R. S.; QURESHI, J. A. 2019. Abundance and distribution of the citrus rust mite (Phyllocoptruta oleivora) and the citrus red mite (*Panonychus citri*) in Citrus Under Protective Screens (CUPS). **TREC South Florida Graduate Research Symposium** (Abstr.). Homestead/FL, United States.

FERRAREZI, R. S.; HERNANDEZ, Y. V.; STEPHENS, J. 2019. Environmental parameters inside the citrus under protective screen system for fresh grapefruit production. **Florida Society of Horticultural Science**, 2019 Annual Conference (Abstr.). Maitland/FL, United States.

FERRAREZI, R. S.; PHUYAL, D.; MEADOWS, T.; MORGAN, K.; KADYAMPAKENI, D. 2019. Nutrient management on HLB-affected grapefruit on Flatwoods soil in the Indian River District. **Florida Society of Horticultural Science**, 2019 Annual Conference (Abstr.). Maitland/FL, United States.

FERRAREZI, R. S.; MACAN, N. P.; QURESHI, J. A.; RITENOUR, M. A.. 2019. Yield and fruit quality of 'Ray Ruby' grapefruit cultivated under protective screen. **Florida Society of Horticultural Science**, 2019 Annual Conference (Abstr.). Maitland/FL, United States.

FERRAREZI, R. S.; QURESHI, J. A. 2019. Citrus Under Protected Screen (CUPS) for grapefruit production in Florida's East Coast. **Sixth International Research Conference on Huanglongbing**, 2019 Annual Conference (Abstr.). Riverside/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.

IV. Extension Bulletins

CASTLE, W. S.; BOWMAN, K. D.; GROSSER, J. W.; FERRAREZI, R. S.; FUTCH, S. H.; S, ROGERS. 2019. Florida Citrus Rootstock Selection Guide, 4th Edition. **EDIS Publication**, UF/IFAS Extension, Horticultural Sciences Department, # SP248. URL: https://edis.ifas.ufl.edu/hs1260

FERRAREZI, R. S. 2019. Citrus Nursery Guide. Chapter 8: Stock Plant and Tree Production: b) Irrigation and Fertilization, **EDIS Publication**, UF/IFAS Extension, Horticultural Sciences Department, #HS1333. URL: https://edis.ifas.ufl.edu/hs1333

V. Extension/Outreach Presentations/Posters

Location	**Date**	**Organizer**	**Event**	**Title**
Fort Pierce, FL	September 16, 2019	UF/IFAS IRREC Ferrarezli Lab	UF/IFAS 4H	How to cultivate citrus potted trees?
Fort Pierce, FL	August 28, 2019	UF/IFAS IRREC	Center Seminar Series	Can advanced horticultural practices benefit the Indian River grapefruit industry?
Fort Myers, FL	August 14, 2019	Florida Grower magazine	2019 Florida Citrus Expo	Planting densities, fertilization methods and irrigation systems for sweet orange production in the Indian River District
Las Vegas, NV	July 23, 2019	ASHS	2019 ICON Workshop	"Don't gamble, travel with money – Funding for international collaboration": Latin America Collaboration Opportunities
Matland, FL	June 10, 2019	FSHS	2019 In-service training	"Agricultural Irrigation, Scheduling and Use of Soil Moisture Sensors": Basic concepts in irrigation management
Faro, Portugal	May 13, 2019	University of Algarve	2019 Academic trip with UF Gators Citrus Club	Strategies for maintaining Florida's citrus production under high HLB incidence
Fuzhou, China	April 19, 2019	Fruit Research Institution, FAAS	2019 Seminar Series (by invitation)	Strategies for maintaining Florida's citrus production under high HLB incidence
Nanning, China	April 24, 2019	Guangxi University	2019 Seminar Series (by invitation)	Strategies for maintaining Florida's citrus production under high HLB incidence
Fort Pierce,	Jan 25,	Florida	2019 Florida	Update on USDA Citrus Scion

FL	2019	Grower magazine and Ferrarezi Citrus Horticulture Lab	Citrus Show	Breeding
Fort Pierce, FL	Jan 25, 2019	Florida Grower magazine and Ferrarezi Citrus Horticulture Lab	2019 Florida Citrus Show	Upcoming variety trials at the Indian River
Fort Pierce, FL	Jan 23-25, 2019	Florida Grower magazine and Ferrarezi Citrus Horticulture Lab	2019 Florida Citrus Show	Welcome Message and Closing Remarks
Fort Pierce, FL	Jan 23, 2019	Indian River Citrus League	2019 Florida Citrus Show	River Cup Award Ceremony
Lake Alfred, FL	Oct 25, 2018	UF/IFAS Extension	Citrus nursery workshop	Alternative irrigation systems to accelerate citrus tree production
Lake Alfred, FL	Oct 25, 2018	UF/IFAS Extension	Citrus nursery workshop	Citrus Nursery Production Guide

C. What was accomplished under the project objectives?

Objective 1

"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 1

"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.

Objective 2
"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.

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

The Citrus Horticulture Laboratory team visited the CREC CUPS once in 2019, hosted several tours for growers and visitors. The masters student attended a special course in root biology sponsored by the project.

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

The Ferrarezi Lab organized the 2019 Florida Citrus Show to bring new information to more than 800 local growers. We prepared publications for citrus trade journals (Citrus Industry Magazine) and the UF/IFAS Citrus Production Guide. Abstracts were also presented in scientific conferences.

F. Changes/Problems
N/A

Idaho

Accomplishments

1. An experimental soil water sensor with wireless transmission to cloud storage and internet access, and a commercially available soil water sensor that I have used for several years

(Decagon 10HS) were both tested over multiple wetting / drying cycles in a controlled laboratory environment for 3 of the most common soil textures in Southern Idaho Irrigated areas: silt loam, sandy loam and clay loam. Sensor readings were correlated with measured soil water content to give a calibration curve for each soil.

2. For equal center pivot application rates, water delivered to a bare soil surface beneath LESA sprinkler varied from 1.2 (low wind conditions) to nearly 2 (high wind conditions) times that under the adjacent MESA sprinklers. Preliminary results indicate about 0.1 inch of irrigation water intercepted by the crop and then evaporated from the leaf surface for irrigation events in mid-season with full crop canopy. Additional work will be done next year to better define these results.

Impacts

1. Soil-texture-specific calibration curves will allow growers to manage irrigation timing and amount with more confidence because of better understanding of actual soil moisture status with depth. This allows growers to maximize crop yield and quality with while minimizing irrigation cost, energy use, water applied and potential impact of water-soluble crop nutrients and ag-chemicals on surface and ground water quality.
2. Reduction in water loss due to evaporation of water droplets as they fall to the crop canopy and reduction of evaporation losses from the crop canopy by conversion of center pivot sprinklers from MESA to in-canopy LESA sprinkler mounting height will help “stretch “limited surface or ground water resources.

Kansas

Objectives:

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

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

(3) Develop technology transfer products for a diversity of stakeholders to promote adoption of microirrigation.

Accomplishments:

Impacts:

Continued adoption of subsurface drip irrigation (SDI) has occurred in Kansas and neighboring Great Plains states with a five-year increase in land area of 18, 82, and 17 percent for Kansas, Nebraska, and Texas, respectively according to USDA-NASS data.

SDI system longevity of greater than 25 years was demonstrated by a system at KSU-NWREC.

SDI economics fluctuate considerably with crop prices and KSU has annually provided an updated template to compare SDI to center pivot sprinkler irrigation.

Simplified equations to size SDI flushlines were developed enabling designers to determine sizes more easily.

What was accomplished under these Objectives?

SDI system uniformity after 26 years of usage was within 5 percent of the original value for 23 zones in a research SDI system. This information indicates that system life can be long allowing for longer amortization of system costs.

Studies to develop mobile drip irrigation (MDI) technologies where driplines are attached to moving center pivot laterals were conducted and published.
A comprehensive review of SDI usage for corn, cotton, tomato and onion was published concentrating on irrigation system comparisons, water and/or nutrient management, and SDI system design criteria.
Simple empirical equations with different numbers of required parameters were developed to determine SDI flushline diameter from design parameters that are readily available near the beginning of the design process. Although the equations developed are approximations of the full Hazen-Williams calculation, they tend to self-regulate their accuracy over the range of practical design limitations.
The 2019 National Soil Moisture Workshop was held from 22-24 May at KSU in Manhattan, KS. The theme of this year was: "Expanding the Frontiers of Soil Moisture Measurements and Applications". Link to workshop: https://soilwater.ksu.edu/nsmw2019
Tests were conducted with biodegradable polymers to identify rates need to minimizes the cumulative evaporative rate from the soil.
Regional conference proceedings papers provided answers for frequently asked questions about SDI and also about the basic design considerations. Extensive additions were made to the K-State SDI in the Great Plains website in the 5-year life of the project.

What opportunities for training and professional development has the project provided?
Undergraduate students had the opportunity to get exposure to field research in this project. Additionally, there was graduate student training with mobile drip irrigation at the KSU SWREC at Garden City, Kansas. On-site training in Kansas was provided for 14 individuals from Pakistan in 2015 and 10 individuals from Italy in 2017.

How have the results been disseminated to communities of interest??
Results have been disseminated through various venues such as field days at the local level, regional meetings such as the annual Central Plains Irrigation Conference, international meetings such as the American Society of Agricultural and Biological Engineers and the Irrigation Association and through various journal articles and conference proceedings. In addition, during the life of the project there was international travel and reporting of project activities in Argentina, China (twice), Germany and Mexico. Kansas has an extensive website, SDI in the Great Plains which is continually updated.

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

Aguilar, J.P., D. Rogers, B. Golden, D. Devlin. Evaluating Mobile Drip Irrigation in Water Technology Farms: CIG Showcase Poster Session. In: Proc. Soil and Water Conservation Society Annual Meeting, Pittsburgh, PA July 28-31, 2019.
Aguilar, J., Oker, T. and Kisekka, I., 2019. Mobile Drip Irrigation for Water Limited Crop Production: Initial Results. Kansas Agricultural Experiment Station Research Reports, 5(7), p.13.
Haacker, E.M.K., V.Sharda, A.M. Cano, R.A. Hrozencik, A. Nunez, Z. Zambreski, S. Nozari, G.E.B. Smith, L. Moore, S. Sharma, P. Gowda, C. Ray, M. Schipanski, R. Waskom. 2019. Transition Pathways to Sustainable Agricultural Water Management: A Review of Integrated Modeling Approaches. JAWRA 55: 6-23.
Lamm, F. R. 2019. Advances in SDI fertigation for corn. In: Proc. 31st annual Central Plains Irrigation Conference, Feb. 26-27, 2019, Kearney, Nebraska. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 108-121.
Oker, T.E., Kisekka, I., Sheshukov, A.Y., Aguilar, J. and Rogers, D., 2019. Evaluation of dynamic uniformity and application efficiency of mobile drip irrigation. Irrigation Science, pp. 1-19.
Rogers, D.H., J. Aguilar, V. Sharda. 2019. Kansas Center Pivot Uniformity Evaluation Overview. Applied Engineering in Agriculture (in press).
Shelia, V., J. Hansen, V. Sharda, C. Porter, P. Aggarwal, C. J. Wilkerson and G. Hoogenboom. 2019. A multi-scale and multi-model gridded framework for forecasting crop production, risk analysis, and climate change impact studies. Environmental Modelling & Software 115:144-154
Sharda, V., P.H. Gowda, G. Marek, I. Kisekka, C.Ray, and P. Adhikari. 2019. Simulating the Impacts of Irrigation Levels on Soybean Production in Texas High Plains to Manage Diminishing Groundwater Levels. JAWRA 55: 56-69

New Mexico

Short-term Outcomes:

A low cost datalogger was developed for recording soil moisture and soil temperature data, and is currently in use in the experimental farm.

Outputs:

- *Mokari E., *J. Fernandez, M.K. Shukla and J. Simunek. 2019. Modeling water and solute fluxes in a Pecan Orchard. Soil Science Society of America Journal. doi:10.2136/sssaj2018.11.0442
- *Yang H, M. K. Shukla, X. Mao, K. Shaozhong, and T. Du. 2019. Interactive regimes of reduced irrigation and salt stress depressed tomato water use efficiency at leaf and plant scales by affecting leaf physiology and stem sap flow. Frontiers in Plant Science. https://doi.org/10.3389/fpls.2019.00160
- *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.
- Ghimire, R., Ghimire, B., Mesbah, A., Idowu, O. J., O'Neill, M. K., Angadi, S., and Shukla M.K. (2018). Current status, opportunities, and challenges of cover cropping for sustainable dryland farming in the Southern Great Plains. *Journal of Crop Improvement, 32*, 579-598,

Presentations

- 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.
- Ben Ali, A. R., M. K. Shukla, B. J. Schutte, and C. Gard. 2019. Irrigation with RO concentrate, and brackish groundwater impacts on pecan trees growth and physiology. *Basin Water Management — Challenges in Water Management at the Basin Scale*. USCID's 12th International Conference Nov. 5-8, Reno.
- Shukla M.K. 2019. Use of brackish water and concentrate for agriculture in arid areas. 2nd annual WIN workshop, BGNDRF, Alamogordo, Oct. 28-29.
- Shukla M.K. 2019. Irrigation with Brackish groundwater and RO. CAU, China.
- Shukla M.K. 2019. Salt tolerant crops. Two Nation One Water Conference, WRRI, Las Cruces.
- Shukla M.K. 2019. Irrigation scheduling. EBID workshop with growers, Las Cruces.
- Shukla M.K. 2018. Sustainable management of soil water. China Agriculture University, June 2018.

Activities: Organized and specific functions or duties carried out by individuals or teams using scientific methods to reveal new knowledge and develop new understanding.
Field and laboratory experiments were designed for using brackish groundwater and reverse osmosis concentrate for irrigating glycophytes and halophytes. These experiments provided new and further insight in to the ion uptake patterns, physiology, salt tolerance, and potential for use in arid saline environment.

Milestones:
Key intermediate targets necessary for achieving and/or delivering the outputs of a project, within an agreed timeframe. Milestones are useful for managing complex projects. For example, a milestone for a biotechnology project might be "To reduce our genetic transformation procedures to practice by December 2004."
Datalogger design was completed and field testing in progress.
Baseline dataset for the microbial diversity and halophytic hits developed.
Irrigation and nutrient scheduling protocol for Pecan orchards suggested.

Publications:

For SAES-422 reports list the publications for **current** year only (with the authors, title, journal series, etc.). If the list exceeds the maximum character limit below, an attachment file may be used.

*Mokari E., *J. Fernandez, M.K. Shukla and J. Simunek. 2019. Modeling water and solute fluxes in a Pecan Orchard. Soil Science Society of America Journal. doi:10.2136/sssaj2018.11.0442
*Yang H, M. K. Shukla, X. Mao, K. Shaozhong, and T. Du. 2019. Interactive regimes of reduced irrigation and salt stress depressed tomato water use efficiency at leaf and plant scales by affecting leaf physiology and stem sap flow. Frontiers in Plant Science. https://doi.org/10.3389/fpls.2019.00160
*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.

Ghimire, R., Ghimire, B., Mesbah, A., Idowu, O. J., O'Neill, M. K., Angadi, S., and Shukla M.K. (2018). Current status, opportunities, and challenges of cover cropping for sustainable dryland farming in the Southern Great Plains. *Journal of Crop Improvement, 32*, 579-598,

Presentations

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.

Ben Ali, A. R., M. K. Shukla, B. J. Schutte, and C. Gard. 2019. Irrigation with RO concentrate, and brackish groundwater impacts on pecan trees growth and physiology. *Basin Water Management — Challenges in Water Management at the Basin Scale.* USCID's 12th International Conference Nov. 5-8, Reno.

Shukla M.K. 2019. Use of brackish water and concentrate for agriculture in arid areas. 2nd annual WIN workshop, BGNDRF, Alamogordo, Oct. 28-29.

Shukla M.K. 2019. Irrigation with Brackish groundwater and RO. CAU, China.

Shukla M.K. 2019. Salt tolerant crops. Two Nation One Water Conference, WRRI, Las Cruces.

Shukla M.K. 2019. Irrigation scheduling. EBID workshop with growers, Las Cruces.

Shukla M.K. 2018. Sustainable management of soil water. China Agriculture University, June 2018.

Funding

1. USDA Hatch grant
2. Nakayama Chair Endowment
3. WRRI-BOR Cooperation grants
4. BOR S&T grant
5. Cochran Grant

Oklahoma

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

Our efforts on promoting sensor-based technologies to improve irrigation scheduling continued during the reporting period. As part of these efforts, canopy temperature and soil moisture sensors were installed at 11 research and demonstration sites across central and western Oklahoma, under cotton, peanut, and chili pepper. Several of the instrumented cotton fields were under subsurface drip irrigation (SDI) system. The canopy temperature technology evaluated during the reporting period was a new wireless technology developed by an Australian Company in collaboration with researchers from USDA-ARS. Our team partnered with this company, ARS scientists, and the Cotton Incorporated to assess the performance of this technology for scheduling cotton irrigation.

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. Please see outputs below.

Peer-reviewed Papers:

1. Masasi B, Taghvaeian S, Gowda P, Warren J, Marek G (2019) Simulating soil water content, evapotranspiration and yield of variably irrigated grain sorghum using AquaCrop. Journal of the American Water Resources Association, 55(3): 18. https://doi.org/10.1111/1752-1688.12757

Magazine Articles:

1. Taghvaeian S (2019) Making sense out of soil moisture sensors. Irrigation Today, 4(1): 14-18. Available online at: http://www.modernpubsonline.com/0A406ys/ITSummer2019/index.html

Presentations:

1. Taghvaeian S (2019) Irrigation management of peanut and cotton. Caddo Research Station Field Day. Sep. 11, 2019; Fort Cobb, OK.
2. Mehata M, Taghvaeian S, Datta S, Moriasi D (2019) Modeling soil moisture dynamics to improve irrigation management. University of Oklahoma International WaTER Conference. Sep. 16-17, 2019; Norman, OK.
3. Datta S, Taghvaeian S, Mehata M, Moriasi D (2019) Irrigation water fluxes in an agricultural watershed in Central Oklahoma. American Society of Agricultural and Biological Engineers Annual International Meeting. Jul. 7-10, 2019; Boston, MA.
4. Mehata M, Taghvaeian S, Datta S, Moriasi D (2019) Simulating soil moisture fluctuations under irrigated crops using HYDRUS model. American Society of Agricultural and Biological Engineers Annual International Meeting. Jul. 7-10, 2019; Boston, MA.
5. Taghvaeian S, Stivers J, Boman R (2019) Impacts of variable irrigation regimes on cotton yield and fiber quality. UCOWR/NIWR Annual Water Resources Conference. Jun. 11-13, 2019; Snowbird, UT.
6. Taghvaeian S, Masasi B (2019) Simulating cotton yield under variable irrigation management scenarios. World Environmental & Water Resources Congress. May 19-23, 2019; Pittsburgh, PA.
7. Taghvaeian S, Masasi B (2019) Response of irrigated sorghum to planting date and density. Oklahoma Irrigation Conference. Feb. 28, 2019; Goodwell, OK.
8. Datta S, Taghvaeian S, Mehata M, Moriasi D (2018) Irrigation water fluxes in the Fort Cobb Reservoir Experimental Watershed. 39th Annual Oklahoma Governor's Water Conference & Research Symposium. Dec. 5-6, 2018; Midwest City, OK.
9. Mehata M, Taghvaeian S, Datta S, Moriasi D (2018) Use of a computer model to simulate soil moisture content in irrigated fields. 39th Annual Oklahoma Governor's Water Conference & Research Symposium. Dec. 5-6, 2018; Midwest City, OK.
10. Sharma S, Warren JG, Taghvaeian S (2018) Canopy temperature, soil moisture and crop water stress index in corn. 39th Annual Oklahoma Governor's Water Conference & Research Symposium. Dec. 5-6, 2018; Midwest City, OK.

11. Sharma S, Warren JG, Taghvaeian S (2018) Irrigation strategies for corn and sorghum under reduced well capacity. Annual ASA-CSSA International Meeting. Nov. 4-7, 2018; Baltimore, MR.

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.

USDA-ARS Texas

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. Two seasons of grain corn and two seasons of grain sorghum production showed consistently smaller ET for SDI compared with MESA, ranging from 138 to 151 mm (5.4 to 5.9 inch) per corn season and from 50 to 112 mm per short-season sorghum season (Evett et al., 2019a). Corn was grown in 2018 and soybean was grown in 2019 after cotton failure. Current work focuses 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 2019, continuing multi-state field trials that began in 2016. At Bushland in 2019, the ISSCADA system was applied to variable rate irrigation (VRI) management of potato and sorghum. Irrigation management of drought tolerant corn using this system was reported by O'Shaughnessy et al. (2019) and by Stone et al. (2019). Its use to manage cotton irrigation was reported by Vories et al. (2019).

The team continued cooperation with Acclima, Inc. and ARS 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 inexpensive (~$185 US), solar powered node collected data from up to seven sensors using the SDI-12 wired data protocol and transmitted the data over distances exceeding 300 m to the gateway (~$225 US) where the data were stored prior to upload to the Internet

Cloud over the cellular telephone network. Reports on the system were given at an International Atomic Energy Agency (IAEA) meeting in October and the Irrigation Association meeting in December 2019 as well as to the U.S. Forest Service. These studies are coordinated with the International Atomic Energy Agency (IAEA), the U.S. Forest Service and the International Centre for Agricultural Research in the Dry Areas (ICARDA). The reports to the U.S. Forest Service, the IAEA and the 2019 Irrigation Show showed how the node and gateway system provided up-to-the-hour soil water data from locations in the Middle East, the U.S. Southeast, and Texas (Evett et al., 2019c,d,e). The team is also working with a World Bank team in Uzbekistan to use the system for cotton irrigation management.

Recently, the team has integrated an SDI-12 infrared thermometer (IRT) into the system and is demonstrating how soil and plant surface temperatures can be sensed along with soil water content and temperature at various depths. This will allow integration of the crop water stress index (CWSI) approach with the soil water approach to irrigation scheduling in a relatively low cost system. The team also contributed to understanding of how "true-TDR" soil water sensor data from the field can be understood in the context of contradictory laboratory-determined field capacity and wilting point values (Evett et al., 2019b).

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. In 2019 based on these QA/QC procedures, the team provided the AgMIP maize modeling team with two seasons of corn data (2013 and 2016) and three seasons of winter wheat data (1989-1990, 1991-1992, 1992-1993). The AgMIP teams are focusing on how well the maize and wheat models simulate reference or potential evapotranspiration. The intention is to improve these models so that it becomes more feasible to use them in decision support.

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

USDA-ARS Texas

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.
The new drip tape was installed at a uniform depth (0.30 m) and uniform lateral spacing (1.52 m) in very dry soil. Winter wheat was planted in September 2018, irrigated uniformly (i.e., no experimental treatments), and harvested in June 2019. Grain yield was ~5.5 Mg ha^{-1}.
Water needs for emergence and early development in the fall and early winter of 2018 were mainly met by irrigation (~200 mm) because little precipitation occurred. However, most water needs from booting to maturity were met by precipitation, but some irrigation (~50 mm) was required when the crop came out of dormancy during March 2019.

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

USDA-ARS Texas
Crop water use efficiency benefits of SDI were explained in a peer-reviewed publication (Evett et al., 2019a) and in presentations in Colby, KS; Las Vegas, NV; and elsewhere.

B. What opportunities for training and professional development has the project provided?
Three students and five adult professionals were trained to install and read soil water sensing systems and to do data analysis.
C. How have the results been disseminated to communities of interest?

USDA-ARS Texas
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. In addition, results have been disseminated through technology transfer to manufacturers who sell the resulting products to the public.

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

USDA-ARS Texas
We will continue field experiments described in the Accomplishments section. The artificial intelligence system for predicting future crop water stress index, soil water depletion, 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
Peer Reviewed Publications
Evett, S.R., D.K. Brauer, P.D. Colaizzi, J.A. Tolk, G.W. Marek and S.A. O'Shaughnessy. 2019a. Corn and sorghum ET, E, Yield and CWP as affected by irrigation application method: SDI

versus mid-elevation spray irrigation. Trans. ASABE 62(5):1377-1393. https://doi.org/10.13031/trans.13314

Evett, S.R., K.C. Stone, R.C. Schwartz, S.A. O'Shaughnessy, P.D. Colaizzi, S.K. Anderson and D.J. Anderson. 2019b. Resolving discrepancies between laboratory-determined field capacity values and field water content observations: Implications for irrigation management. Irrig. Sci. https://doi.org/10.1007/s00271-019-00644-4

O'Shaughnessy, S.A., M. Kim, M.A. Andrade, P.D. Colaizzi and S.R. Evett. 2019. Response of drought tolerant corn to varying irrigation levels in the Texas High Plains. Trans. ASABE 62(5):1365-1375. https://doi.org/10.13031/trans.13234. 2019.

Symposium and Conference Proceedings Papers (Non-Peer Reviewed)

Evett, S.R., K. Prussian and A. Holt. 2019c. Watershed Restoration and Monitoring Workshop Report. U.S. Forest Service report.

Evett, S., R. Schwartz, S. Strohmeier, M. Haddad and H. Schomberg. 2019d. Increasing Utility of True TDR Soil Water Sensing Systems, Third Research Coordination Meeting of the IAEA Coordinated Research Project D1.50.17, October 14-17, 2019, Vienna, Austria

Evett, S., S. Strohmeier, M. Haddad, H. Schomberg, S. O'Shaughnessy, and A. Thompson. 2019e. Soil water sensing from afar: How the Cloud is enabling remote data collection. 2019 Irrigation Show, Dec. 2-6, Las Vegas, NV, USA.

O'Shaughnessy, S.A., M.A. Andrade, P.D. Colaizzi and S.R. Evett. Using sensor feedback with variable rate irrigation. 2019 Irrigation Show, Dec. 2-6, Las Vegas, NV, USA.

Stone, K., P. Bauer, S. O'Shaughnessy, M. Andrade and S. Evett. 2019. A variable rate irrigation decision support system for corn in the US eastern coastal plain. Pp. 673-679 In: Stafford, J.V. (ed.) Precision agriculture '19 - Proceedings 12th European Conference on Precision Agriculture, July 8-11, 2019. Montpellier, France. 2019. Wageningen Academic Publishers, Netherlands. eISBN: 978-90-8686-888-9 | ISBN: 978-90-8686-337-2 https://doi.org/10.3920/978-90-8686-888-9_83.

Vories, E., S. O'Shaughnessy and M. Andrade. 2019. Comparison of precision and conventional irrigation management of cotton. Pp. 695-702In: Stafford, J.V. (ed.) Precision agriculture '19 – Proceedings 12th European Conference on Precision Agriculture, July 8-11, 2019. Montpellier, France. 2019. Wageningen Academic Publishers, Netherlands. eISBN: 978-90-8686-888-9 | ISBN: 978-90-8686-337-2 https://doi.org/10.3920/978-90-8686-888-9_86

Symposium and Conference Abstracts

Andrade, M.A., S.R. Evett, Q. Xue, and G.W. Marek. 2019. Software for quality control of weighing lysimeter evapotranspiration data. 2019 ASA-CSSA-SSSA International Annual Meeting, San Antonio, TX.

Colaizzi, P.D., F.R. Lamm, and J.P. Bordovsky. 2019. Comparison of SDI and alternative irrigation systems for cotton, grain sorghum, and soybean. Presented at the SDI Field Day, Colby, KS.

Evett, S., P. Colaizzi, G. Marek, J. Moorhead, D. Brauer, K. Copeland, and B. Ruthardt. 2019f. Subsurface drip irrigation (SDI) compared with mid elevation spray application (MESA) for corn. Presented at the SDI Field Day, Colby, KS, August 2019.

Evett, S., S. Strohmeier, M. Haddad, H. Schomberg, A. Thompson, and J. Anderson. 2019g. Watershed moisture sensing in Jordan: Water in the Cloud. Presented at the 2019 National Soil Moisture Workshop, Manhattan, KS, May 16, 2019.

Evett, S., and R. Schwartz. 2019h. Soil water measurement and sensing. Presented at the Watershed Restoration and Monitoring Workshop, Amman, Jordan, May 5-7, 2019, ICARDA, WADI, USFS, USDA-ARS.
Evett, S., S. O'Shaughnessy, A. Andrade, and R. Schwartz. 2019i. Some research at Bushland, Texas and elsewhere. Presented to USDA-ARS, Florence, SC, March 19, 2019.
Schomberg, H., A. Thompson, S. Evett, C. Reberg-Horton, and S. Mirsky. Gateway-node network for on-farm soil water measurement. 2019 National Soil Moisture Workshop, Manhattan, KS, May 16, 2019.

Impact Statements

A decision support system for variable rate irrigation (VRI) center pivot systems developed by scientists at the USDA ARS Conservation & Production Research Laboratory, Bushland, TX, was beta tested from 2016 through 2019 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. The patent has been licensed for commercialization by Valmont Industries, Inc.

Soil water sensing can be effective for irrigation scheduling only if the data are available to the farmer easily and with a minimum of labor. A team of scientists and engineers from the USDA ARS at Bushland, TX, and at Beltsville, MD, worked with Acclima, Inc. through a Cooperative Research And Development Agreement (CRADA) to develop and make commercially available a node and gateway system for automatic, unattended wireless transmission of soil water sensor data from the field to the Internet Cloud. USDA ARS at Bushland has developed an app that allows a user to easily download the data from the Cloud. The system is manufactured for USDA ARS and used from Alaska to the Southeastern USA as well as in Jordan and Uzbekistan. A fully commercial system is expected to be for sale at the end of the first quarter 2020.

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

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 (patents 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, Bushland and Dalhart, Texas. On-Farm Producer/Cooperator Locations: Decagon/METER GS1 sensors continued to be used through the 2019 crop season, and data were accessed 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. After some sensors and telemetry systems were destroyed by field operations at the Canyon/Bushland site during the winter (2017-2018), some of the GS1 sensors were replaced with WaterMark™ sensors, allowing evaluation of the lower cost sensors with the AgSense telemetry units. Soil moisture and weather data (from on-site weather stations) were made available via a password protected Internet website to the cooperators, research team and interested USDA-NRCS staff, with permission from the cooperators. With continued positive feedback and funding support from Texas Corn Producers Board, this work will continue through the 2020 crop season. Because of some producer negative feedback about reliability issues with some sensors and the telemetry system, and in light of promising early results from related work, we plan to expand use of the WaterMark™, sensors, most likely with the Trellis telemetry system (or similarly compatible system) in this planned future on-farm work.

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

A microirrigation controller (patent pending) has been developed to automate irrigation applications (timing, rates, start/stop times, etc.). The system optimizes irrigation allocations and start/stop times to multiple zones in complex irrigation systems to minimize the total irrigation time. Pressure, flow and safety constraints are built into the system, which can accommodate a relatively large number of irrigation zones for microirrigation or other fixed zone irrigation systems.

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 continued to be 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 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. Users include agricultural producers, crop consultants, agribusiness, research and other professionals.

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). These and other technology transfer activities are included below.

Educational Activities

Seminars, workshops similar education events

Porter, Dana. 2019. Irrigation Management for Horticulture. County Agent Training Webinar. Lubbock, TX. June 17, 2019.

Porter, Dana. 2019. Irrigation Management for Texas High Plains Cotton Production. County Agent Training Workshop. Plainview, TX. August 29, 2019.

Porter, Dana. 2019. Irrigation Management for Texas High Plains Corn and Small Grains Production. County Agent Training Workshop. Amarillo, TX. September 4, 2019.

Porter, Dana. 2019. Irrigation Scheduling Tools and Approaches. Irrigation Management and Technology Workshop. San Benito, TX. Sept. 25, 2019.

Porter, Dana. 2019. Irrigation Scheduling Tools and Approaches. Irrigation Management and Technology Workshop. Edinburg, TX. Sept. 26, 2019.

Papers and presentations

Porter, Dana. 2019. Irrigation technologies and management strategies. Invited presentation for Region O (Llano Estacado) Regional Water Planning Group, Lubbock, TX. February 20, 2019.

Yang, Yanxiang, Jiang Hu, Dana Porter, Thomas Marek, Hongxin Kong and Lijia Sun. 2019. Deep Reinforcement Learning Control and Smart Scheduling for Micro-irrigation. Technical paper for ASABE Annual International Meeting, Boston, MA. July 7-11, 2019. *Submitted to Transactions of the ASABE. August 2019.*

Presentations at Extension meetings

Porter, Dana. 2019. Irrigation Update for the Texas Southern High Plains. Southern Mesa Ag. Conference, Lamesa, TX. January 15, 2019.

Porter, Dana. 2019. Irrigation management for cotton production. Northwest Panhandle Cotton Conference. Dalhart, TX. January 23, 2019.

Porter, Dana. 2019. Soil and Water Relationships. Top of Texas Cotton Conference. Pampa, TX. January 28, 2019.

Porter, Dana. 2019. Soil and Water Relationships. Northeast Panhandle Cotton Conference. Spearman, TX. February 1, 2019.

Porter, Dana. 2019. Irrigation technologies and management. Crop Consultants Meeting, Dimmitt, TX. Feb. 25, 2019.

Porter, Dana. 2019. Irrigation and Salinity Management with Lagoon Effluent. Dairy Outreach Program Area Meeting. Stephenville, TX. April 9, 2019.

Porter, Dana. 2019. Irrigation Management for Texas High Plains Hemp Production. Dawson County Field Day, Lamesa, TX. September 17, 2019.

Impacts

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 well over 500,000 acres (increase from an estimated 20,000 acres statewide in 2000 to estimated 700,000 statewide in 2019). 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.

Publications

Refereed journal articles

Chen, Yong, Gary W. Marek, Thomas H. Marek, Kevin R. Heflin, Dana O. Porter, Jerry E. Moorehead, and David K. Brauer. 2019. Soil Water Sensor Performance and Corrections with Multiple Installation Orientations and Depths under Three Agricultural Irrigation Treatments. Sensors 2019, 19(13), 2872; https://doi.org/10.3390/s19132872

Gaffney, Jim, Ignacio Ciampitti, John Sawyer, Tony Vyn, James Bing, Kenneth Cassman, Deborah Delmer, Jeffrey Habben, Jeff Schussler, David Warner, Patrick Byrne, Tim Setter, Robert Sharp, Honor Lafitte, Ulrika Lidstrom, Dana Porter. 2019. Science-based intensive agriculture: Sustainability, food security, and the role of technology. Global Food Security 23:236-244. Elsevier. ISSN: 22119124.

Acknowledgements and Considerations

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Prairie View A&M University

Accomplishments

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

Study 1: Improving Irrigation Scheduling Tools

We improved web-based irrigation scheduling tool **IrrigWise** and the Android app **WeatherAndSoil**. IrrigWise uses several databases including USDA-NRCS's Soil Survey Geographic Database, rainfall, and evapotranspiration data from multiple weather networks across Texas, and forecasted weather data for five consecutive days from the National Weather Service. **IrrigWise-PRISM** extended the use of daily gridded climate data, PRISM (Parameter elevation Regression on Independent Slopes Model), which is available at 30-arcsec (800 meters) and 2.5 arcmin (4 km) resolution across the US. The tool with extended capability in incorporating PRISM data allows IrrigWise-PRISM to establish irrigation scheduling programs across the US for any crop grown in a specific location and during a particular growing season. The tool allows the user to modify crop and soil-related default parameters to fit specific needs. The tool tracks the daily status of the different soil water budget components including irrigation amount and near real-time weather data. The tool provides the user information on when and for how long to irrigate. The tool also predicts the change in soil water content of the selected field during the five consecutive days based on forecasted weather data and crop water uptakes. The wide use of the tool by the farming and urban communities could help increase irrigation water use efficiency of agricultural crops and urban landscape in the U.S. We also improved **Irrigation Water Estimator for Texas (IWET)**. IWET is a web-based tool for crop and urban landscape irrigation water requirement calculation. All these tools are available on the website: http://irrigwise.pvamu.edu/introduction/index.php.

Study 2: Optimum Turf Grass Irrigation Requirements and Corresponding Water-Energy-CO_2 Nexus across Harris County, Texas

Harris County is one of the most populated counties in the United States. About 30% of domestic water use in the U.S. is for outdoor activities, especially landscape irrigation and gardening. Optimum landscape and garden irrigation contributes to substantial water and energy savings and a substantial reduction of CO_2 emissions into the atmosphere. Thus, the objectives of this work are to (i) calculate site-specific turf grass irrigation water requirements across Harris County and (ii) calculate CO_2 emission reductions and water and energy savings across the county if optimum turf grass irrigation is adopted. The Irrigation Management System was used with site-specific soil hydrological data, turf crop water uptake parameters (root distribution and crop coefficient), and long-term daily rainfall and reference evapotranspiration to calculate irrigation water demand across Harris County. The Irrigation Management System outputs include irrigation requirements, runoff, and drainage below the root system. Savings in turf irrigation requirements and energy and their corresponding reduction in CO_2 emission were calculated. Irrigation water requirements decreased moving across the county from its north-west to its south-east corners. However, the opposite happened for the runoff and excess drainage below the rootzone. The main reason for this variability is the combined effect of rainfall, reference evapotranspiration, and soil types. Based on the result, if the average annual irrigation water use across the county is 25 mm higher than the optimum level, this will result in 10.45 million m3 of water losses (equivalent water use for 30,561 single families), 4413 MWh excess energy use, and the emission of 2599 metric tons of CO_2.

Publications

I. Peer Reviewed Publications:

- Awal, R., Fares, A., and Habibi, H.: Optimum Turf Grass Irrigation Requirements and Corresponding Water-Energy-CO_2 Nexus across Harris County, Texas, *Sustainability* 2019, 11(5), 1440.
- Awal, R., A. Fares 2019. Potential Impact of Climate Change on Irrigation Water Requirements for Some Major Crops in the Northern High Plains of Texas. In: O. Wendroth, R.J. Lascano, L. Ma, editors, *Bridging Among Disciplines by Synthesizing Soil and Plant Processes*, *Adv. Agric. Syst. Model. 8*. ASA, CSSA, and SSSA, Madison, WI. doi:10.2134/advagricsystmodel8.2017.0014

II. Symposium and Conference Proceedings Papers (Non-Peer Reviewed)

- None

III. Symposium and Conference Abstracts

- Awal, R., Fares, A., and Habibi, H.: Web-Based Irrigation Scheduling Tool: IrrigWise, *2019 ASA-CSSA-SSSA International Annual Meeting*, Nov. 10-13, San Antonio, Texas.
- Awal, R., Fares, A., Habibi, H., Ray, R., and Daniels, N.: IrrigWise: A new irrigation scheduling tool for agricultural crops and urban landscape in Texas, *Southern Region Water Conference 2019*, July 23-25, 2019, College Station, TX.
- Omari, S.A., Awal, R., Fares, A., Habibi, H. and Bhattarai, S.: Improving Irrigation Scheduling Tool: IrrigWise, *14th Annual Research Symposium*, April 11, 2019, Prairie View, TX.
- Awal, R., A. Fares, and H. Habibi: An Overview of Irrigation Scheduling Tool: IrrigWise, *ARD Research Symposium 2019*, March 30 - April 3, 2019, Jacksonville, FL.
- Habibi, H., R. Awal, A. Fares, and Q. Liu: *WeatherAndSoil*: An Android App for Location Specific Soil and Forecasted Weather Data, *ARD Research Symposium 2019*, March 30 - April 3, 2019, Jacksonville, FL.
- Awal, R., Fares, A., Habibi, H., and Ray, R.L.: Gridded Climate Data based Irrigation Scheduling Tool for Agricultural Crops and Urban Landscapes in the United States, Texas, *AGU Fall Meeting 2019*, December 9-13, 2019, San Francisco, CA (Accepted).
- Awal, R., Habibi, H., and Fares, A.: IrrigWise: An Irrigation Scheduling Tool to Increase Irrigation Water Use Efficiency in Texas, *Research Week Creative Activities Display*, April 10, 2019, Prairie View, TX.
- Habibi, H., Awal, R., and Fares, A.: WeatherAndSoil: A Site Specific Soil Parameters and Weather Forecast Android App, *Research Week Creative Activities Display*, April 10, 2019, Prairie View, TX.
- Duong, J., R. Awal, A. Fares, H. Habibi, and H. Oshiemele: Developing an Automatic Irrigation System based on Soil Moisture, *ARD Research Symposium 2019*, March 30 - April 3, 2019, Jacksonville, FL.

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.

IMPACTS

California

University of California Riverside

The HYDRUS models are being constantly updated based on research carried out by the W3188 group. The HYDRUS 1D model was downloaded more than ten thousand times in 2019 and over forty 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 new capabilities to rigorously consider processes in the soil profiles with furrows (the Furrow module), to calculate cosmic ray neutron fluxes (the Cosmic module) and to simulate the translocation and transformation of chemicals in the soil plant continuum (A Dynamic Plant Uptake module).

Finally, in 2019 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) Indian Institute of Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, and d) the Sede Boker Campus of the Ben Gurion university, Israel. About 100 students participated in the 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.

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.

PUBLICATIONS (Peer-reviewed Journal Articles)

California

University of California Riverside

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New Mexico

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