

Colorado Water

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IRRIGATION INNOVATION AND TECHNOLOGY



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On the cover—unmanned aerial systems (see page 24) are being used to estimate crop biophysical characteristics and water use. © iStock.com

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Published by
Colorado Water Institute
Reagan Waskom, Director

Editors
Melissa Mokry
Catie Boehmer

Design
Emily Pantoja
Emmett Jordan

Production Director
Nancy Grice

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Director's LETTER



Irrigated agriculture and landscapes account for the largest proportion of consumptive freshwater use in the world, about 70% of global freshwater withdrawals. The benefits we gain from this use of water are essential—plentiful food supplies and livable urban environments. Global food demands are projected by the Food and Agriculture Organization of the United Nations to increase by more than 50% by 2050 as we continue experiencing growing urban populations, shifting food preferences, unsustainable rates of aquifer depletion, and a growing recognition of the need for water left in the environment to restore and maintain ecosystem services. Further confounding these trends is strong scientific consensus that climate change-driven water scarcity, rising global temperatures, and extreme weather will have significant long-term effects on crop yields. Given the forces competing for a finite freshwater supply, it is unlikely we will see significantly more water developed in

the future for the purpose of irrigated food production or landscapes.

If additional water is not available in the future to meet irrigation needs, yet the demands placed on the food system only grow, the questions before us are: Can we use innovation and technology solutions to stretch limited irrigation water resources? Will technology provide the tools to improve productivity per unit of water; reduce weather risk and increase resiliency; take better advantage of plentiful water in good years and stretch limited water in dry times? Further, can technology help us reduce energy consumption for irrigation, conserve nonrenewable aquifers, better manage drought risk and other water shortage conditions, and reduce labor and input costs?

The array of newly available technologies developed for military, medical, communications, and other sectors of the economy are astounding. Remote image and data sensing from satellite and unmanned drones, wireless sensors, robotics and pervasive automation, real-time decision systems, 5G broadband connections, long-term weather forecasts, genetic technologies, global positioning systems, big data systems, to name a few—all hold potential to be added to water resource managers' toolboxes. As a result, we are in the midst of a new agricultural revolution as these innovations are integrated into food systems and irrigation. We see a future where irrigators rely on soil, plant, water, and atmospheric sensors with smartphone apps, integrating data for irrigation decisions that incorporate real-time economic data, input costs, market forecasts, and other variables. 5G broadband connections and low-band spectrum frequency network coverage will increase communication capacity in rural areas, paving the way for the next generation of wireless technology. Precision and variable rate irrigation equipment and controllers combined with precision inputs, genetics, and management will provide the increased "crop per drop" needed to meet future needs and social expectations.

While the common view is that agriculture is risk-averse and slow to change, producers rapidly adopt new technologies proven to increase productivity and net revenue. Observe how rapidly producers adopted new genetic biotechnologies once they hit the marketplace. One significant barrier to adoption, however, is the growing number of new technologies and companies vying for producers' attention. Each farm and commercial landscape is different; each has a unique set of soil, water, plant, weather, and management interactions. Best solutions will integrate the right combination of technologies into the individual production system.

This newsletter provides an introduction to the newly formed Irrigation Innovation Consortium (IIC) and reports from a few of the current projects underway by members of the IIC. The IIC is a joint initiative between the Foundation for Food and Agriculture Research (FFAR) and private, public, and university organizations to address growing water scarcity in the western U.S. and the world. The initial university partners are Colorado State University, Fresno State, Daugherty Water for Food Global Institute at the University of Nebraska, Kansas State University, and Texas A&M AgriLife Research, with CSU serving as the overall financial management and oversight entity. The goal of the Consortium is to serve as a center of excellence in irrigation innovation and technology to enhance energy and water use efficiency in irrigated food systems and amenity landscapes across the globe. This partnership strategically capitalizes on existing strengths to develop powerful synergies between the universities, USDA-ARS, the Irrigation Association, the Irrigation Foundation, and numerous irrigation equipment manufacturers, with opportunities for joint collaborations in demonstrations, technology transfer, tailored workshops, certifications, and student training.

We see a bright future for irrigated agriculture and landscapes and are excited by the possibilities innovative technologies will bring to the sector. For more information on the IIC, visit irrigationinnovation.org/.

Reagan Waskom

Director, Colorado Water Institute

The Newly Founded

IRRIGATION INNOVATION CONSORTIUM

Gets Underway in 2018

Stephen Smith, Wade Water LLC, Buena Vida Farm,
and Longs Peak Nursery LLC

In April 2017, the Foundation for Food and Agriculture Research (FFAR; <https://foundationfar.org/>) hosted a “Convening Event” in Lincoln, Nebraska. The question for the convened group at that time was “is there need and suitable industry support for focused research, demonstration, and training in irrigation—both landscape and agriculture irrigation?” The Convening Event participants strongly affirmed the need and validity of the idea. Supporting comments from the participants in Lincoln then resulted in an intense year-long effort to develop a proposal to form the consortium between five land-grant universities, the irrigation industry, FFAR, and others. The formative effort came to be known as the Irrigation Innovation Consortium (IIC), and the formal negotiated proposal for funding was submitted to FFAR in February 2018.

FFAR, as a 501(c)3 non-profit organization, was both founded and funded by the 2014 Farm Bill. Initial funding for FFAR was set at \$200 million, and FFAR has subsequently funded many significant projects in the gap or white space that exists in much of our funded agriculture research programs nationwide. Projects are funded on a 1:1 match basis with any non-federal matching dollars.

The Irrigation Innovation Consortium (<http://irrigation-innovation.org/>) was formally announced April 28, 2018 in Denver, Colorado, with FFAR, all the universities, and participating industry partners present. Since the announcement, the 2018 objectives under four identified research themes came together quickly under the guidance of the Colorado Water Institute.

Twelve additional universities are interested in joining the Consortium in its second phase. It should be noted that the Consortium is definitely not a “project” per se but, just as with a high technology start-up business, it is intended to be sustainable based on present and future identified needs and funding within the irrigation industry.

The governance of the Consortium is overseen by an Executive Committee (EC) and a Director. The EC consists of representatives from FFAR, the Irrigation Association, all five of the founding universities, and irrigation industry founding members. The EC is directly advised by a Research Steering



Division of Water Resource staff testing the sustainable flow rate from one of the wells at ITC.



Siphon tube irrigation from the existing concrete delivery ditch on the Consortium's ITC site.

Committee (RSC), which recently met formally for the first time in Fresno, California. Fresno State hosted the first meeting of the RSC. The RSC and the EC met again in Long Beach, California, concurrently with the Irrigation Association Annual Meeting on December 6 and 7, 2018.

While the IIC's governance model emphasizes that strategic research direction will be set by the Executive Committee, with technical advice from the Research Steering

Committee, the prioritized focus areas are set within the following theme areas:

- water and energy efficiency,
- remote sensing and big data applications, (known as IoT) for irrigation water management
- system integration and management, and
- irrigation technology acceleration and technology transfer.


At the core, the IIC is a collaborative research effort intended to accelerate the development and adoption of water and energy-efficient agriculture and landscape irrigation technologies and practices through public-private partnerships. Public sector researchers and industry partners will co-develop, test, prototype, and improve innovations, equipment, technology, and decision and information systems. The goal is to design tools to equip “farms of the future” with cutting-edge technologies and optimization strategies to enhance irrigation efficiency.

Under the IIC banner, current plans in Colorado include a new Irrigation Technology Center that will be located on an irrigated farm in Fort Collins, Colorado, at the interchange between Interstate 25 and Prospect Road. The farm was offered to the IIC by the Colorado State University Research Foundation (CSURF). Multiple water sources ensure a reliable water supply as would be needed for any research facility. Detailed water delivery, pond, power, and irrigation design plans have already been commissioned. The multiple water sources available at the site include Lake Canal surface

supplies (diverting off the Cache la Poudre River), Gray Lakes late season supplies, a decreed well, and leased Colorado-Big Thompson (CBT) units currently owned by Colorado State University.

At present, the conceptualization of the site has an on-site weather station, a flux tower, a lined pond to capture multiple water sources, VFD pump stations, a center pivot with variable rate irrigation, and subsurface and surface drip irrigation. The on-site building will have offices for staff, students, and supporting industry people.

Laboratories will have equipment suited to the IIC needs, such as irrigation control and monitoring and data collection.

Any organizations interested in joining the Irrigation Innovation Consortium are invited to contact Stephen Smith at swsmith@buenavidafarm.com. 



IRRIGATION INNOVATION CONSORTIUM FOUNDING MEMBERS

- Aqua Engineering
- Fresno State
- Colorado State University
- Daugherty Water for Food Global Institute at the University of Nebraska
- Foundation for Food and Agriculture Research
- Irrigation Association
- Jain Irrigation
- Kansas State Research and Extension, Kansas State University
- LI-COR Biosciences
- Lindsay Corporation
- Northern Water
- Rubicon Water
- Texas A&M AgriLife Research
- Valmont Industries, Inc.

FFAR

Aims to Combat Water Scarcity and Increase Agricultural Profitability

LaKisha Odom, Foundation for Food
and Agriculture Research

Background

American agricultural producers are expected to play an active role in meeting growing global needs for food, feed, and fiber while land, water, and soils decline in availability and quality.

The Foundation for Food and Agriculture Research (FFAR, <https://foundationfar.org/>) was created by the 2014 Farm Bill to support food and agriculture research, foster collaboration, and advance the mission of the U.S. Department of Agriculture (USDA). FFAR assists producers in meeting increasing global agriculture needs.

U.S. farmers have seen crop prices drop by nearly half over the last few years, while input costs continue to grow. Water scarcity, in particular, continues to be a challenge in large agricultural regions affecting yields, profits, and water availability for the public. According to the National Centers for Environmental Information (NCEI), in 2017, several states experienced drought from March to December that resulted in \$2.5 billion in losses; the most extensive damage hit agriculture. The report goes on to state,

“field crops including wheat were severely damaged, and the lack of feed for cattle forced ranchers to sell off livestock (NOAA, 2018). In California, consecutive years of drought are making it hard for farmers to cope due to revenue losses and higher water costs. This drought has also contributed to





the increased potential for severe wildfires,”

including wildfires in Montana that burned over 1 million acres (NIDIS, 2018). Crop and forage yield shocks caused by drought lead to losses of income for farmers and major economic disruptions (Wallander, 2017). Additionally, groundwater depletion has expanded beyond the Southeast and High Plains as demands on groundwater have overstressed aquifers in many areas across the U.S.—not just in arid regions (USGS, 2016)—affecting the public.

FFAR believes that in order to address the challenges faced in agricultural production, our food system must evolve. Our organization brings togeth-

er leading stakeholders that consist of academics, industry leaders, farmers, and producers to identify and investigate key research questions that focus on environmental resilience of our food supply in an economically viable way.

With water availability continuing to be a major issue affecting U.S. agriculture and the public, FFAR has prioritized Overcoming Water Scarcity as one of its strategic challenge areas (<https://foundationfar.org/challenge-areas/>). Specifically, FFAR aims to increase the efficiency of water use in agriculture, reduce agricultural water pollution, and develop water reuse technologies with the goal of sustainably increasing water availability for agricultural use and protecting clean water supplies.

FFAR’s focus on increasing leveraged support in food and agriculture research through public-private partnerships invests in much needed interdisciplinary cooperation. We bring individuals from various sectors to the table to catalyze transformative, real-world results to produce knowledge that benefits end users.

The Overcoming Water Scarcity Scientific Program focuses on identifying research that contributes to understanding and addressing issues of water scarcity. It also aims to address the social and economic realities that challenge farmers, ranchers, private businesses, and other stakeholders in meeting the demand for increased productivity and limited resource availability.

Current Program Priorities Under Water Scarcity

In addition to investing in research, FFAR recognizes the importance of engaging with the public. We host convening events and listening sessions, attend conferences and industry association meetings, and provide numerous opportunities to engage with our stakeholders—all in an effort to hear from their view as the potential white spaces and intractable research in agriculture. This open dialogue with our stakehold-

ers is invaluable as we seek to prioritize areas of focus. The Overcoming Water Scarcity Challenge areas, based on stakeholder input, includes the following priorities. Detailed descriptions of the work in each of these areas are outlined in the Vision/Concept Document (https://foundationfar.org/challenge_trashed/overcoming-water-scarcity/).

- Irrigation
- Plant Efficiency
- Water Reuse/Recovery
- Groundwater Recharge
- Systems in Agriculture

Irrigation

FFAR has prioritized the significant role that irrigation plays in food production and agriculture production generally. Agricultural producers, as well as stakeholders from the industry, municipal, and environmental sectors, have a number of interconnected vested interests surrounding water availability, agricultural water use, and improved water use efficiency. Potential areas of focus related to irrigation include:

- irrigation technologies and best management practices,
- on-farm demonstrations,
- modeling and reporting,
- water demand management (metrics, crop monitoring and coefficients, soil, and evapotranspiration-based decision support technologies),
- governance mechanisms and training,
- water and energy efficiency, and
- system integration and management.

Plant Efficiency

Water shortage is a limiting factor in crop production, which in turn increasingly affects food production and food security. For this reason, scientists maintain ongoing efforts to improve the efficiency of water usage and reduce the effect of water shortages on crop production (Zhou et al., 2016). Potential areas of focus related



Photo courtesy of FFAR.

to plant efficiency include:

- new genetic pathways to increasing water use efficiency,
- multiple stressors,
- impact of water scarcity on crop quality, and
- alternative crops and a systematic approach to abiotic stress.

Water Reuse and Recovery

The safe use of nontraditional waters, such as treated or mixed saline waters or treated wastewaters for agricultural production, is an important component of improving agricultural water use efficiency. Growers are increasingly looking to recycled water as a way to consistently meet their irrigation demands in the face of growing water scarcity and pollution concerns (Schulte, 2016). Potential areas of focus related to water reuse and recovery include:

- quantification of the nonmonetized costs and benefits of potable and non-potable water reuse compared with other water supply sources to enhance water management decision making;
- examination of the public acceptability of engineered multiple barriers compared with environmental buffers for potable reuse, and examination of the impact of reclaimed water quality on public health; and
- development of rapid screening methodologies, and research related to purposeful ecological enhancement with reclaimed water.

Groundwater Recharge Research

Freshwater resources are vulnerable and have the potential to be strongly impacted by climate change (IPCC, 2008). Groundwater supplies nearly half of the world's drinking water and much of its irrigation water supply. Population growth, overexploitation, salinization, and nonpoint source pol-

lution from agricultural activities have reached a global scale and threaten the health and livelihood of this planet. Improved observational data and data access are necessary to improve understanding of ongoing changes, as well as increased innovation. Potential areas of focus related to groundwater recharge research include:

- development of 3D capabilities for geologic modeling to a level that can be integrated routinely with hydrologic models;
- improvement of groundwater recharge modeling and other hydrologic applications, and development of more sophisticated flow and transport processes in variably saturated flow models; and
- improvement of expertise in bridging soil, vegetation, and atmospheric modeling with hydrologic modeling to create a broader understanding of the groundwater component of the hydrologic cycle (Sanford et al., 2006).

Systems in Agriculture

A systems approach to fostering agricultural sustainability is the most effective means of tackling the challenges in water scarcity. Funding programs that support connectivity among goals ensures robustness and resilience. Decision-makers at each level need metrics and information that help optimize the sustainability goals. **Potential areas of focus related to systems in agriculture include** farming system planning and monitoring water quality.

The Future of Water Scarcity Research at FFAR

FFAR is committed to continuing to increase efficiency in water use in agriculture and the development of water use technologies. As we evolve in this strategic research space, there are certain areas that are of strong interest, includ-



FFAR believes that in order to address the challenges faced in agricultural production, our food system must evolve.

ing opportunities to diversify production systems that could result in more climate resilience and less water-intensive production systems. FFAR also invests in innovative practices that may result in cross-sectional improvements in agricultural water productivity, from crop to livestock production, that incorporate best practices in soil management and sustainable grazing methods. Potential areas of focus related to the future of water scarcity research at FFAR include:

- on-farm water reuse and recycling,
- food-energy-water nexus,
- groundwater recharge,
- diversification of agricultural systems, and
- sustainable improvements in agricultural water productivity.

In September 2018, FFAR released a new set of priorities for public comment

as well as a new proposed name for our challenge area: Sustainable Water Management. For more information on our challenge area changes, please visit <https://foundationfar.org/ffar-challenge-area-realignment-2019/>. We are committed to working with our public and private partners to fund the most innovative research that will move toward a more coordinated landscape approach with the goal of sustainably increasing water availability for agricultural use.

Conclusions


These identified scientific priorities represent the areas of focus for the FFAR's Overcoming Water Scarcity Challenge Area. While these priorities are by no means exhaustive, they do represent FFAR's commitment to the needs expressed by our stakeholders and to the precompetitive space where our impact may be the most substantial. 



Photo courtesy of FFAR.

Connecting Technology to Growers

Deborah M. Hamlin, Irrigation Association;
Anne Blankenbiller, *Irrigation Today* Magazine and Irrigation Association



Prototype robots are being tested for use on drip irrigation systems. Photo by Thomas Thayer, Irrigation Today.

As growers look to technology to help make their operations more efficient and profitable, the new Irrigation Innovation Consortium (IIC) can be the conduit to connect them with innovative technology solutions.

In today's agriculture print and digital landscape, it is nearly impossible to leaf through a magazine or scroll online without coming across an article or announcement about new technology and innovations. Everything from robotics and satellite imagery to virtual fencing for cattle is on the table. It shows the vibrancy of our industry and breeds a sense of excitement and anticipation of what could be.

In my industry—agriculture and landscape irrigation—technology is a huge driver on which many of our member companies are focusing their research and innovation efforts. For the Irrigation Association (IA), it is also at the forefront of our efforts as we work to promote efficient irrigation technologies, practices, and services.

The IA is excited and honored to be a part of this new Irrigation Innovation Consortium. Through our involvement with irrigation companies and researchers, we are aware of the multitude of new technologies on the market—and yet to come—that can help growers and landscape irrigation professionals become more efficient and profitable. From a more

global perspective, we can also see that innovations in our industry have solutions to mitigate drought to provide enough water to support the world's needs.

However, only a small portion of agricultural producers are using the technologies available. The goal is to provide the information, research, and training necessary for growers to be comfortable embracing and adopting new technologies.

The Grower Mindset

Put yourself in the shoes of a grower, and you soon realize the myriad factors that affect their business...many of which they have no control over.

Weather can delay planting, delay harvesting, affect yields and even completely decimate a crop. Foreign policy decisions and international markets affect a grower's ability to sell their products. Fluctuating commodity prices dictate how much profit (or loss) they can make per bushel.

Input costs is an area where growers can have some influence. Although these costs range from everything from seed and crop protection to fuel, for an irrigator this extends to water, energy use, and even equipment and vehicle costs.

Growers are craving ways to make the most of every drop of water they use for irrigation, while being as energy efficient as possible, using the least amount of fuel and causing a limited amount of wear and tear on equipment. Cutting down on labor or production time required is icing on the cake. For irrigators, being efficient is a key to improving their bottom line.

Bridging a Connection

With the irrigation market ripe for new and innovative technologies and growers in search of solutions, the key is connecting this technology with growers.

However, this can be a challenge for various reasons. New technology in irrigation is more complicated than just simply introducing it on social media like Apple does with a new iPhone.

For a grower, technology can be costly and potentially challenging to grasp. They are savvy business owners and are not blinded by shiny new gadgets; instead, they look for tried and true technology, equipment, and practices that are proven to provide a positive impact on their operation. They want to see a return on their investment, and many want to see their neighbor try something first before making a commitment.

According to Chip Flory, Farm Journal economist and host of the AgriTalk and AgriTalk After the Bell podcasts, some growers feel like they are on a "technology treadmill."

"They're running harder every year to keep up with the technology, but they don't feel like they're getting anywhere when it comes to their financial balance sheets," Flory said. "Show them a piece of technology that does improve the balance sheets, and they'll be more than willing to adopt that technology and put it to use in a hurry."

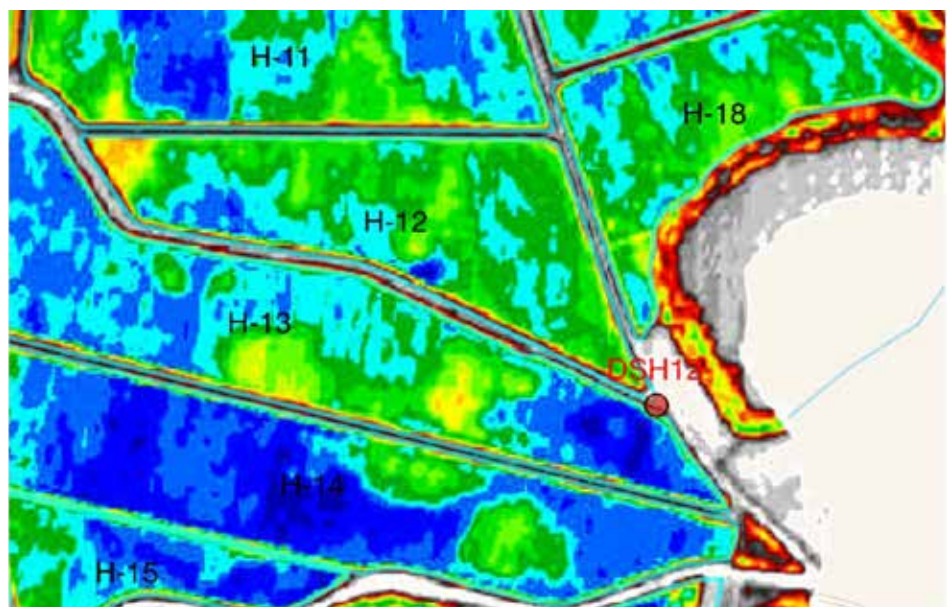
Developing new technology is not enough. Taking the important necessary steps to secure acceptance and adoption by growers is vital.

From the very first convening meeting in early 2017 bringing together public and private entities interested in the IIC, the adoption component by end users has been a priority. Even the best technology is useless if it sits on a shelf. The more successful route to market is to have research that proves success, showing performance in the field and producing results showing reduced inputs and increased outputs.

The new Irrigation Innovation Consortium will be an excellent conduit to bring new ideas, technologies, and practices into the industry through research, testing, and case studies. Involving growers in this process will not only lead to better technology but also increase the likelihood of it being accepted into the market and, in turn, benefitting the industry.

The Irrigation Association looks forward to continuing to support the work of the new IIC and the important contributions it will make toward the betterment of irrigated agriculture and irrigated landscapes. 

For more information about the Irrigation Association and its work to promote efficient irrigation, visit www.irrigation.org.



Field satellite imagery gained by using Landsat technology. Photo by Bowles Farming Company, Irrigation Today.



INTENSIFICATION OF CORN PRODUCTION Through Subsurface Drip Irrigation

Freddie Lamm, Northwest Research Extension Center, Kansas State University

Crop water productivity (CWP, also known as water use efficiency, WUE) is defined as the crop yield divided by the total water use. Thus, it can be easily recognized that either the numerator can be increased, or the denominator can be decreased, to increase CWP.

One strategy to increase CWP is to employ deficit irrigation, which results in a reduction in water withdrawals. It is hoped that this level of deficit irrigation will not reduce farm profitability by negatively impacting crop yields to a large extent. In fact, a traditional definition of deficit irrigation is a level of irrigation anticipated to reduce crop evapotranspiration (ET_c) to less than the full potential amount. Since crop yield and ET_c are typically linearly related, a reduction in ET_c means a reduction in crop yield. Additionally, it often can be shown that appropriate levels of irrigation can actually increase CWP (Figure 1).

Subsurface drip irrigation (SDI) has great potential to optimize crop production at a greater level while efficiently using water. Earlier studies have indicated CWP could be maximized with SDI at about 80% of full irrigation for corn and still result in high crop yields (Figure 2 and Rogers, 2014).

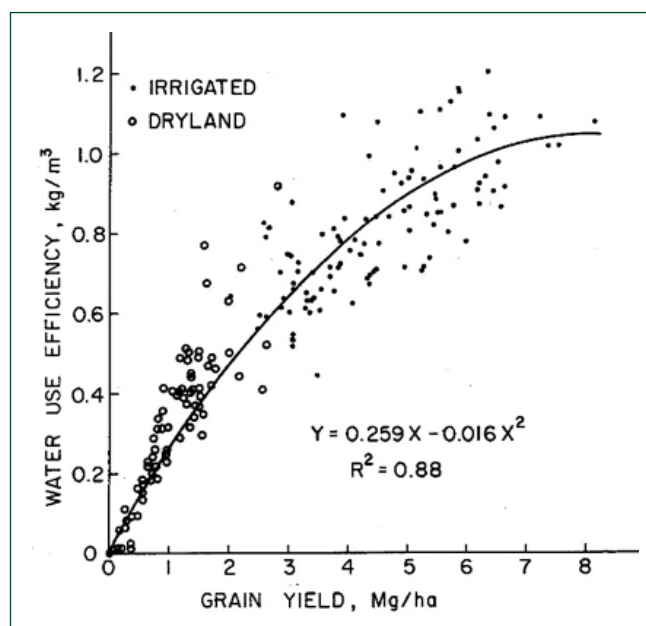


Figure 1. Wise use of irrigation can increase CWP, here expressed as WUE (Data after Evett et al. 2014, using data from Musick et al., 1994).

Although the corn yields in these earlier studies were high (200-250 bushels/acre), with additional intensification greater yields are anticipated (consistently greater than 280 bushels/acre). These greater yields are not unrealistic, as SDI corn yields as high as 304 bushels/acre were obtained in a research study in Kansas in 1998 (Figure 3).

We already know that intensification can have positive results. Comparing crop yields for the period pre- and post-introduction of commercial fertilizers is a prime example. Future efforts will concentrate on optimizing more inputs: the focus of such efforts will be to increase the numerator of the equation (the yield) to increase CWP through crop production intensification.

Plant density of modern corn hybrids can be increased to reasonably high levels without plant barrenness due to advances in genetics. In SDI studies at Colby, Kansas, there appeared to be little yield penalty with greater plant density even when irrigation and precipitation were very limited (Figure 3). It is thought that even small amounts of water applied daily with SDI can help alleviate some of the water stresses that occur with other types of more infrequent irrigation (e.g., surface or sprinkler irrigation). Plant hybrids also play a major role in high-yielding systems. It is important to examine multiple hybrids using available information from seed companies to choose hybrids that can respond well to crop intensification.



Table 1. Corn yield and water use parameters in an SDI study with intensive management at the KSU-NWREC, Colby, Kansas in 2017.

Main Effect	Grain Yield (bu/a)	Plant Density (p/acre)	Ears /Plant	Kernels /Ear	Kernal Mass (mg)	Crop Water Use (inches)	Crop Water Productivity (lb/a-in)
<i>Effect of Irrigation Level</i>							
Irr 1, 115% ETc (16.75 inches)	293	37679	1.02	587	33.3	29.19 A	563 C
Irr 2, 100% ETc (14.50 inches)	292	37716	1.02	586	33.3	27.10 B	605 B
Irr 3, 85% ETc (12.00 inches)	289	37752	1.01	580	33.6	25.50 C	638 A
<i>Effect of Hybrid</i>							
Hybrid 1, Pioneer 1151	280 B	37873	1.01	556 B	33.7	26.68 B	590 B
Hybrid 2, Pioneer 1197	304 A	37558	1.02	612 A	33.1	27.84 A	614 A
<i>Effect of Plant Density</i>							
Plant Density 1, 42K p/a	296 A	41600 A	0.99	552 C	33.0	27.35	607
Plant Density 2, 38K p/a	295 B	37788 B	1.02	587 B	33.3	27.30	608
Plant Density 3, 34K p/a	285 B	33759 C	1.03	614 A	34.0	27.14	591
Data for a main effect within a column followed by different letters are significantly different at P=0.05 level.							

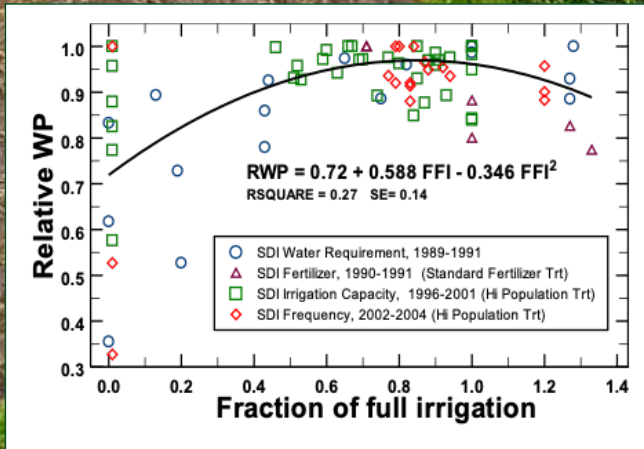


Figure 2. Crop water productivity maximized at about 80% of full irrigation in four different SDI studies at Colby, Kansas from 1989 through 2004. Graph summarized by Lamm and Rogers, 2014.

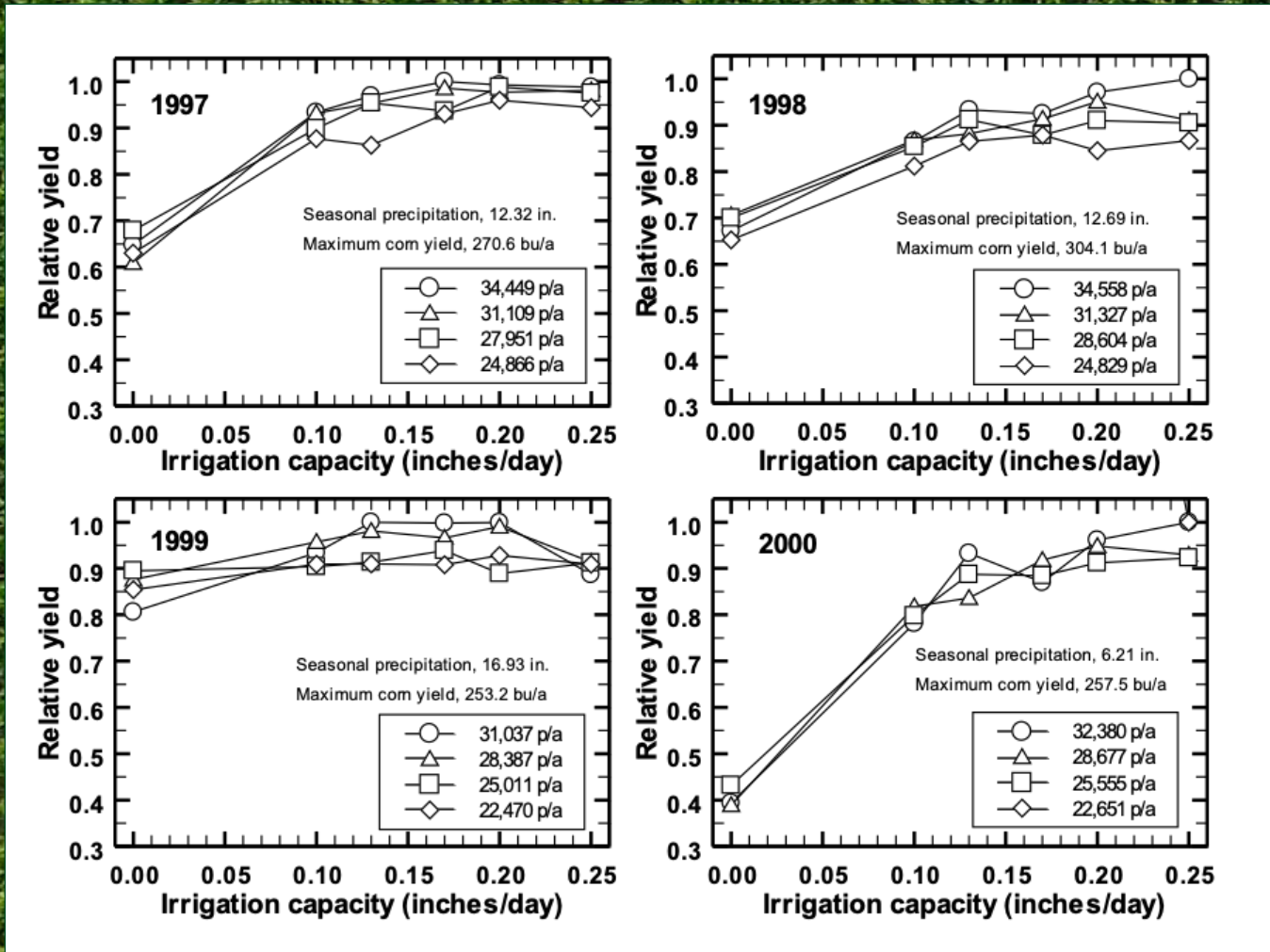


Figure 3. Maximum SDI corn grain yields ranging from 253.2 to 304.1 bushels/acre with modest irrigation capacities and in-season precipitation ranging from 6.21 to 16.93 inches at Colby, Kansas. Average in-season precipitation is approximately 12.3 inches. It can be noted that the greatest yield in most years was at the greatest plant density and that the maximum yield (304 bushels/acre) in 1998 still appears to be increasing.




Consistently increasing yields to more than 280 bushels/acre will require optimal fertilization. SDI allows for timely in-season fertigation (application through the subsurface driplines to the center of the root zone). Micronutrients can also be applied easily and efficiently with SDI systems, and micronutrients can become another limiting factor under crop intensification strategies.

Current Research

Our current research at Kansas State University with the intensification of corn production through SDI began in 2017 and involves examination of three irrigation levels, three planting densities, and two corn hybrids with a fixed but advanced fertilization scheme. This includes in-season fertigation of nitrogen, phosphorus, and potassium, as well as micronutrients. Although the first year's results are too preliminary to draw firm conclusions, they are encouraging.

Yields were not affected by irrigation level, which corresponded to earlier findings that SDI levels approximating 75%-80% of full irrigation will maximize yields (Table 1). Irrigation increased crop water use, but this only reflects the higher irrigation amounts, which were likely due to increased deep percolation. This is further emphasized by the greatest crop water productivity at the irrigation level designed to match 85 % of E_{Tc} minus precipitation.

There also was a strong hybrid effect on yield: Pioneer 1197 exceeded Pioneer 1151 by 24 bushels/acre, emphasizing that hybrid selection remains an important factor in intensively managed corn. This yield increase for Pioneer 1197 was caused primarily by the greater number of kernels per ear. Pioneer 1197 also had higher crop water productivity than Pioneer 1151, but crop water use was slightly greater with Pioneer 1197. A plant density of 38,000 or 42,000 plants/acre resulted in significantly greater yield than 34,000 plants/acre, but crop water use was not affected at approximately 27.26 inches. Although the lower plant density had a greater number of kernels per ear, this value was not able to compensate for the lower plant density. This reflects a growing understanding that maximizing irrigated corn yields often requires maximizing the intermediate yield component of kernels/area (i.e., plant density multiplied by ears per plant multiplied by kernels per ear).

Intensification of corn production with SDI appears to be a promising approach to improving the use of our limited land and water resources. As we move forward with the research, it is likely that some other inputs will become a limiting factor in increasing crop yield. That is to be anticipated and can be addressed at that time. Essentially, all farming advances have led to intensification. As we move towards further intensification, we have to work wisely to do it in an environmentally, ecologically, and economically acceptable manner. 

EVALUATION OF MOBILE DRIP IRRIGATION

for Corn Production in Western Kansas

Jonathan Aguilar, Southwest Research Extension Center,
Kansas State University;

Melissa Harvey, Kansas Center for Agricultural Resources
and the Environment (KCARE), Kansas State University

Background

There are over 2 million acres of irrigated cropland in western Kansas. On any given day during the growing season, visitors and residents alike will see—but may not actively recognize—irrigation systems in action. Ninety percent of farms in this area utilize center pivot systems, rather than flood irrigation or subsurface drip (SDI), because center pivots are more cost-effective and less labor-intensive. For producers in western Kansas, these irrigation systems are more than a lifeline: the region uses more irrigation water than many other parts of Kansas because crops grown here receive less than 20 inches of annual rainfall, and farmers must compensate by pumping water from the Ogallala Aquifer. But the aquifer is declining faster than it can be replenished.

Producers and university researchers are taking a close look at irrigation methods that can help conserve Kansas water. Traditional irrigation systems take groundwater from the Ogallala and spray it into the crop canopy. During its journey from well to center pivot to thirsty corn plants, that water can drift meters away from intended fields—strong Kansas winds whip the spray onto a neighboring crop, scatter it into a buffer strip, or shower it onto highway asphalt. That same water can also evaporate before it reaches the plant roots. A commonly-used phrase when discussing the Ogallala, and water use in general, is to “make every drop count.” New irrigation technologies offer some solutions to this dilemma and a fresh option for farmers.

One such option is Mobile Drip Irrigation (MDI). Officially marketed in late 2014, MDI replaces the sprinklers or nozzles of



Mobile drip irrigation. Photo by Kansas State Research and Extension.



IRIGATION



a typical center pivot irrigation system with long dragline hoses. These draglines, or driplines, apply water directly to the soil at the base of the plant. Yet when MDI first started appearing in western Kansas and beyond, producers were not sure if it was a system that would maintain the yields they needed, if the drip lines would work efficiently with lower well capacities, or even how the drip lines should be spaced for efficient water use in the silt loam soils of southwestern Kansas.

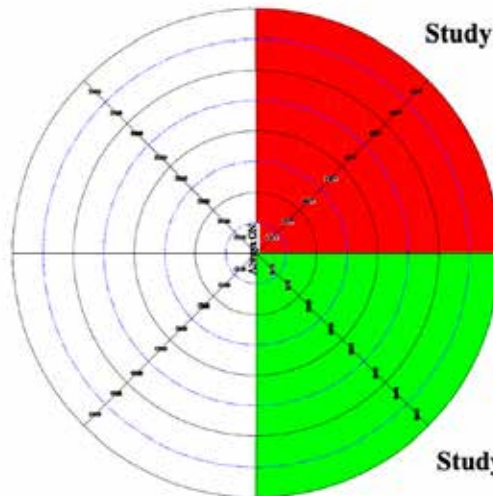
Experimental Design

Keeping these questions in mind, researchers from Kansas State University's Southwest Research Extension Center (SWREC) initiated a study during the 2015-2016 growing seasons to compare MDI to low-elevation spray application (LESA) irrigation nozzles. Because MDI draglines apply water directly on the soil at the base of the plant, rather than spraying water into the crop canopy, the team believed that the MDI system would reduce soil water evaporation due to reduced surface wetting as well as decreasing water loss from both canopy evaporation and drift.

At the time of this project, MDI was relatively untried, but by gathering more information on this new technology, researchers would be able to give area producers an effective alternative in their irrigation toolkit. To begin with, spray irrigation and MDI are vastly different systems. The big question was: How much of a difference? How much could MDI reduce soil water evaporation? How much would soil water become redistributed? How much would the crops yield?

Outside of Garden City, Kansas, the SWREC team planted 125 acres of corn. Each field utilized a center pivot irrigation system that was divided into four experimental areas: two quadrants used LESA nozzles, and the other two used MDI systems with a drip line spacing of 60 inches. In addition, each of these fields compared MDI and LESA at high (600 gallons/minute) and low (300 gallons/minute) well capacities in order to mimic the conditions producers might face within a growing season (Figure 1).

Accurate measurement was essential for a successful comparison of the systems. To ensure that LESA nozzle performance matched the designed flow rates, team members used a spot-on device—a hand-held flow meter—to measure how much water went through the irrigation nozzle. The team also had to determine how far apart the MDI lines should be spaced. They placed the lines at every other row of corn, which meant



Study 1: 600 gpm

Study 2: 300 gpm

Figure 1. Experimental layout of two studies comparing Mobile Drip Irrigation (MDI) and in-canopy spray nozzles at Kansas State University's Southwest Research Extension Center (SWREC), near Garden City, Kansas.

that there was an MDI hose every 60 inches. The team hoped that this spacing would ensure availability of water for each root system.

In order to gauge the effect of the 60-inch lateral spacing on soil water redistribution, the team placed a neutron probe in the center of each field at a depth of eight feet and monitored these throughout the season. The neutron probes served an additional purpose: they allowed researchers to assess the movement of water through the soil. The MDI system does not visibly saturate soil across a field, and it was important to measure the “wetting front,” which is the depth of water in the soil five hours after irrigating.

Finally, researchers calculated soil water evaporation in the early part of the growing season using 4-inch mini-lysimeters placed between the corn rows in both the MDI and LESA research plots. At the end of the season, the team determined corn yield by harvesting two 40-foot rows from the center of each plot.

Results

Logic dictated that, due to the design of each system, there would be a difference in soil evaporation. The difference was not surprising, but the magnitude was unexpected. Results indicated that soil water evaporation under MDI was lower than in-canopy LESA nozzles by an average of 35 percent. Corn irrigated with MDI averaged 1.0 mm/day of measured soil water evaporation, while corn irrigated with nozzles averaged 1.6 mm/day of soil water evaporation. When multiplied over the vast numbers of Kansas corn acreage, this could represent a significant amount.

Yield results were not as conclusive, however, as fields received above-normal rainfall during the 2015 growing season. The region received 18 inches of rain between the months of May to September, which is almost the total amount the region would receive during an average year. Although fields irrigated with MDI on both high and low well capacities did have a higher yield, the difference was not statistically significant.

Although the difference in yield between MDI and sprinklers was not remarkable, it is worth noting that there was a significant effect on the end of season soil water. Because the amount of precipitation varies from year to year, soil water is important for many farmers. At the beginning of a new growing season, starting with some moisture already in the soil is vastly preferable than starting with nothing and having to accumulate

soil water from scratch. Under low well capacity, MDI fields measured more soil water compared to spray nozzles. From the information collected by the soil moisture sensors, soil water was greatest at the midpoint between two drip lines spaced 60 inches apart and at an approximate depth of 20–24 inches (Figure 2). This stored moisture will act as a type of “savings account,” allowing producers to utilize water left in the soil from one growing season to the next.

This research uncovered one additional management benefit for farmers; MDI’s system of drag lines and precise water placement helped to keep wheel tracks dry. Farmers using MDI would avoid the onerous task of digging out wheels mired in muddy fields.

The Future of MDI in Kansas

Kansas State University has joined the Kansas Water Office and eight producers in various watersheds around the state to develop and implement a series of Water Technology Farms. These farms represent an initiative allowing producers, state agencies, and university researchers to work in partnership to apply new irrigation technologies on a field scale. Water tech farms use new irrigation systems—like MDI—in concert with different management techniques to demonstrate effective water conservation. Results are promising, and ongoing.

For producers who must manage their farms despite dwindling water resources, mobile drip irrigation is neither a quick fix nor a piece of miracle machinery. It is emerging technology in an expanding array of available tools. Kansas State University researchers, particularly in western Kansas, will continue to study this type of irrigation, hoping to quantify its capabilities during any type of season, from drought to flood. 🌱

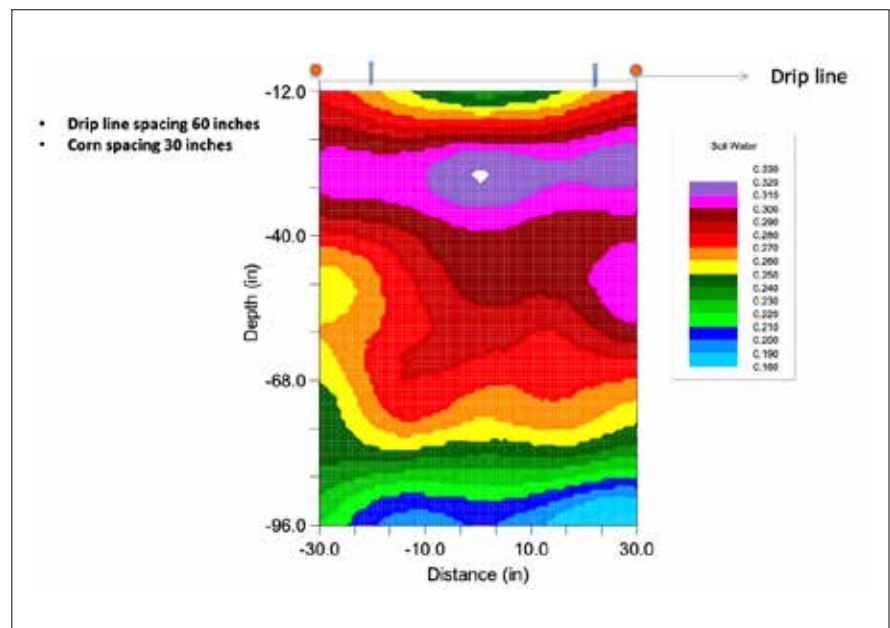


Figure 2. Soil water at different points within the root zone under Mobile Drip Irrigation (MDI); drip line lateral spacing is 60 inches, data is from transect of five neutron probes access tubes and surface created using Kriging.



University of Nebraska-Lincoln Testing Ag Performance Solutions

TAPS

Daran Rudnick, Biological Systems Engineering Department,
University of Nebraska-Lincoln;

Matt Stockton, Agricultural Economics, University of Nebraska-Lincoln;

Chuck A. Burr, CropWatch, University of Nebraska -Lincoln

The University of Nebraska's Testing Ag Performance Solutions (TAPS) research and education program was created to streamline and promote solutions to the wicked problem faced by agricultural producers. This program uniquely incorporates and engages agricultural researchers, technology and service providers, agricultural producers, government agencies, and other interested partners in an interactive, real-world way to increase crop productivity, environmental sustainability, and individual farm profitability. The University of Nebraska-Lincoln Research and Extension personnel and facilities act as the common ground, synergy zone, the facilitator, and hosts for the program. This structure provides the needed oversight and neutrality needed to maintain a healthy objective environment for producers, researchers, and industry suppliers to innovate, test, adopt, learn about and develop new technologies, try new management practices and techniques, and make the needed adjustments in the efficient and profitable production of crops.

The TAPS program hosts annual farm management competitions

where competitors (individuals and/or groups) compete to achieve optimal profitability. This requires teams to consider the individual value each resource contributes to profit and ultimately requires the careful and wise use of limiting resources while developing strategies related to business pressures. This requires a systems approach to managing and thinking. The team competes for three possible awards: the greatest profit, the most efficient use of water and nitrogen, and the highest yield. Competitors make six primary types of decisions, including the following: 1) crop insurance selection, 2) hybrid selection, 3) planting density, 4) crop marketing decisions, 5) irrigation scheduling, and 6) nitrogen fertilizer choices. Each entrant is assigned three randomized plots watered by a variable rate irrigation system located at the West Central Research and Extension Center (WCREC) in North Platte, Nebraska. These plots are used to extrapolate the cost and revenues of a 3,000-acre corn farm or, in the case of the grain sorghum contest, a 1,000-acre sorghum farm. Unlike a yield contest, where costs

are irrelevant, profit drives home the need to consider water and fertilizer use carefully. Choices are made in an environment with real-time information regarding field conditions, using a variety of new and emerging technologies and current market conditions. Stakeholders meet and discuss outcomes, challenges, and share their experiences, which has proven to be valuable to all participants.

Some of the program features provide the following benefits: 1) university researchers and extension professionals are in direct competition with farmers under real-world conditions, 2) farmers are able to use and test new and emerging methods, tools, and ideas without fear of business loss, 3) industry groups are able

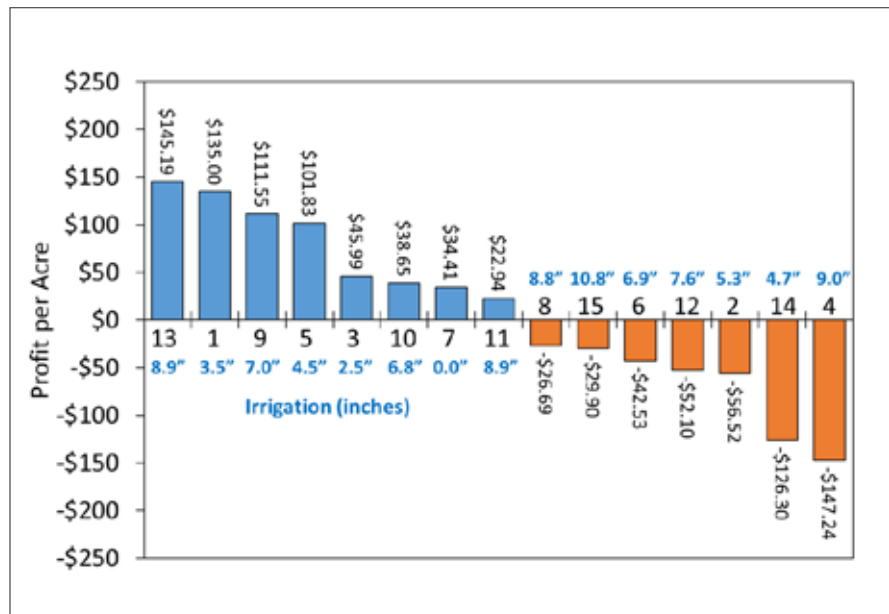


Figure 1. Profitability (\$ per acre) for individual farms ranked from highest to lowest, along with their corresponding seasonal irrigation amount (inches).



Figure 2. Pictures of the 2017 TAPS Farm Management Competition outreach events, including (A) producers, industry, academics, non-profit reps, and others touring the competition plots on June 27th, (B) WCREC Water and Crops Field Day's growers' panel consisting of the TAPS participants on August 24th, and (C) the TAPS awards banquet on December 12th where the winners for Most Profitable Farm, Highest Input Use Efficiency, and Greatest Grain Yield were recognized.

to observe if and how tools, technology, and methods are being adapted and adopted, and 4) regulatory groups become observers of production challenges and the effect policies have on them. These benefits have led to increased understanding and more open discussion and work among all of the involved groups, which ultimately will lead to better research; quicker adoption of ideas, technology and practices; and, clearer and more relevant policy recommendations.

First Results of the TAPS Corn Farm Management Competitions

The first annual TAPS Farm Management Competition in 2017 had a total of fifteen farm teams who were

mostly professional corn farmers, with several other groups including university experts, students, and associated stakeholders. The participants represented eight different Nebraska Natural Resource Districts (NRDs). Their many different production decisions resulted in a wide range of irrigation efficiencies, nitrogen efficiencies, yield responses, and profit levels. Figure 1 shows the variability in farm profit per acre, with corresponding seasonal irrigation amounts ranked from lowest to highest profits.

The TAPS program included several in-season extension workshops, which included contestant panel discussions, field tours of the plots, and program updates. The pictures in

Figure 2 capture some of the participants as they were involved in these workshops. A description of management decisions made and the results of the 2017 Farm Management Competition can be found at TAPS.unl.edu.

In 2018, the TAPS program expanded to 28 farms (teams) with nearly 90 participants from Nebraska and Kansas, representing twelve Nebraska NRDs and two Kansas Groundwater Management Districts (GMDs) (Figure 3). The corn and sorghum competitions closed on November 15th, which was the last day for the participants to market their grain. The results were presented and winners were acknowledged at the awards banquet on December 6th, 2018 in North Platte, Nebraska.

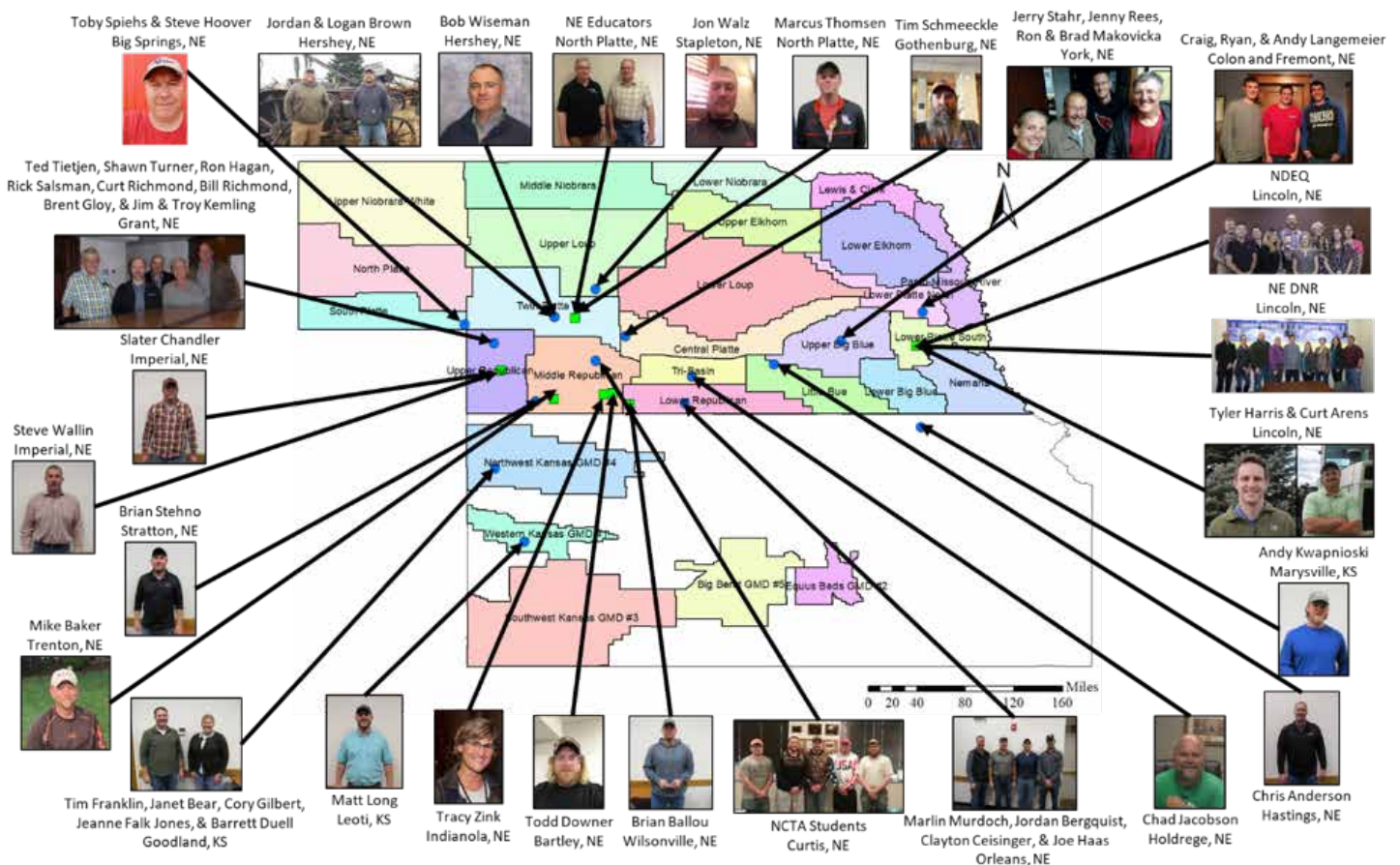
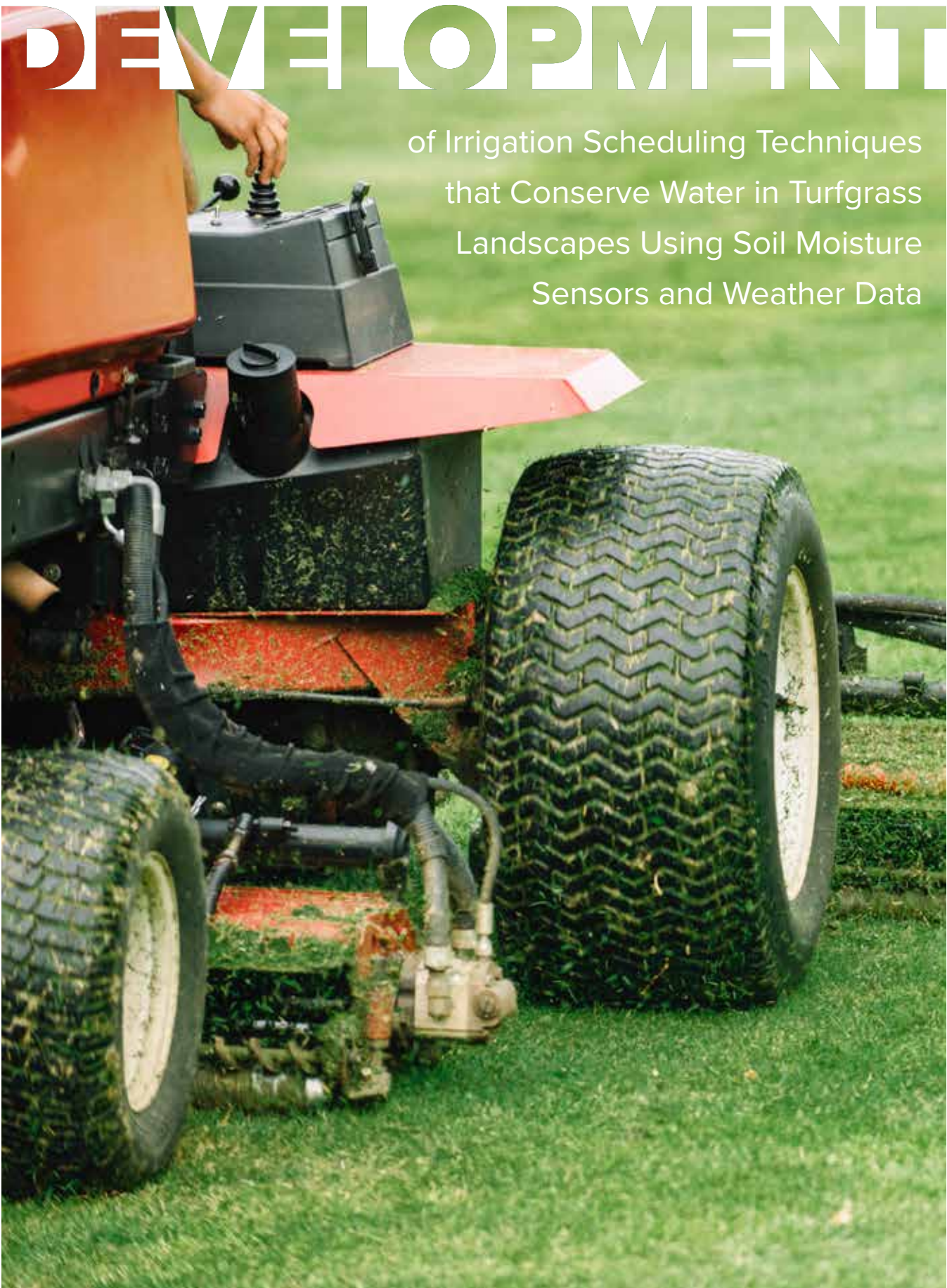


Figure 3. Location of the 2018 TAPS Farm Management Competition participants. Blue circles indicate participants competing in the corn competition, and the green squares represent those competing in the sorghum competition. The Nebraska Natural Resource Districts' and Kansas Groundwater Management Districts' boundaries are also presented.

DEVELOPMENT

of Irrigation Scheduling Techniques
that Conserve Water in Turfgrass
Landscapes Using Soil Moisture
Sensors and Weather Data



Dale Bremer, Horticulture and Natural Resources, Kansas State University;

Cathie Lavis, Horticulture and Natural Resources, Kansas State University;

Andres Patrignani, Agronomy, Kansas State University;

Josh Friell, Toro Company;

Jack Fry, Horticulture and Natural Resources, Kansas State University;

Don (Wes) Dyer, Horticulture and Natural Resources, Kansas State University;

Jared Hoyle, Horticulture and Natural Resources, Kansas State University

Introduction

Irrigation water management is critical to ensure turfgrass health and landscape aesthetics, as well as to conserve and protect increasingly limited local water resources. Efficient water application matching, but not exceeding, minimal turfgrass requirements is crucial, especially for high-quality turf on golf courses or commercial and residential lawns. In the United States, there are an estimated 16 to 20 million hectares of turfgrass (Milesi et al., 2005), both irrigated and unirrigated. Within that, approximately 1.5 million acres are high-quality turf maintained on golf courses using nearly 2 million acre-feet of water per year (EIFG, 2007, 2015). Most irrigation systems operate on a calendar schedule, without regard to soil water status. As a result, turfgrass irrigated with automated systems is almost always overwatered.

The use of soil moisture sensors to control irrigation may be a powerful method to conserve water in turf and landscape irrigation while maintaining plant health. Integrating information from soil moisture sensors into existing irrigation techniques has the potential to substantially advance irrigation management by improving the timing and amount of each irrigation event. For example, previous research has indicated up to 70% water savings when soil moisture sensors were used compared to irrigating on a calendar schedule (Chabon et al., 2017; Dukes, 2012).

Golf courses often are irrigated to maintain high-quality turfgrass. Fairways represent about 30% of the turfgrass acreage on a typical 18-hole golf course. Therefore, reducing irrigation on fairways has the potential to conserve significant amounts of water (EIFG, 2007). However, scientific research has been limited regarding the potential for saving water on fairway-height turfgrass using soil moisture sensors to control irrigation. Despite the availability of commercial systems that promise water conservation by using soil moisture sensors to control irrigation, golf courses have not taken full advantage of soil moisture technology in fairways. This may be because of cost, but is also due to a lack of research into fundamental questions such as sensor placement, soil moisture thresh-

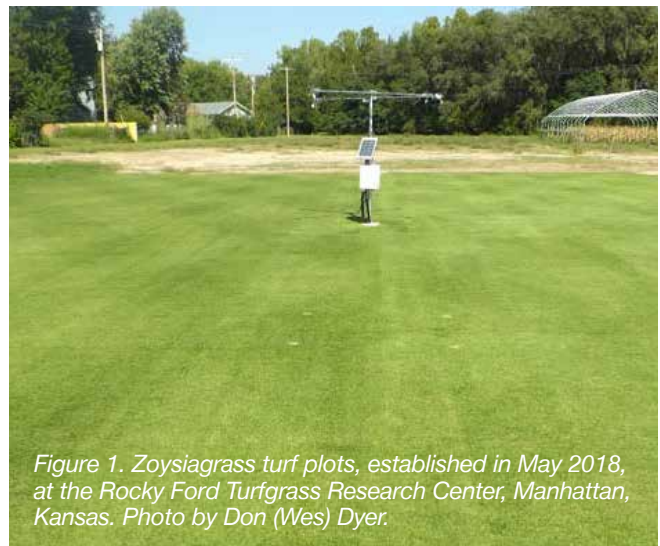


Figure 1. Zoysiagrass turf plots, established in May 2018, at the Rocky Ford Turfgrass Research Center, Manhattan, Kansas. Photo by Don (Wes) Dyer.

Table 1. Project treatments showing tentative treatment values.

Treatment ID	Description
1. Traditional	Traditional management based on a fixed irrigation schedule. No or little soil water stress. Usually leads to over-application irrigation. Three irrigation events target 1 to 1.5 inches per week.
2. 60% ETo	Deficit irrigation. Irrigation represents a fixed portion of the reference evapotranspiration (ETo). Arbitrary percentages are often hard to estimate accurately and vary across locations. We will start with 60% ETo and adjust as necessary.
3. Soil moisture-based	Irrigation based on plant available water. The concept of plant available water links the soil moisture condition with plant water stress, improving the timing and amount of the irrigation event. The irrigation threshold will be determined from phase 1 of the project.



Figure 2. Campbell Scientific (CS655, left panel) and Toro Turf Guard (right two panels) soil moisture sensors were installed in each plot. Photos by Don (Wes) Dyer.

olds for initiating irrigation, effects of soil type on irrigation thresholds, and unknown quantitative relationships between soil moisture and turfgrass quality and performance.

Researchers at Kansas State University (K-State), in collaboration with the U.S. Golf Association (USGA), the Toro Company, and other landscape industry supporters, are beginning fundamental research to improve irrigation by using soil moisture sensors to control irrigation. This research addresses several important questions, including 1) What are the plant available water thresholds for initiating irrigation based on turfgrass visual quality and the onset of stress symptoms, and how do different soil properties affect those thresholds? 2) Can current and forecasted reference evapotranspiration (FRET) data be used to potentially delay irrigation in order to conserve water without risking unacceptable damage to turfgrass? 3) Can we use historical and FRET data to predict soil moisture deficits? and 4) How closely does the increase or decrease in soil moisture correspond to evapotranspiration (ET) and irrigation inputs?

This research at K-State will involve a controlled study to investigate the underlying factors governing irrigation scheduling using soil moisture sensors in high-quality turfgrass. In addition, remote sensing techniques will be used to evaluate turfgrass health. This will include the measurement of vegetative (i.e., normalized difference vegetation index, or NDVI) and thermal (i.e., canopy temperature) properties using both small unmanned aircraft systems and ground-based instruments.

We hypothesize that when used properly, the integration of soil moisture, reference ET, and turfgrass quality data can be used to improve irrigation scheduling and to reduce total water use in turfgrass. By extension, the goal is to encourage turf and landscape managers to adopt new irrigation scheduling techniques for water and cost savings. Our objectives

include 1) determining quantitative turf canopy responses to plant available water from in-situ soil moisture sensors (Phase 1), 2) comparing soil moisture-based irrigation scheduling to traditional irrigation and ET-based irrigation scheduling (Phase 2), and 3) prototyping a simple turfgrass irrigation forecasting tool (Phase 3).

Research Methods

This research is in its early stages, with results forthcoming in 2019-2020. A new 16-zone, in-ground irrigation system was installed in March 2018, consisting of Toro T5 Rapid-Set® Rotors that apply water controlled by a Toro Evolution® controller. Zoysiagrass (*Zoysia japonica*) plots were sodded in May 2018 at the Rocky Ford Turfgrass Research Center in Manhattan, Kansas (Figure 1). Plots are maintained at fairway height (5/8 inch) and fertilized with two pounds of nitrogen per 1,000 square feet annually.

Objective 1

Turfgrass responses to soil water deficits will be studied during multiple soil drydown cycles in the field (i.e., from field capacity to permanent wilting point) during the first year of the project. Soil moisture will be measured at four inches in the field (Figure 2), and responses of the zoysiagrass canopies to drought stress will be evaluated using visual quality ratings and measurements of percentage green cover, canopy temperature, and NDVI (Figure 3). Soil physical properties from the research site will be determined in the lab, along with soil moisture retention curves. In the field, upper and lower limits of plant available water will be determined using turf canopy responses, soil moisture measurements during the dry downs and lab-determined soil properties. We will use statistical and time-series analyses to approximate the upper and lower limits of water-holding capacity directly from sensor readings.

Objective 2

Soil moisture-based irrigation thresholds and quantitative relationships between plant available water and turfgrass quality from objective one will be tested versus traditional and ET-based approaches (Table 1). Evapotranspiration information will be obtained from an onsite Kansas Mesonet station (<http://mesonet.k-state.edu>).

Upon initiation of treatments, total irrigation applied and a number of irrigation events will be recorded for each plot (Figure 4). Soil moisture, soil matric potential, canopy NDVI, and canopy thermal temperatures will be continuously measured for all plots. Thermal and NDVI images will be collected periodically to provide maps of the relative quality and stress level of the turfgrass across each irrigation zone (Bremer et al., 2011).

The results of Phases 1 and 2 will produce a thorough understanding of the relationships between soil moisture, plant available water, and turf health.

Objective 3

Our hypothesis for this phase of research is that turfgrass managers can successfully conserve water by incorporating multiple sources of information into a simple irrigation decision-support tool. Soil moisture information, turfgrass quality, short-term rainfall forecasts, and forecasted reference ET will

be integrated into a tool providing the most probable number of days until stress and the required amount of irrigation to be applied. This tool will allow managers to test multiple alternatives and to make decisions according to their accepted risk. Finally, actual reference ET from the on-site weather station will be compared with FRET values from the NWS to evaluate their accuracy.

Expected Results

From this work, we expect to gain a more thorough understanding of how to best select plant available water thresholds for implementing soil moisture-based irrigation scheduling. The information gained from this project will begin to provide turfgrass managers a more meaningful way of interpreting soil moisture data and enable them to make meaningful changes in their irrigation practices. In addition, an achieved water savings quantification generated through the use of data-directed irrigation scheduling can increase turf managers' motivation to invest in new technology, allowing them to be better water managers.


These results conceivably can drive changes in other industries. Residential, commercial, and agricultural irrigation all have the potential to benefit from the methods and knowledge developed in this work. 



Figure 3. Infrared thermometers (SI-111, Apogee Instruments) and Decagon spectral reflectance sensors (SRS-NDVI) measure canopy thermal temperature and vegetative properties, respectively. Photo by Don (Wes) Dyer.



Figure 4. Water applications will be quantified for each plot using Rainbird water-flow meters (Model FM100B). Photo by Don (Wes) Dyer.



UAS-Based Variable Rate Irrigation

Is it Possible?

José L. Chávez, Civil and Environmental Engineering,
Colorado State University;

Huihui Zhang, Water Management and Systems
Research Unit, U.S. Department of Agriculture-Agricultural
Research Service;

Daran Rudnick, Biological Systems Engineering
Department, University of Nebraska-Lincoln;

Joel Schneekloth, Colorado Water Institute

Remote sensing (RS) techniques have been used to identify crops grown during different seasons and to estimate crop biophysical characteristics and water use. Images from satellites such as Landsat 5, 7, and 8 have been used extensively to map crop actual evapotranspiration rates (ETa) using a suite of algorithms. However, Landsat satellites have a fixed revisit frequency (e.g., 16 days) and pixel spatial resolution of 30 meters (33 yards) for the visible (VIS) and mid-infra-red (MIR) bands, while the thermal infra-red (TIR) band pixel size is 100-120 meters (109-131 yards). Furthermore, some RS of ETa algorithms require that the TIR band be corrected for atmospheric effects, which is a computationally demanding process. These characteristics limit the application of satellites' imagery to generate frequent (e.g., every 2-3 days) and higher spatial resolution (e.g., 1-5 meters pixel size) ETa maps, which are needed in soil-water balance methods to help manage irrigation effectively over heterogeneous fields. These fields' irrigation hardware, if irrigated with a center pivot or a linear move, could potentially be equipped with a Variable Rate Irrigation (VRI) system capable of applying variable irrigation amounts per location in the field. VRI demands higher spatial and temporal resolution ETa maps to generate irrigation application prescription maps.

In this context, Unmanned Aerial Systems (UASs) are amenable to VRI imagery and map demands.

In a study at the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Limited Irrigation Research Farm (LIRF, Figure 1) near Greeley, Colorado, in 2017, a multi-rotor UAS was used to monitor corn ETa over a fully irrigated field and a deficit irrigated field. The irrigation method was sub-surface drip irrigation (SDI).

The remote sensing UAS acquired multispectral (multi-band) and thermal (band) data in July and August. The airframe (Figure 2) used was a DJI Spreading Wings S900 hexacopter (Da-Jiang Innovations Science and Technology Co., LTD, Shenzhen, China). The S900 frame weighs 3kg and has a max takeoff weight of 8.2kg. The system is powered by a MaxAmps 13500XL 6S 22.2v 13500mAh LiPo battery (MaxAmps, Spokane, WA, USA). Overall, the airframe, battery, and land payload S900 weighs 5.8kg and flies safely for about 13 minutes.

A 3DR Pixhawk PX4 flight controller (3D Robotics, Berkeley, California, U.S.) was installed on the UAS. Managing and coordinating the output of six motors manually would be an impossible task; as such, a flight controller is a necessity. The flight controller translates control inputs from the user and data of current orientation from onboard sensors and sends the appropriate signal to the motors. The Pixhawk PX4 also acts as an autopilot, allowing for, under supervision, fully autonomous control of the UAS. The PX4 features a 168Mhz Cortex M4f CPU with 256KB of RAM and 2MB of flash memory. The PX4 also features a 3d accelerometer, magnetometer, gyroscope, and barometer sensors. The PX4 is also paired with a 3DR/Ublox GPS and compass module and a LightWare SF11-C 120m laser rangefinder. The accelerometer, magnetometer, compass, and gyroscope make up the inertial measurement unit (IMU), which calculates UAS pitch, yaw,

(Above) Landsat 8 data courtesy of USGS and processed by Pierre Markuse.



Sub-surface drip irrigation



Figure 1. USDA-ARS Limited Irrigation Research Farm (LIRF) near Greeley, Colorado, depicting fields flown by the UAS in 2017. Courtesy of Maria Cristina Capurro

and roll data. The GPS, compass, barometer, and laser range-finder calculate UAS positional data.

The UAS has two radios installed; a 3DR SiK 915MHz telemetry radio, and a Sanwa (Sanwa Electronic Instrument Co., Ltd., Higashi-Osaka, Japan) RX-861, 2.4GHz FHSS-3 eightchannel receiver. The telemetry radio communicates with a second 3DR SiK 915MHz radio attached via USB to the ground control station. The ground control station, a Panasonic Toughbook CF-31 with ArduPilot's open source Mission Planner software, handles autonomous/semi-autonomous control of the UAS. The RX-861 receiver pairs to a Sanwa SD10GS ten channel 2.4GHz FHSS transmitter for manual/semi-autonomous control of the UAS.

The payload for the UAS consists of a thermal camera FLIR Tau2 LWIR (Figure 3 left, FLIR Systems, Inc., Wilsonville, Oregon, U.S.), and a Tetracam Mini-MCA6 multi-

spectral camera (Figure 3 right, Tetracam Inc., Chatsworth, California, U.S.) to obtain surface (light) reflectance imagery. The Tau2 contains a 640 x 480 pixel (0.3 megapixel) image sensor and has a spectral range from 7.5 to 13.5µm (for surface temperature imagery acquisition). The Mini-MCA6 features a six camera array, with each camera containing 1280 x 1024 pixel (1.3 megapixel) image sensor. A band-pass filter is fitted to each of the six cameras with 10nm bandwidth. The center wavelengths of filters used in the study were 860nm, 720nm, 680nm, 570nm, 530nm, and 490nm; which correspond to the following bands of the electromagnetic spectrum: NIR, Red-edge, Red, Green, Green, and Blue, respectively.

Missions were flown at 95 meters above ground level (AGL) with a 90% overlap and 70% sidelap, which gives a pixel spatial resolution of 5.2 cm and 8.5 cm for the Mini-MCA6 and Tau2, respectively. At the beginning and end of each mission, images of a blackbody and reflectance targets were taken. The blackbody (Omega BB701 Portable blackbody) was set to 100°F. Images of reflectance targets (Labsphere Spectralon



Figure 2. DJI UAS platform operated at USDA ARS LIRF (left) by Kevin Yemoto and Joe Miller, on the ground (top), and closer view of UAS flying (bottom). Photos courtesy of Dr. Huihui Zhang.

targets, 99%, 50%, and 10%) were taken at 95 meters, and ground truth measurements of the targets were taken using a spectroradiometer PSR-1100 (Spectral Evolution Lawrence, Massachusetts 01840, U.S.). Images and mission telemetry logs were downloaded after flights, and a separate GPS file was created from the mission telemetry log.

To create an ortho-rectified mosaic from the raw images acquired from the UAS, a number of steps were taken including: a) raw multispectral imagery conversion to “.tif” (8-bit) format and individual bands stacking; b) thermal imagery format conversion from png (16-bit) to tif format; c) imagery alignment based on the orientation file and the features



Figure 3. FLIR Tau2 LWIR (top), Tetracam Mini-MCA6 (bottom). Photos courtesy of Dr. Huihui Zhang



Figure 4. Handheld multispectral radiometer taking readings over fully irrigated corn (top) and deficit irrigated corn (bottom), on 20 August 2017. Photos courtesy of Dr. José L. Chávez.

detected in adjacent images; d) an ortho-rectified mosaic was generated; e) the multispectral mosaic was aligned to a base-map, and f) the thermal mosaic was aligned to the multispectral aligned mosaic.

Finally, the multispectral mosaic is calibrated using surface reflectance values collected at several locations along the field. A multispectral scanner or a spectrometer can be used for this purpose (Figure 4). The thermal mosaic was rescaled back to the original 16-bit values, and then a linear transformation was performed using surface temperature values collected with a handheld Exergen infra-red thermometer (IRT) to calibrate the thermal (surface temperature) imagery.

Surface reflectance values in the red and near infra-red bands were used in the method proposed by Trout et al. (2008) and Johnson and Trout (2012) to calculate a remote sensing actual basal crop coefficient (K_{cb_rs}). The method first converts reflectance values to Normalized Difference Vegetation Index (NDVI) using a linear transformation equation. Next, NDVI is converted to crop fractional cover (f_c), and another linear transformation is used to convert f_c to K_{cb_rs} . These K_{cb_rs} values represent crop transpiration ratios (in relation to a grass reference ET or ET_o). That is, K_{cb_rs} represents a quasi-real time crop coefficient adjustment that incorporates the response of the crop to actual soil/environmental conditions and stressors (i.e., adequate or shortage of water, salinity, lack of fertilizers, waterlogging). Depending on the crop health status, the plant response is represented through the estimated K_{cb_rs} , which is used to calculate actual crop transpiration rates by means of multiplying K_{cb_rs} by ET_o . ET_o was calculated using the 2005 ASCE-EWRI standardized Penman-Monteith (PM) equation. This ET_o approach needs weather data. Weather data for the calculation of hourly and daily ET_o were downloaded from the Colorado AGricultural Meteorological nETwork (COAGMET). Specifically, weather data were used from station Greeley 04.

Figure 5 (left) shows a map of bulk electrical conductivity (ECb), to a depth of 0.9 meters (3 feet), for the study fields. ECb data were collected with a Veris mapping system. In Figure 5 (left), the light color (yellow) represents areas with low salinity (~ 1 dS/m), while the dark color (dark brown) represents areas of high soil salinity (~ 4 dS/m). ECb is used as a surrogate for soil texture. That is, the low salinity areas equate to (light) sandy soils while the high salinity equates to (heavy) clay soils. It is known that heavy soils depict a larger soil water holding capacity than lighter soils. Therefore, crops may be able to extract water for longer periods of time through the root depth from heavier soils than from lighter ones. This fact was captured by the UAS-derived multispectral surface reflectance imagery (Figure 5 right). Comparing the left portion of Figure 5 (left and right), it is evident that the sandy soils of the deficit irrigation treatment (west field) did not provide sufficient water to sustain a healthy corn growth.

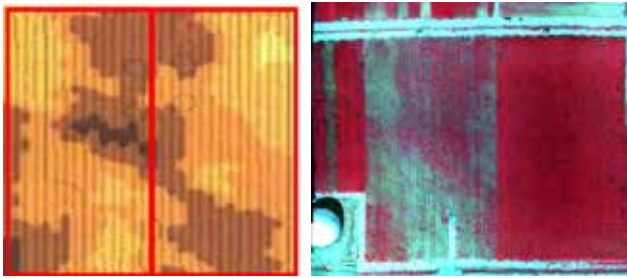


Figure 5. ECb map (left) and surface reflectance imagery (right) from UAS data collected on 22 Sept. Left photo courtesy of USDA ARS LIRF and right photo courtesy of Ashish Masih.

In the reflectance imagery, poor plant growth is shown as brighter reflectance (from dry soil background), while better crop growth due to heavier soils (larger water holding capacity) is depicted as less light reflectance. In Figure 5 (right), surface reflectance is characterized by a false color composite (band stack in the order NIR, Red, Green), where the more intense the red hue the healthier the plant, the more biomass, and therefore the larger the transpiration potential. Thus, the UAS-derived surface reflectance showing less plant growth matches well the sandy areas of the deficit irrigation treatment (west field). This is an indication that irrigation management zones (hydrozones) may be defined with UAS multispectral cameras for VRI. In the case of the fully irrigated treatment (east field), a lighter red hue can also be attributed to sandy areas. However, this is not as evident as in the deficit irrigation treatment because the entire field was managed to avoid crop water stress.

Estimates of ET_a using Kcb_{rs} derived from surface reflectance (Figure 5b) acquired with the UAS, and ground-based multispectral radiometry, are mapped in Figure (6).

The limited irrigation field (west) ET_a rate was about half of the fully irrigated field (east). More variability in ET_a rates can be seen in the west corn field due to the presence of two different soil types (i.e., fine sandy loam and clay loam). The two different soil types and the different irrigation strategies (i.e., full and deficit) could be managed using VRI driven by ET_a maps like the one shown in Figure (6). To do so, ET_a values per identified/defined hydrozone are inserted in a soil water balance (SWB). The SWB tracks the change in soil water content (SWC) in the crop root zone (per hydrozone) by accounting for the water additions (i.e., net irrigation and precipitation) and water removal (i.e., ET_a, runoff, deep percolation). And when the SWC approaches a pre-determined level (per hydrozone) then an irrigation is scheduled/triggered. At that moment, amounts of water (depth) to be applied per hydrozone are known.

Thus, for the data in the study, a neutron probe (NP) SWC sensor was used on a weekly basis to measure soil volumetric water content (VWC) every 30 cm from a depth of 0.3 meters to a depth of 2.0 meters. The NP data

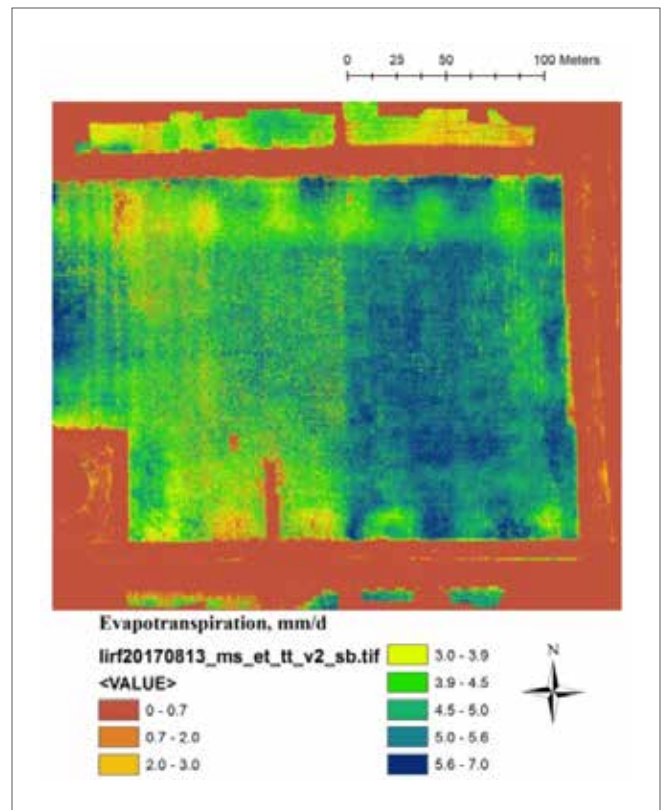



Figure 6. Corn transpiration rates (mm/d) on August 13th, 2017. Photo courtesy of Dr. José L. Chávez.

were used to evaluate the SWB estimates of VWC. The first analysis presented below is for corn percent cover or $fc \leq 60$. The associated mean bias error (average difference between estimated and measured values) was -9.7 % with a root mean square error (RMSE or variance around mean errors) of 19.7 % (absolute). However, for $70 \leq fc \leq 92$ %, the RMSE was 14%. These errors are somewhat low and an indication that the UAS ET algorithm has the potential to be used in VRI to produce irrigation prescription maps. Furthermore, it seems that the ET algorithm based on percent cover works better over crop fractional cover above 70 %. In this case, a combination of SWC sensors and the UAS-based processed imagery may be an approach to produce more accurate VRI prescription maps.

Acknowledgments

This study was possible thanks to funding received from the U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) under award number 2016-68007-25066, "Sustaining Agriculture Through Adaptive Management to Preserve the Ogallala Aquifer Under a Changing Climate," Colorado Northern Water Conservancy District; and Colorado State University Extension. The authors are thankful to the following individuals for their involvement: Jon Altenhofen, Maria Cristina Capurro, Ashish Masih, Dr. Kendall DeJonge, Kevin Yemoto, and Joe Miller. 

Variable Rate Irrigation in the High Plains

Derek Heeren, Biological Systems Engineering Department, University of Nebraska-Lincoln

There is increasing pressure on our water resources, which prompts us to manage our water more precisely. With an increasing demand for food production, variable rate irrigation (VRI) is a technology that may improve irrigation water productivity (yield produced per unit of water diverted for irrigation). VRI may reduce pumping for irrigation, resulting in energy savings and reduced deep percolation of water below the root zone. Reduced leaching of nitrates from the soil would improve water quality in aquifers.

The University of Nebraska-Lincoln and the Daugherty Water for Food Global Institute have been performing field research on VRI for several years. The primary field sites have been the Eastern Nebraska Research and Extension Center near Mead, Nebraska, and the West Central Water Resources Field Laboratory near Brule, Nebraska. Funding from the Irrigation Innovation Consortium (IIC) enabled this field research to continue at the Brule field site in 2018, which represents the High Plains and provides an important semi-arid location to compliment the research at the sub-humid Mead field site.

With an increasing demand for food production, variable rate irrigation (VRI) is a technology that may improve irrigation water productivity.




Variable rate irrigation system and catch cans at the Brule field site. Photo courtesy of Sandeep Bhatti.

Remote sensing imagery from satellites was used along with the SETMI model in order to quantify spatial variability in evapotranspiration (ET) and to develop VRI prescription maps. The crop was soybean, which was the first time this research had been performed on soybean at the Brule location (previous years were corn). Also, deficit irrigation treatments were implemented for the first time, resulting in a total of four treatments: full VRI, deficit VRI, full conventional irrigation, and deficit conventional irrigation. Deficit irrigation allowed soil water to decline to a management-allowed depletion of 75% late in the season.

John Burdette Barker, Post-Doctoral Research Associate, led the field research at the Brule field site. Barker noted two key observations in 2018:

“During irrigation scheduling, the remote-sensing-based model did not seem to drift much as compared to the neutron-probe-based treatments; also, preliminary irrigation results (produced in early September) indicated reduced irrigation for each VRI treatment when compared with its corresponding conventional irrigation treatment and similarly reduced irrigation for each deficit treatment as compared to the corresponding fully irrigated treatment”.

We are thankful for IIC’s support as a way to leverage and extend this ongoing research program. Additionally, the IIC is a great avenue for collaborating with researchers in other states in order to regionalize our work. To learn more about VRI research, visit: <https://heeren.unl.edu/variable-rate-irrigation>. 

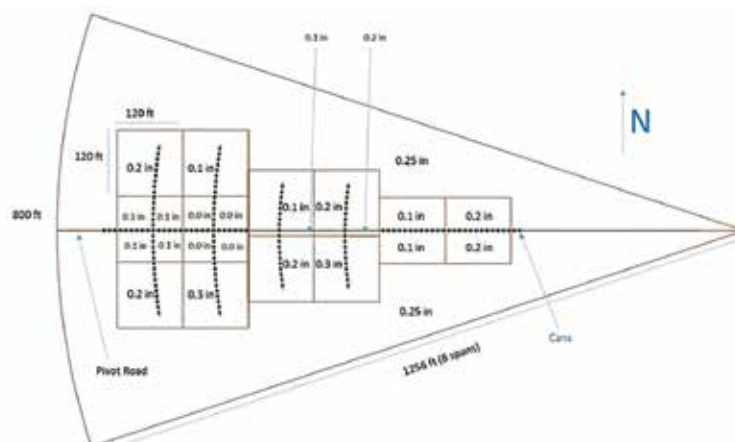


Figure 1. Design layout for system evaluation and catch can test to ensure that the VRI system is working properly. Image courtesy of Burdette Barker.

Back to the Basics

Using a “Water Balance” to Schedule and Monitor Irrigation

Brent W. Auvermann, Texas A&M AgriLife Research and Extension Center at Amarillo;
Thomas H. Marek, Texas A&M AgriLife Research and Extension Center at Amarillo;
Dana O. Porter, Department of Biological and Agricultural Engineering, Texas A&M University;
Texas A&M AgriLife Research and Extension Center at Lubbock

The science, engineering, and art of irrigation management can be summed up in the well-known formula, “applying water at the right amount, at the right time, in the right place, in the right way.” It is easy to say, but it is not so easy to do in practice because every field, every soil, every crop, every day’s weather, and every year’s climate pattern differ from the next. What is more, no two producers farm alike.

Despite those layers of difficulty and uncertainty, engineers, crop scientists, soil scientists, and meteorologists have done a magnificent job over the past 50 years increasing the accuracy, precision, and efficiency of irrigation on a wide range of soils and crops and across a wide spectrum of climates. As recently as the 1990s and early 2000s, the state of the art was the use of mesoscale weather data and crop-specific coefficients to predict daily evapotranspiration, and state-level weather station networks popped up all across the United States to take advantage of the research-based improvements in crop coefficients and weather monitoring.

There is no question that those “evapotranspiration (ET) networks,” as they were called, improved farmers’ ability to schedule irrigation according to how much water the plants were using. Along with advances in irrigation technology, like low-energy precision application (LEPA) and low-energy spray application (LESA) on center-pivot systems, irrigated farms were able to deliver up to 98% and 95% of the applied water into the crop’s root zone (that is, instead of evaporating before the plant could use it) and achieve

greater crop yields per unit of water applied.

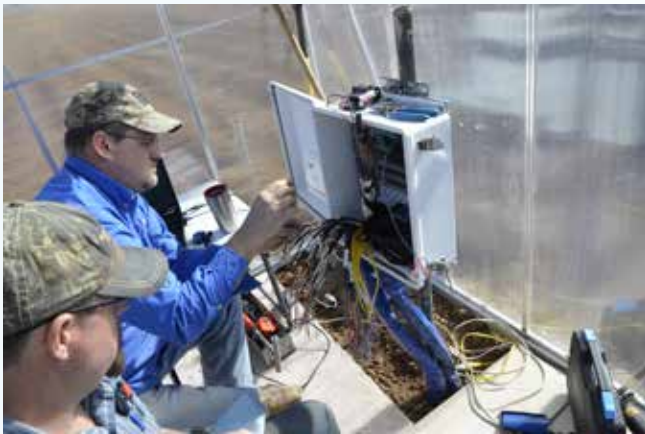
Despite those efficiency achievements, there is still room to improve our irrigation scheduling. The next frontier of irrigation technology is a combination of variable-rate application—putting different amounts of water on different parts of a field to account for within-field variation in soil type, plant vigor, and disease pressure—and real-time water balancing.

Real-time water balancing is analogous to balancing one’s checkbook: what comes in has to be equal to what goes out plus any change in the account balance. At the end of each day, each week, each month, or each year, we can add up all of our revenues and all of our expenses, and the difference between those two numbers is supposed to be equal to the change in what our bank says we have in that account. If the bank balance does not match the difference between revenues and expenses, we know something is amiss, and we can go looking for the error(s).

Similarly, in water-balance irrigation scheduling, we treat soil water as our bank account. We measure the amount of water that we pump onto the field, which is straightforward: we can measure it directly, by installing a water meter on the center pivot, or indirectly estimate it, by monitoring the electrical current that the irrigation pump is consuming. Then we can measure the change in soil water in the root zone by monitoring soil-water sensors installed in various areas and at different depths across the field. Finally, we can estimate evaporation (water losses from the soil surface) and transpiration (beneficial



Later season pivot sector illustrating multiple crops and hybrids. Note the sensor enclosure centered in corn spans (mid-picture) to the right of XTRA semi in background. Photo by Thomas Marek, PE, Texas A&M Agrilife Research.



crop water use) by monitoring the crop's canopy temperature, for example, or through advanced technologies like infrared thermometers (IRTs) or scintillometry. At whatever time interval we desire, we should be able to confirm that the sum total of evaporative losses, crop transpiration, and changes in soil-water storage is equal to the amount of water that we pumped through the irrigation system.

One benefit of this approach is diagnostic: if the soil-water account does not balance—hourly, daily, weekly—we know that something we are measuring is not being measured properly, and our irrigation system is “flying blind,” like a pilot who has lost one or more of his instruments. But if our monitoring systems are operating correctly and generating accurate data, we can realize an operational benefit, adjusting the amount of water we are delivering to the field, or to discrete portions of the field, or even to individual plants, to match the evapotranspiration and changes in soil water storage precisely during the current time period.

The implications of water-balance irrigation scheduling are profound. First, because water has to obey the ancient Law of Conservation of Mass, water-balance irrigation scheduling is constrained by a basic, universal principle, which means if the input data are accurate, the conclusion simply has to be true. Second, as a corollary to the first, the same law applies at any spatial scale and over any time period, which means that we can achieve our scheduling-accuracy goals in real time and at as fine a spatial scale as our monitoring systems can accommodate. Third, because advances in monitoring and data-acquisition technology are allowing us to generate more and more in-field data ever more cheaply and accurately, the practical limits on irrigation efficiency and crop production are still a ways off, as we have not yet approached the theoretical limits of energy conversion and productivity.

So, raise a toast to the Law of Conservation of Mass, an ancient principle that members of the Irrigation Innovation Consortium are exploiting to optimize agricultural water use to a remarkable degree. In the context of water-balance irrigation scheduling, conservation of mass is not just a law of physics; it is also a great idea! 🍷

(Top) Labeled sensor installation at multiple depths and configurations illustrating the mass of sensor lead wires of the study. (Middle) Dr. Kevin Heflin (Texas A&M) and Dr. Gary Marek (ARS) wiring the sensor wires into a multiplexed datalogger in the pivot field under temporary shelter. (Bottom) One of the three completed pivot sectors instrumentation enclosures shown with diverter setup to prevent hang damage from the pivot drops. Photos by Thomas Marek, PE, Texas A&M Agrilife Research.



Water & Energy Efficiency

David Zoldoske, Center for Irrigation Technology, Fresno State

Over-drafting major aquifers for use in food and fiber production is threatening agricultural sustainability regionally, nationally, and globally. Two critical agricultural areas in the United States where this threat is most acute are found in the Ogallala-High Plains Aquifer (which provides water in part to the eight Great Plains states of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming) and the significant aquifers underlying the San Joaquin Valley (SJV) in California. The Great Plains region is often described as the bread basket of the United States. California's SJV has been called the nation's "salad bowl," providing the majority of fruits and vegetables as well as nuts grown in the U.S. Most of the agriculture in these regions is in part or totally dependent on groundwater for irrigation. Current over-draft in these regions creates concerns not only in terms of the quantity of water available to irrigate crops, but also from the perspective of water quality and the energy consumed in transporting water to where it is needed.

In California, estimated statewide over-draft of groundwater averages vary between 500,000 acre-feet a year to more than 1.5 million acre-feet a year (Faunt et al., 2009). The California Farm Water Coalition Agricultural Water Supplier 2015 Survey states that over 2.8 million acres, or about 30%, of California's irrigated farmland, received zero surface water supplies in 2015. The ongoing severe drought in California is one of the major reasons for this and will bring additional pressure on groundwater sources. Any water that is pumped also has an energy component attached to it. Groundwater pumping

energy is about 2% of California's electricity use (5,800 GWh/yr of total 280,000 GWh/yr) (Lund and Hartner, 2013).

Similarly, the Ogallala-High Plains Aquifer is the only and most important source of water in the High Plains region and about 94% of the groundwater use is for irrigation and farming (Kromm and White, 1992). From 1949, after large-scale irrigation started in that region, the water level has declined more than 100 feet in different states where this aquifer is located (McGuire-USGS, 2014).

There are three main areas where water and energy use can be optimized. First, a pumping plant should be designed to operate at a high operating pumping efficiency (OPE/55-65%) as it delivers water to the field. When the pump is operated under multiple pump conditions (flows and/or pressures), it will likely benefit from a variable frequency drive (VFD). This allows the pump to change speeds (RPM) and adjust the pump curve to meet changes in flow/pressure required in the field.

The second important area is water distribution in the field. This can be characterized as Distribution Uniformity (DU) and involves a physical measurement of water distribution in the field, comparing the driest area (water applied) to the average area (water applied). In a perfect system, the driest and average areas would receive the same amounts of water and the DU would be described at 100%. However, in the field, we should expect 90% to 95% for new drip/microsystems, and for sprinkler systems we can typically expect uniformities somewhat lower due to the effects of wind. Most



(Clockwise from top left) water meter, soil moisture probe, direct leaf monitoring, drone helicopter, and remote sensing image. Photos courtesy of David Zoldoske.


irrigation systems deliver high distribution uniformity when first operated, but will decline over time due to wear, plugging, and/or changes to operating conditions.

While operating an irrigation system may appear straight forward, without quality data, it is nearly impossible to achieve high water and energy use efficiency. Every acre-foot of water that does not have to be pumped will save energy and will help to sustain underlying aquifers. Given these scenarios, it stands to reason that improving the efficiency of any aspect of the water delivery system (pumps, distribution, or scheduling) can contribute to significant savings and thus provide a meaningful contribution to sustaining irrigated agriculture in the U.S.

Currently, agricultural management of the water and energy nexus is limited by the existing capabilities of commercially-available data collection, communication, and control tools. Today's best practices include field-level data acquisition and monitoring, including soil moisture content, plant water accumulation, plant stress, water source data, water loss, flow meters, pressure sensors, electricity meters, electromagnetic soil mapper, remote sensors, wireless and/or wired connections, and aerial imaging. These data points provide detailed and in-depth evaluations that inform localized, field-level management about how resources can be cost-effectively optimized to meet crop needs. This methodology allows for first-order resource management, where water can be used most efficiently for the crop and electricity consumption can be scheduled to avoid peak charges.

Integrating various sources of data into a single actionable platform is highly desirable. Those data sources can be many, including pump station performance, weather data, and soil and plant status. However, no platforms are commercially available that fully aggregate this field-level data to evaluate it at the farm-scale—integrating multiple optimization problems in a comprehensive computation module. Without such a platform, farm-scale energy consumption cannot be optimized to account for the needs across fields, soil types, and irrigation systems.

Collecting field measurements and putting them into a standard platform that can monitor and allow growers to act upon the various inputs is a major challenge. Currently, growers may be faced with having dozens of apps all independent of each other. Work is being done to bring the multitude of this information into smart phones, so that management decisions can be addressed in near real-time.

The Irrigation Innovation Consortium is dedicated to addressing both the parts and the whole of managing the water and energy efficiency of an irrigation system. The holy grail will be irrigating each plant independently. Until that time, we will address every small part of the field to manage it independently for local conditions. Our researchers are currently working with their industry partners to develop new sensors, advancing remote sensing and integrating vast amounts of data into a single platform from which growers will be able to make critical decisions on their finite resources. 



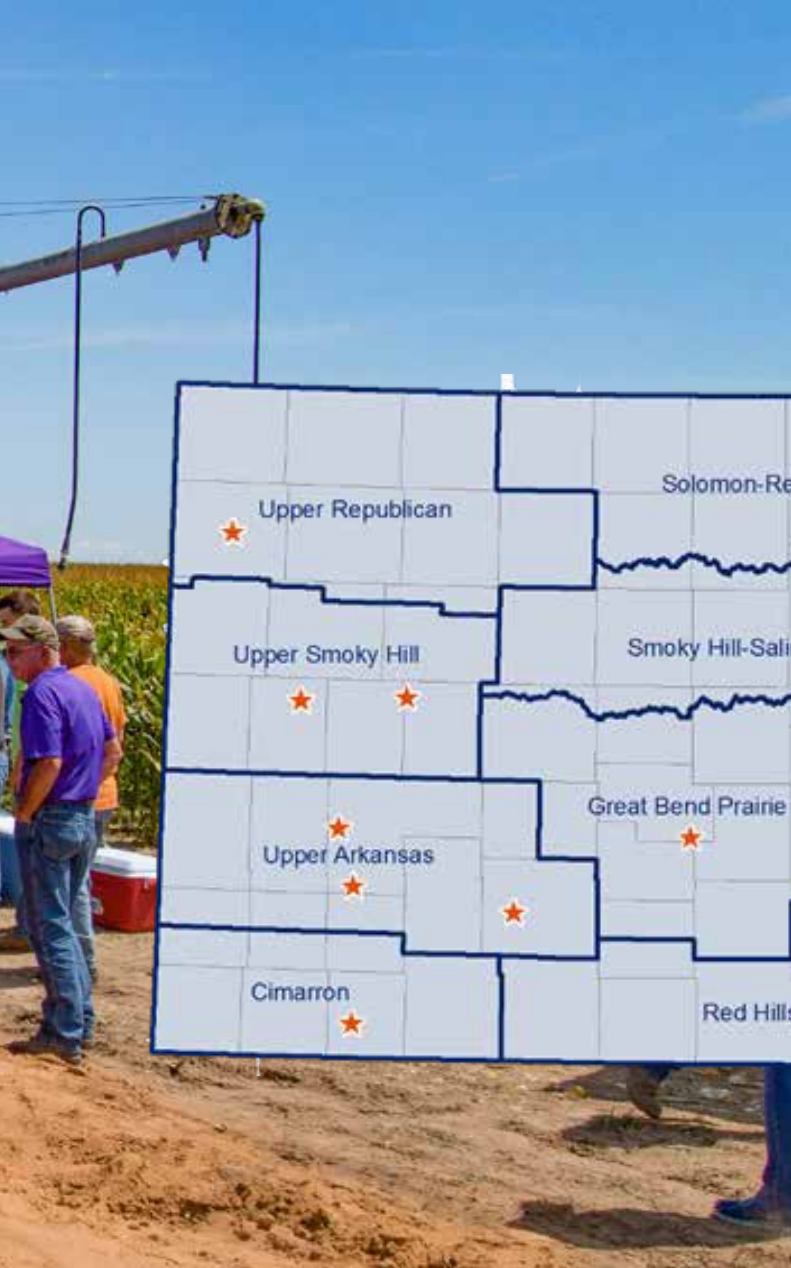
Letting it All Soak In

Water Technology Farms Lead the Way in Water Conservation

Melissa Harvey, Kansas Center for Agricultural Resources
and the Environment (KCARE), Kansas State University

On a sun-drenched August day, a group of farmers, sales representatives, government officials, and university scientists were gathered in the middle of a cornfield. Under the unrelenting sun, everyone had one thing on their minds: water and how to use less of it. This is a Water Technology Farm, one of ten working farms on more than 30 fields sprinkled across Kansas whose owners volunteer to implement various techniques to improve water conservation and water quality on their land. New irrigation technologies can be commercially labeled as “efficient” or “cost-effective,” but farmers never really know how those technologies—so triumphant in a controlled experimental field—will perform in their own operations. On a water technology farm, producers can see first-hand how the latest irrigation products work in a real-world setting.

Jonathan Aguilar, a water resource specialist with Kansas State University Research and Extension, is one of the experts working with producers on water tech farms. According to



(Left) Interested producers gather at the WaterPACK/ILS farm south of Larned, Kansas, to learn more about how water technology farms work.

(Below) Locations of water technology farms in Kansas.

Photo and map courtesy of the Kansas Water Office.

him, these farms operate by showcasing technologies such as mobile drip irrigation (MDI), evapotranspiration (ET)-based scheduling, soil water sensors, cropping patterns, and other tools, so that producers have visible proof of how these experimental methodologies can assist them in their individual efforts toward water conservation.

“It’s important to address all of the farmers’ issues regarding water irrigation systems and the ways that you can properly increase the efficiency in terms of water use,” says Aguilar. To do this, each technology farm hosts an annual field day where interested landowners and farmers can speak directly to the farm’s producer, researchers like Aguilar, irrigation company representatives, and other specialists.

Although water conservation and quality is a common theme, each water technology farm has its own unique set of challenges. Soil type, well volume, and salinity are only a few of the issues that Kansas farmers need to address. “There is no

‘one size fits all’ technology that will work,” says Aguilar. And, it is usually a combination of technologies that best fit a farmer’s production. This makes the partnerships inherent in this concept even more important. The Kansas Water Office funds and administers the program through public-private partnerships for cash and in-kind contributions from 22 agencies and partners. Armando Zarco, program manager for the water technology farms, says the idea is gaining momentum in the state: the program added four new farms in 2018, and the Kansas Legislature has approved \$75,000 in funding from the State Water Plan Fund for 2019—a significant increase over previous years.

Doing More with Less

One successful water technology farm is located in Finney County, in western Kansas. Operated by Dwane Roth and owned by the Garden City Company, this farm uses irrigation water from the Arkansas River, which has salinity issues. The operation is comparing the effectiveness of bubblers, iWob, and MDI systems at different spacings. While the MDI system applies water directly to the soil using long lines that drag on the ground, bubblers are irrigation nozzles located 12 inches above the soil that apply water directly below the nozzle. Both systems hope to avoid wind-drift and evaporation losses. iWob nozzles use a low-pressure operation to deliver a

consistent water droplet size and apply water consistently and uniformly over a large area, like an imitation rainstorm. To monitor the effectiveness of these three systems, Roth's farm has soil water sensors in place.

Richard Wenstrom, a member of the Water Protection Association of Central Kansas (WaterPACK), helped to establish another water technology farm located just south of Larned, Kansas. This farm, owned by Innovative Livestock Solutions (ILS), was one of the first to volunteer for the program. The focus of the WaterPACK/ILS farm is to evaluate the performance of MDI on a higher volume well in an area that has sandy soils. To compare the irrigation systems, the farm planted one corn circle in straight rows using spray nozzles and planted another in a circle using a combination of spray nozzles and MDI. The farm also uses weather-based and soil water sensors for irrigation scheduling. The sensors below the soil's surface help growers make decisions more quickly and accurately—including having the confidence to turn their systems off when they are not needed.

"We farm where we live," Wenstrom told the dozens of producers gathered at his farm's field day last August. His point that water conservation affects everyone in the community is especially true in many parts of Kansas, where the Ogallala Aquifer, the main source for irrigation, is depleting faster than it can replenish. Farmers like Wenstrom, along

with university scientists and the state government, hope that water technology farms will inspire more producers to embrace water-saving ideas.

Each farm is as unique as its producer, but Zarco highlights the water technology farm at the Northwest Kansas Technical College (NWTC) in Goodland, Kansas, as a unique opportunity for hands-on training and workforce development. While the other water tech farms only can focus on one producer and one farm at a time, the NWTC farm represents a partnership between landowners and students in the college's Department of Precision Agriculture. Around 40 students are learning to implement technologies like moisture probes and pivot controls in a whole-field setting. Zarco hopes that their experiences mapping fields or installing cutting-edge irrigation technology at the college's water technology farm will encourage the students to implement water conservation techniques in their future agricultural careers.

Like those at NWTC, Kansas water technology farms represent the confluence of many partnerships. According to the Kansas Water Office, the ten farms have 80 sponsors offering advice and assistance with irrigation application methods, cropping patterns, soil moisture probes, mapping tools, aerial imagery, and more. Some of these technologies, like MDI, are available from only a few vendors, while others, like soil moisture probes, are popular and available in many options.



Photo courtesy of the Kansas Water Office.

When facing these choices, Zarco says that producers can use the experience found on water technology farms to help them choose what is best for their setup.

Producers Can See Results

At their August field day, the Garden City Company/Roth Farm reported the use of 5.7 inches of irrigated water, barely half of their Water Conservation Area (WCA) allocation. Roth credits the use of soil water probes for these results, telling the Kansas Water Office that the probes “showed more water in the soil than we realized,” which meant that the farm had been overwatered in the past. “Not only is the farm using less water,” Roth reports, but it is also seeing “record” yields.

Matt Long, a Wichita-area producer who joined a WCA agreement and has volunteered to take a 29% reduction in irrigation, also reports success using soil moisture probes on his water tech farm outside of Marienthal, Kansas. At his farm’s field day, Long told attendees that he has cut his water use in half, irrigating fields with only 4-6 inches.


With most of the farms still in their beginning three-year phase, Zarco says, “it is difficult to track the overall effectiveness of the technology and techniques. Although many farms have seen a ‘definite’ reduction in their irrigation use, some of that could be attributed to local rainfall amounts. At the moment, economics are actually the best gauge for

success.” Using less irrigation means using less fuel to run the pumps, which leads to more profits for the producer.

The Future of Water Technology Farms in Kansas

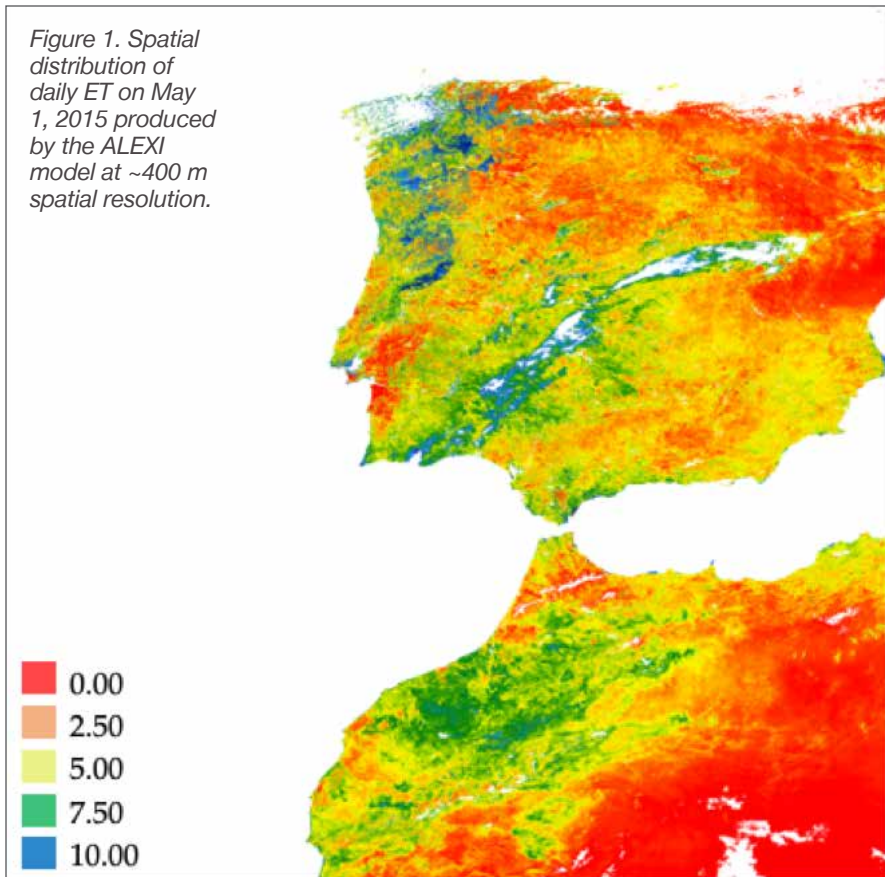
Zarco is working with producers so that the program continues to flourish. Adding more water tech farms creates greater benefits, and not just because more farms are using less water. With additional sites spread around the state, more producers have an opportunity to see these practices put into action. More locations also give researchers and farmers a good idea about how different techniques can function in different watersheds.

Producers interested in joining the program can do so through the Kansas Water Office, with priority given to farms located in documented conservation programs like Water Conservation Areas or Local Enhanced Management Areas. Zarco says, “the number of farms accepted is dependent on the budget and the sponsors willing to contribute; the application deadline is December 1st.”

Currently, three water tech farms have completed their final year in the program, but Zarco is working on the possibility of renewing those farms for another three years so that more data can be collected on the efficacy of the technologies they are using. “We want them to stay committed for quite a long time,” he says. 



Daily Satellite-Based Evapotranspiration for Irrigation Water Management



Christopher M.U. Neale, Daugherty Water for Food Global Institute at the University of Nebraska

As the world population grows and increased pressures on freshwater resources occur from competing uses, it has become imperative to carefully account for water availability in watersheds at all scales. Evapotranspiration (ET) from natural and agricultural vegetation is the main consumptive use of water in the hydrologic cycle, and estimating it correctly allows for improved estimates of runoff and recharge, particularly in ungauged basins. In addition, ET data are used in irrigation water management at field and system scales and are important inputs to crop yield models. The Daugherty Water for Food Global Institute at the University of Nebraska and its partners at U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS), National Aeronautics and Space Administration (NASA), and the University of Maryland are generating a global satellite-based daily ET product using the ALEXI model (Anderson et al., 2007; Anderson et al., 2011) with inputs from the Visible Infrared Imaging Radiometer Suite (VIIRS) satellite instrument (<https://ncc.nesdis.noaa.gov/VIIRS/>). The ALEXI model is presently being run in real time for the Middle East and North Africa (MENA) region at the Holland Computer Center at University of Nebraska-Lincoln, using the VIIRS satellite data and other global atmospheric and climate datasets as inputs (Figure 1). This effort is funded through the United States Agency for

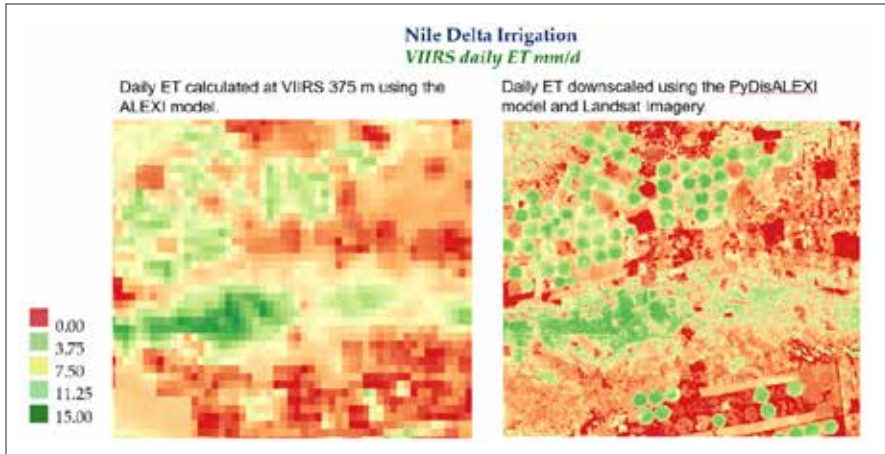


Figure 2. VIIRS based ALEXI evapotranspiration downsampled to 30 m using PyDisALEXI and Landsat data.

ranspiration Estimates

International Development (USAID) and is part of a drought monitoring project in the region that involves the National Drought Mitigation Center at the University of Nebraska-Lincoln and the International Center for Biosaline Agriculture (ICBA).

The daily ET data product is served through the Global Daily ET (GLO-DET) webpage and has a spatial resolution of 400 meters. Daily ET estimates can be downscaled to 30-meter spatial resolution using ancillary Landsat satellite imagery and an open source Python version of DisALEXI, a disaggregation approach developed for this purpose (Figure 2). In this way, field scale values of evapotranspiration can be obtained

for irrigation water demand estimates and management.

As part of the Irrigation Innovation Consortium (IIC) activities, the ALEXI ET product will be generated for the central plains, including irrigated areas and the corn and soybean belt production areas. In order to verify and improve the accuracy of the satellite-based product, a network of eddy covariance flux stations will provide real-time, corrected, and quality-controlled daily crop evapotranspiration data that will anchor the spatially distributed satellite-based estimates. These flux towers will be located in agricultural and natural vegetation systems in different states and include towers managed by IIC partner-


ing universities and USDA-ARS in the region. The Smartflux2 system that runs EddyPro in real time is the backbone system at each station in the network, allowing for real-time processing of the data at each flux tower, applying all pertinent corrections and calibrations. The data and evapotranspiration measurements are accessed through cell phone communication with each tower using the FluxSuite online software. Industry partners for this activity include LI-COR Biosciences, farmer groups in different states, and Natural Resource Districts in Nebraska, and government partners include the USDA-ARS National Laboratory for Agriculture and the Environment in Ames, Iowa. 



Figure 3. Mobile eddy covariance flux tower positioned in a cornfield near Brule Nebraska running SmartFlux2 and connected with FluxSuite. Photo by Dayle McDermitt, LICOR Biosciences, Lincoln, Nebraska.

Subsurface Wireless Networks for Soil Moisture Sensing and Irrigation Water Management

Allan A. Andales, Soil and Crop Sciences, Colorado State University;
Jay Ham, Soil and Crop Sciences, Colorado State University

Typically, irrigation scheduling is performed with the soil water balance method (Andales et al., 2015), which uses weather-based estimates of crop evapotranspiration (ET) and approximations of soil water content in the root zone. This approach is also employed by the Water Irrigation Scheduler for Efficient Application (WISE; <http://wise.colostate.edu/>), a digital tool developed by researchers at Colorado State University (Andales et al., 2014; Bartlett et al., 2015). WISE provides online irrigation scheduling information in a convenient and cost-effective way, using publicly available data on soils and weather (Fig. 1). It has been tested in Colorado for common irrigated crops (corn, sugar beets,



Figure 1. The WISE Web browser interface (above) and auxiliary smartphone app (left). Initial setup of each irrigated field is done in a cloud-based GIS (eRAMS; <https://erams.com/>). Once each field is set up, the irrigation requirements of each field can be tracked using the smartphone app.

and alfalfa), and testing continues for more crops. Adoption of this tool has led to irrigation scheduling decisions informed by local soil and weather conditions.

Since WISE currently relies on modeled soil water content in the root zone, the tool's accuracy can be affected by errors in soil, weather, or irrigation inputs as well as modeled values of ET. Integration of Internet-of-Things (IoT) soil moisture sensors (SMS) with WISE could improve the accuracy of irrigation requirements by providing real-time measurements of actual soil water content. Low-cost SMS, currently being developed in Jay Ham's lab, will be linked to the WISE app to show real-time status of root zone soil moisture at selected

points in a field. This information will be used to calculate the soil water deficits (net irrigation requirement) in different zones within a field.

This new soil moisture measurement technique uses underground wireless networks. Core technology is low-cost wireless sensor nodes that communicate by radio through the soil (vs. through the air)—eliminating the need for aboveground infrastructure and greatly simplifying the logistics of instrumenting a field with IoT sensors. Changes in soil moisture are quantified by detecting how radio signals and data are attenuated when passing through the soil. Higher soil moisture content results in weaker signals and lower network integrity. Conversely, as the soil dries, signal strength between nodes increases, and data packet transfer improves. Thus, there is a mathematical relationship between soil water content and network performance, providing a method for water content detection (patent pending). Each domino-sized node is powered by a small internal battery that can last for five years. Once installed, the sensor network detects real-time changes in soil moisture and communicates the results to an aboveground cellular gateway and the cloud (Fig. 2). First-generation prototypes have been tested in the laboratory and small plots. Large-scale field trials are planned for 2019 in agricultural and urban applications. Data from the sensor networks will be integrated into the WISE software, allowing for more informed irrigation scheduling.

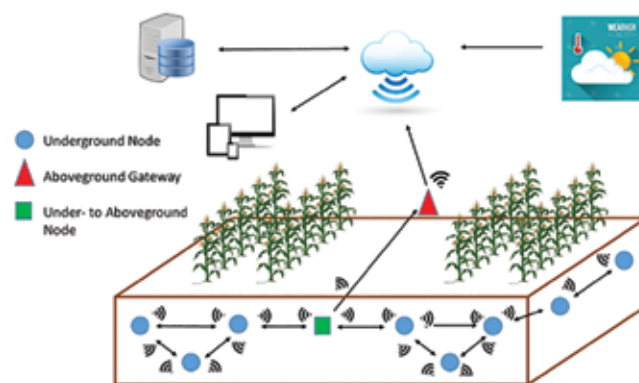


Figure 2. Diagram of a wireless underground sensor network used to measure soil moisture (adapted from Ojha et al., 2015). The IoT based system transfers data to the cloud where it can be used by the WISE irrigation software.

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*An increasing demand for food production is driving innovations in irrigation efficiency technology.
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