Innovative Extension Methods in the U.S. to Promote Irrigation Water Management

Daran Rudnick
University of Nebraska-Lincoln, daran.rudnick@unl.edu

Matt Stockton
University of Nebraska-Lincoln, matt.stockton@unl.edu

Saleh Taghvaeian
Department of Biosystems and Agricultural Engineering, saleh.taghvaeian@okstate.edu

Jason Warren
Oklahoma State University, jason.warren@okstate.edu

Michael D. Dukes
University of Florida, mddukes@ufl.edu

See next page for additional authors

Authors
Daran Rudnick, Matt Stockton, Saleh Taghvaeian, Jason Warren, Michael D. Dukes, Amy Kremen, Christopher G. Henry, Jonathan Aguilar, Brenda Ortiz, Allan A. Andales, Chuck A. Burr, Xin Qiao, Wei-zhen Liang, Steven Walthour, and Steve H. Amosson

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HIGHLIGHTS

- University extension has been playing a larger role, serving a larger number of irrigated farms.
- Extension programs in irrigation water management (IWM) have been transitioning away from lectures and field tours as the primary means of knowledge transfer.
- New IWM programs focus on experiential learning, development of practitioner networks, and industry participation.

Abstract. *Promotion and adoption of irrigation water management (IWM) technology, tools, and best management practices are important as water availability concerns are addressed. Traditional extension programs have relied on lecture presentations, field tours, fact sheets, and on-station demonstrations to promote IWM practices and tools. However, these platforms tend not to provide the experience and opportunity for growers to identify and become comfortable with innovative solutions, such as new technology. To address these challenges and to appeal to an ever-changing client base, innovative and locally relevant extension and outreach programs have been devised to engage and educate growers. This article describes some of these programs that extend beyond previous traditional programs to connect growers with IWM.*

Keywords. *Demonstrations, Experiential learning, Grower competition, Outreach, Practitioner networks.*

Poor or ineffective irrigation management has had a negative impact on the quality and quantity of water resources, environmental health, and financial sustainability of agricultural areas. With concerns for future water availability coupled with increased competition for freshwater sources across varying sectors of society, the value of water conservation technologies and new practices to improve irrigation water management (IWM) have escalated. Numerous IWM methods and technologies are used by growers and land owners, such as soil water and plant sensors, daily estimates of evapotranspiration (ET), visual observation, mimicking neighbors, and the feel of the soil, among others (USDA-NASS, 2019; Rudnick et al., 2019). These methods vary widely in their ability to match irrigation with crop water needs. To mitigate the disparity among irrigators, extension services and water conservation programs (e.g., USDA-NRCS EQIP) have demonstrated, promoted, and incentivized the use of more effective techniques. Countless research efforts have been made to develop improved tools, technologies, and methods. This was done assuming that superior methods would naturally replace less effective methods over time. However, adoption has been slower than expected, as reflected in a survey by the USDA National Agricultural Statistics Service (USDA-NASS, 2019). Lo et al. (2019) explained that adoption of new methods requires that growers recognize the need to improve IWM, along with being informed of the tools available. However, due to the constantly proliferating technolog-

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The authors are **Daran R. Rudnick,** Assistant Professor, Department of Biological Systems Engineering, University of Nebraska-Lincoln, Lincoln, Nebraska; **Matt Stockton,** Associate Professor, Department of Agricultural Economics, University of Nebraska-Lincoln, Lincoln, Nebraska; **Saleh Taghvaeian,** Assistant Professor, Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma; **Jason Warren,** Associate Professor, Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, Oklahoma; **Michael D. Dukes,** Director, Center for Landscape Conservation and Ecology, University of Florida, Gainesville, Florida; **Amy Kremen,** Project Manager, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, Colorado; **Christopher G. Henry,** Associate Professor, Rice Research and Extension Center, University of Arkansas, Fayetteville, Arkansas; **Jonathan Aguilar,** Associate Professor, Department of Biological and Agricultural Engineering, Kansas State University, Garden City, Kansas; **Brenda Ortiz,** Associate Professor, Department of Crop, Soil, and Environmental Sciences, Auburn University, Auburn, Alabama; **Allan Andales,** Professor, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, Colorado; **Chuck A. Burr,** Extension Educator, West Central Research and Extension Center, University of Nebraska, North Platte, Nebraska; **Xin Qiao,** Assistant Professor, Department of Biological Systems Engineering, University of Nebraska-Lincoln, Scottsbluff, Nebraska; **Weizhen Liang,** Post-Doctoral Research Associate, Panhandle Research and Extension Center, University of Nebraska-Lincoln, Scottsbluff, Nebraska; **Steven Walthour,** General Manager, North Plains Groundwater Conservation District, Amarillo, Texas; **Steve H. Amosson,** Professor, Department of Agricultural Economics, Texas A&M University, West Amarillo, Texas. **Corresponding author**: Daran Rudnick, 247 Chase Hall, East Campus, University of Nebraska, Lincoln, NE 68503; phone: 308-696-6709; e-mail: daran.rudnick@unl.edu.

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ical changes (hardware and software), philosophies, practices, and methods, it is difficult for new users to assess the value, costs, and risks of investing the time and resources required to make the change.

The USDA-NASS surveys also indicated regional differences in adoption rates for the various irrigation scheduling methods (USDA-NASS, 1998, 2019). These differences were likely due to proximity to technology providers, maturity of the technology or method for various crops, incentive structures, geographic and climatic variations, institutional and regulation differences, local norms, and peer and societal pressures. Some differences in adoption rates were also expected to be associated with varying extension and outreach efforts, priorities, and programs. For example, Nebraska had the most growth in the use of soil water monitoring relative to other categories for irrigation management, from 6% in 1998 to 31% in 2018, while Kansas had the fastest growth in the use of ET-based scheduling, from 7% in 1998 to 17% in 2018. These two methods may have had the most growth in their respective states, as compared to other scheduling methods, because of the extension and research mission of their university faculty. Kansas State University faculty developed and promoted the use of an ET-based irrigation-scheduling tool titled KanSched (Rogers and Alam, 2007), while University of Nebraska-Lincoln faculty promoted soil water sensors (Irmak et al., 2010, 2016; Rudnick et al., 2016) along with ET-based estimates.

The mission of extension has been to bring the most current science and technology to growers and to better understand the issues and challenges that stakeholders face (Ryan et al., 2018). Furthermore, education and extension programs that promote irrigation best management practices have also focused on public understanding and the importance of irrigation (Porter et al., 2010). Extension's primary audience for irrigation technology adoption includes agricultural producers, crop consultants, technical service providers, and irrigation professionals (Porter et al., 2010) as well as home and business owners, landscape professionals, and green industries (IFAS, 2017). This audience has continued to evolve due to education, information accessibility, communication technology, societal expectations, regulatory increases, equipment sophistication, changes in production systems, productivity changes, and ever-escalating capital needs and intensity. To remain relevant and effective, the space and methods in which extension professionals engage growers and landowners must be just as dynamic. The objective of this article is to introduce, describe, and discuss some of the more recent innovative and non-traditional extension programs that promote the adoption of more efficient IWM across the continental U.S. This documentation will serve as a resource for program comparison and new program development in IWM.

IWM and the Role of Extension

Many of the new IWM practices are supported by incentive payments provided by USDA-NRCS Irrigation Water Management Practice Standard 449 (USDA-NRCS, 2002). Land grant universities have often aligned their extension programs to support and facilitate conservation practices when incentives are available. Historically, USDA-NRCS programs have focused on structural and hardware practices, such as sprinkler nozzle replacement, land leveling, tailwater recovery, etc. However, Practice Standard 449 provides an incentive payment for irrigation management technology and tools, such as soil water sensors, weather stations, and computerized scheduling. This provides an opportunity for extension programs to create synergy for their efforts in improving adoption of IWM practices in their regions.

The most recent survey by USDA-NASS (2019) indicated that university extension is a major source of information for reducing irrigation costs and/or conserving water. Among the top 28 irrigated states, which collectively contain 97% of the irrigated land in the U.S., 26% to 79% of irrigated farms relied on extension as a source of information. Specifically, university extension was the leading source of information for 39% of the top irrigated states and the second leading source for 46% of these states as compared to seven other sources of information, including private consultants, equipment dealers, and federal agencies.

Comparison with previous USDA-NASS surveys indicates that extension is playing a larger role, serving a larger number of irrigated farms. Compared to 2003, 24 of the top 28 irrigated states have experienced a greater reliance on extension programs (fig. 1). The percentage change in farms relying on extension during the period from 2003 to 2018 ranged from a 7% decrease in South Dakota to a 29% increase in Indiana. Georgia and Florida were second highest, each with a 26% increase in the number of farms relying on extension for irrigation information.

Innovative Extension Programs

Traditional extension programs have relied on lecture presentations, field tours, fact sheets, and on-station (i.e., research farm) demonstrations. These methods, which are primarily didactic, work well for many topics but seem to fall short with changing paradigms, and their impact is difficult to measure. These methods also tend not to provide the experience that growers need to become comfortable with innovative solutions, whether new management practices or the use of new technology. Furthermore, as spectators of technology or management, attendees of an extension event may not feel comfortable investing time and resources or experimenting on their own farms. To address these challenges and to appeal to an ever-changing client base, innovative and locally relevant extension and outreach programs have been developed to engage and educate growers. A selection of these innovative programs is described in the following sections.

Competitions to Promote Efficiency

To facilitate engagement at a higher level and to create a real change in thinking about agricultural production, faculty at the University of Nebraska-Lincoln recognized that extension should address five points. First, producers need to be present, engaged, and committed to learning. Second, adult learners are hands-on, action oriented, and they readily learn

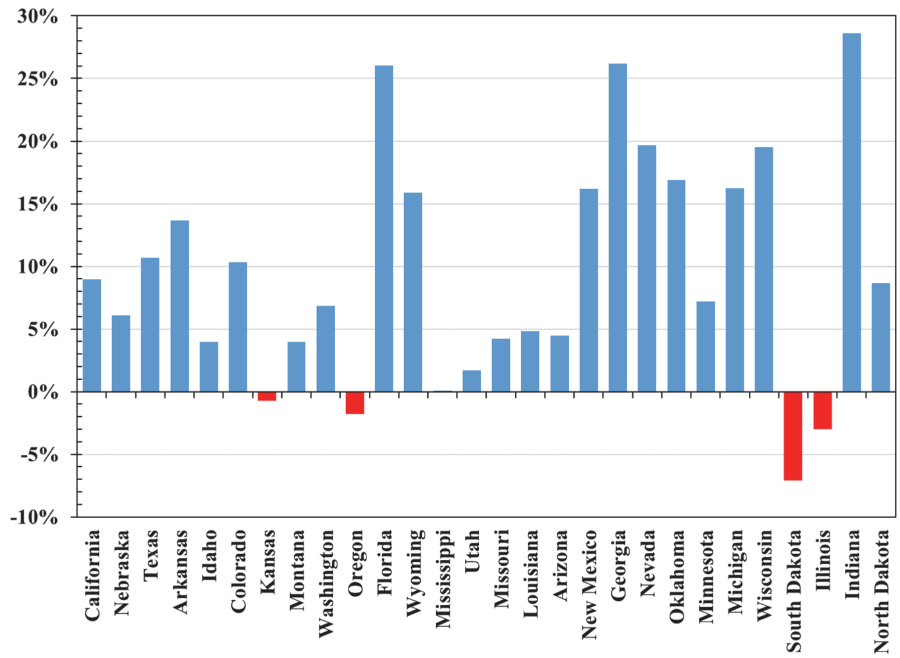

Figure 1. Change in the percentage of irrigated farms that relied on university extension for irrigation information during the period from 2003 to 2018 based on data from USDA-NASS (2003, 2019).

from their peers. Third, producers and industry representatives are practical experts and should be involved in the teaching. Fourth, many producers, while interested in university results, are reluctant to trust them without further experience (adoption risk). Lastly, the focus of educational programs can be one-sided, considering only conservation or economics, with little insight into how they relate, threaten, or appear to producers and their goals. To this end, the Testing Ag Performance Solutions (TAPS) program was conceived in 2017 (Rudnick, 2017).

The TAPS program hosted Farm Management Competitions in which teams (individuals or groups) competed in the production and marketing of crops. The competitions were conducted under variable-rate irrigation systems at the University of Nebraska-Lincoln West Central Research, Education, and Extension Center in North Platte, Nebraska, and at the Oklahoma State University McCaull Research and Demonstration Farm near Eva, Oklahoma (fig. 2). The TAPS program reached out to producers from neighboring states and included participants from outside Nebraska and Oklahoma.

The competitions were structured as research experiments using a randomized complete block design with three replications (fig. 3). Each team was randomly assigned a plot within each block. The teams made all production, management, and marketing decisions for their plots during the competition. The results of their decisions were combined with other budget information and amplified to represent a sizable farm (405 to 1,214 ha depending on crop and system type). Each team competed to be (1) the most profitable farm, (2) the most efficient user of water and nitrogen (N) fertilizer, and/or (3) the greatest grain yielding farm. Their decisions were made under conditions that closely reflected an actual farm business. Options included crop insurance coverage, crop variety and planting density, marketing decisions, irrigation amount and timing, and N fertilizer amount, timing, and method. The research team recorded the pre-season and post-season management choices and measured data during the growing season, including weather conditions, soil properties, soil water content, canopy reflectance and temperature, crop growth and development, grain yield, and N uptake, among others. The TAPS program involved many different groups, including producers, natural resource district leaders, NRCS technical staff, professional farm advisors, university extension specialists, agricultural suppliers and services, and local, state, and federal agency experts, which provided a rich source of ideas and learning opportunities.

The TAPS program was innovative because it bridged the gaps between the many different institutions and entities that are part of production agriculture. As a farm management competition, it directly related to integrated management and the relationships among resource use and conservation, management, profitability, and sustainability. Unlike many traditional extension activities, the TAPS program unleashed the power of individual motivation, creativity, and innovation, directly engaging stakeholders in finding efficient and profitable ways to manage production. The participants tested their own management methods using new and emerging technologies in a scientifically sound and risk-free environment that allowed strategies to be evaluated for their potential commercial success without the threat of negatively affecting farm operation if they did not perform as expected. With so many new tools available today, growers need to know which are reliable for making agronomic and economic decisions. Data were collected on replicated plots to determine the reliability of these tools, to make appropriate recommendation to growers, and to provide feedback to industry on product performance. This scientific evaluation of farm management practices was especially valuable to producers because it provided a thorough understanding of grower-based management practices

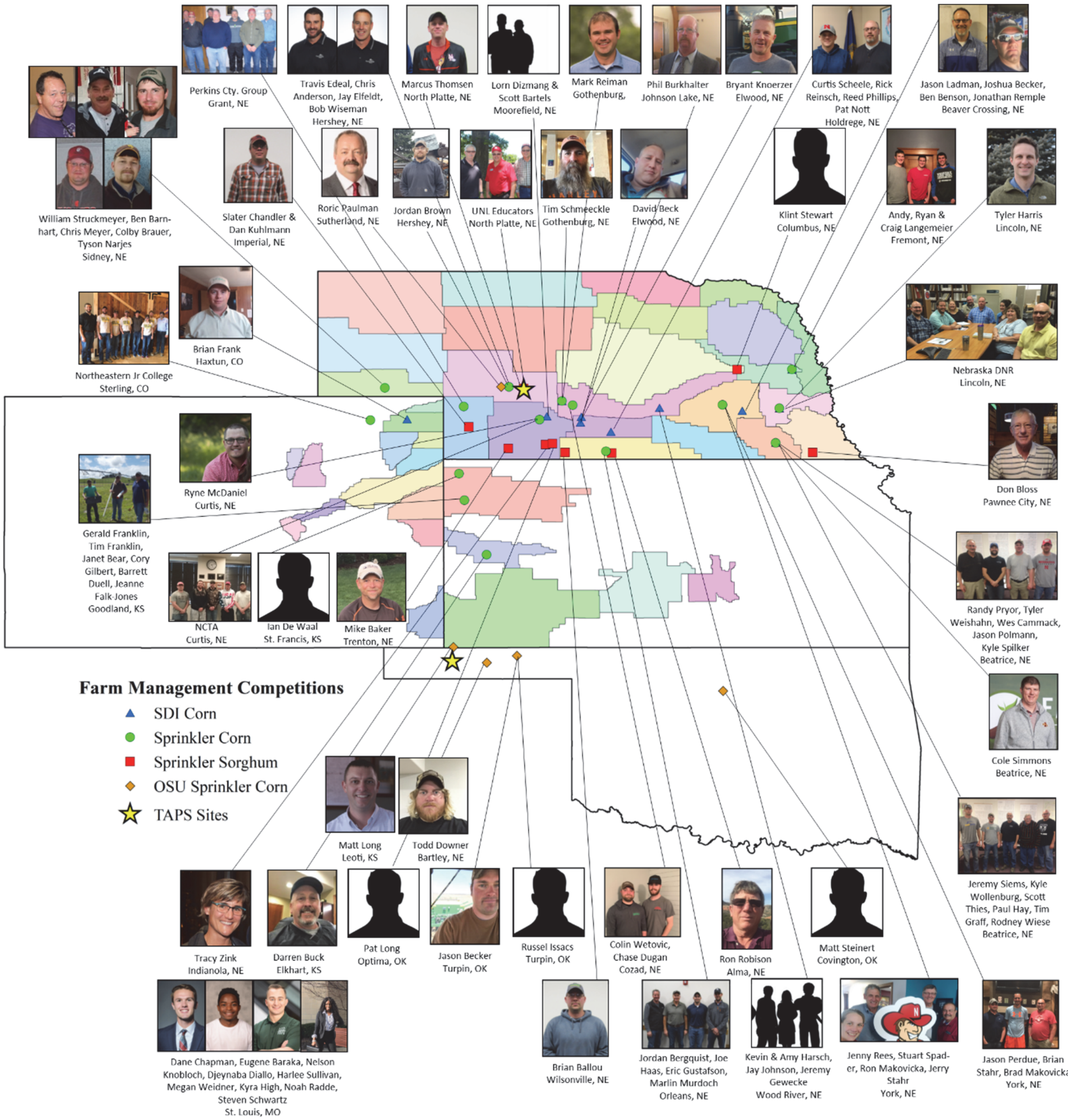

Figure 2. Location of the 2019 TAPS Farm Management Competitions, photos of the participants, and boundaries of the Nebraska Natural Resource Districts, Colorado Groundwater Management Districts, and Kansas Groundwater Management Districts.

among their peers as well as against a university team that applied extension recommendations to a set of plots. Furthermore, Lo et al. (2019) used data from the 2017 TAPS competition to study the theory and practical significance of water and N use efficiency indices to develop appropriate metrics and recommendations for growers. The TAPS competitions directly addressed the adoption challenges mentioned above and created excitement among producers, educators, and other stakeholders.

Following each annual competition, the participants were surveyed to evaluate the impact of the program. The following is a summary of the 2018 survey related to irrigation technology. These results show a high potential for individuals to learn and incorporate new ways of thinking and doing. The survey had four parts. Part 1 addressed why the participants joined the TAPS program, parts 2 and 3 addressed changes in their thinking and behavior, and part 4 solicited information about program concerns, changes, and improvements:

- Part 1: 34% of the participants joined TAPS to learn from other competitors, 31% to test new technology, 14% to help a friend, and 21% for other reasons. Program satisfaction was high, with 77% reporting that TAPS met or exceeded their expectations. If asked by a neighbor about TAPS, 72% said that it was a

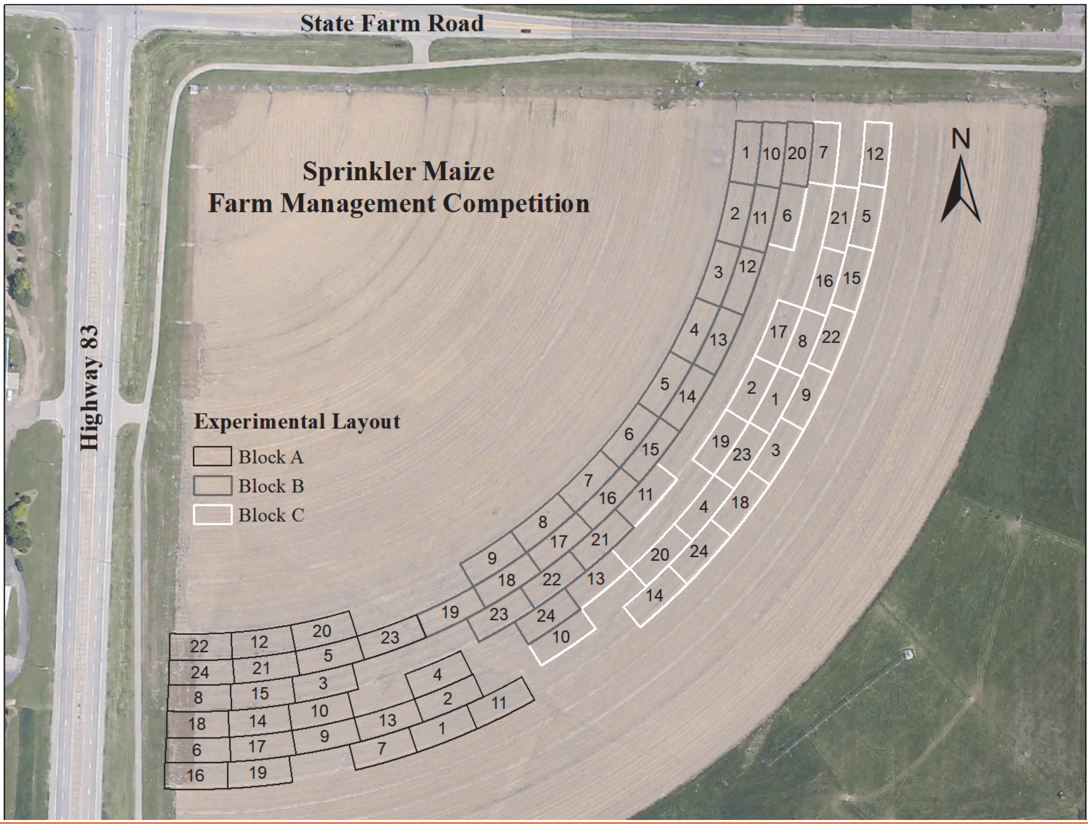

Figure 3. Experimental layout for the 2019 Maize and Sorghum Farm Management Competitions held at the West Central Research, Extension, and Education Center in North Platte, Nebraska. Each team had a randomized plot located in blocks A, B, and C (AirScout imagery collected by Flying M Aviation on June 13, 2019).

"great" program, 25% thought it was a "good" experience, and the rest were just "okay" with it. All participants would recommend the experience to others.

- Parts 2 and 3: Irrigation skills were increased. For example, 68% of the participants increased their confidence in irrigation technology (e.g., soil water sensors), 68% adopted soil water sensors to schedule irrigation, 65% reported an increased understanding of crop irrigation requirements, and 47% reported an increased understanding of how to use and interpret plant sensors (e.g., dendrometery).
- Part 4: Participants' opinions on the program design and possible future changes were solicited as: "If you were running the TAPS program, what specific things would you do?" The responses indicated that 81% of the participants would include more web-accessible information, and 82% wanted more information on how to use technology.

The contest approach used in the TAPS program has real promise as an effective engagement model to help producers move forward in their use of technology and adopt new methods for crop production. Another contest-based extension program titled "Arkansas Irrigation Yield Contest: Most Crop per Drop" was developed in 2018 (Henry et al., 2019). This irrigation contest was similar to a commodity-based yield contest in which water use efficiency, rather than yield, was used as the evaluation metric.

Certificate Programs

The North Plains Groundwater Conservation District (NPGCD, 2020), located in the northernmost counties of the Texas Panhandle, recognized the need for a practical and science-based program to assist producers in exploring how IWM tools and strategies might be appropriate given bio-geophysical constraints (i.e., pumping capacity, soil type) and on-farm production habits. Furthermore, the NPGCD felt that such a program should provide growers with needed information and a knowledgeable social network to rely on in selecting tools and strategies that are practical, affordable, and relevant to their farm business. To this end, the Master Irrigator program was created. The NPGCD Master Irrigator program required the following elements: (1) a focus on agricultural irrigation, (2) a program advisory committee (PAC) of stakeholders and local experts, (3) at least 24 h of instruction (four days or more), (4) locally relevant instruction on systems, agronomics, and irrigation scheduling, and (5) techniques and equipment that are commercially available. The program reflected a solid understanding of farmers' attitudes about managing water and their short-term and long-term production goals. The program also encouraged peer-to-peer exchange among producers. The NPGCD Master Irrigator program started in 2016 and was used as a template for the development of a Master Irrigator program in northeast Colorado and Oklahoma.

The attendance at the first four trainings conducted by the NPGCD was 90 participants (78 producers and 12 industry

professionals) who represented 106,432 ha of irrigated land. A recently completed implementation survey of the 2016 graduates found that 100% of the respondents adopted one or more conservation strategy (average of 3.25 practices adopted) from the training. All respondents reported gains in water use efficiency (yield per irrigation applied), and 67% reported applying an average of 69 mm less water.

The PAC was a critical component of all Master Irrigator programs. The PAC was responsible for engaging and fostering dialogue with regional partners by (1) supporting conversations and activities among individuals and groups that share a common goal to sustain farming in the region, and (2) identifying a range of externally supported opportunities and incentives for program graduates, encouraging them to pursue their water and energy conservation goals. Examples of PAC-identified incentives included access to additional professional development and training opportunities, heightened eligibility for cost-share programs, and discounts for inputs, tools, technology, and equipment. Another key component added to the Colorado program was to have graduates identify a commitment to experiment with conservation practices and tools based on information covered during the program.

On-Farm Research and Demonstrations

Water Technology Farms

To address growing concerns about the ability of the Ogallala Aquifer to support irrigated agriculture, several Kansas producers approached K-State Research and Extension (KSRE), the Kansas Water Office (KWO), and other government and private entities for help in identifying economically viable solutions to extend the usable life of the aquifer. Specifically, the producers were looking for visible proof about which IWM technologies, methods, and practices could work for their location and situation. Through this partnership, the design, installation, and monitoring of research-based demonstration farms, known as Water Technology Farms (WTFs), were established (KWO, 2015). The WTF network grew from three farms in 2016 to 15 farms in 2019 (fig. 4).

As part of the WTFs, IWM techniques were demonstrated, field-scale research was conducted, and water conservation was supported on producer-owned fields. The WTFs extended beyond traditional demonstration sites because KSRE was able to work with multiple farms to develop unique, location-specific, and research-based demonstrations of water conservation. Historical on-farm demonstrations have focused on agronomic studies, with less emphasis on differences in irrigation system configuration and management practices, primarily due to costs. This limitation was overcome through the unique public-private partnership of the WTFs. The farmers identified the objectives they wanted to achieve and the technologies they were interested in, while KSRE designed the experiments and evaluated the outcomes. The participating producers considered numerous technologies, including new water applicators (e.g., mobile drip and low-elevation spray) and irrigation scheduling tools (e.g., soil water sensors and ET-based models), and management practices (e.g., circular planting, cover crop rotation, and high planting rates). The participating producers also agreed to provide agronomic and economic information, host field days, and share their experiences through various outlets. Collectively, the lessons learned on these farms and the producers' testimony on the technology they tested was a significant catalyst for efforts to improve IWM in the region.

The WTFs were instrumental in expanding the conversation about water conservation from producers to the general public, policy makers, and water managers. As a result, KWO hired a coordinator, and Kansas legislators allocated funding in 2019 to support the program. Expansion of the WTFs allowed the program to expand its focus from technology to workforce development and from water quantity issues to water quality and soil health, particularly as it expanded toward the eastern part of the state. Most of the farms agreed to reduce

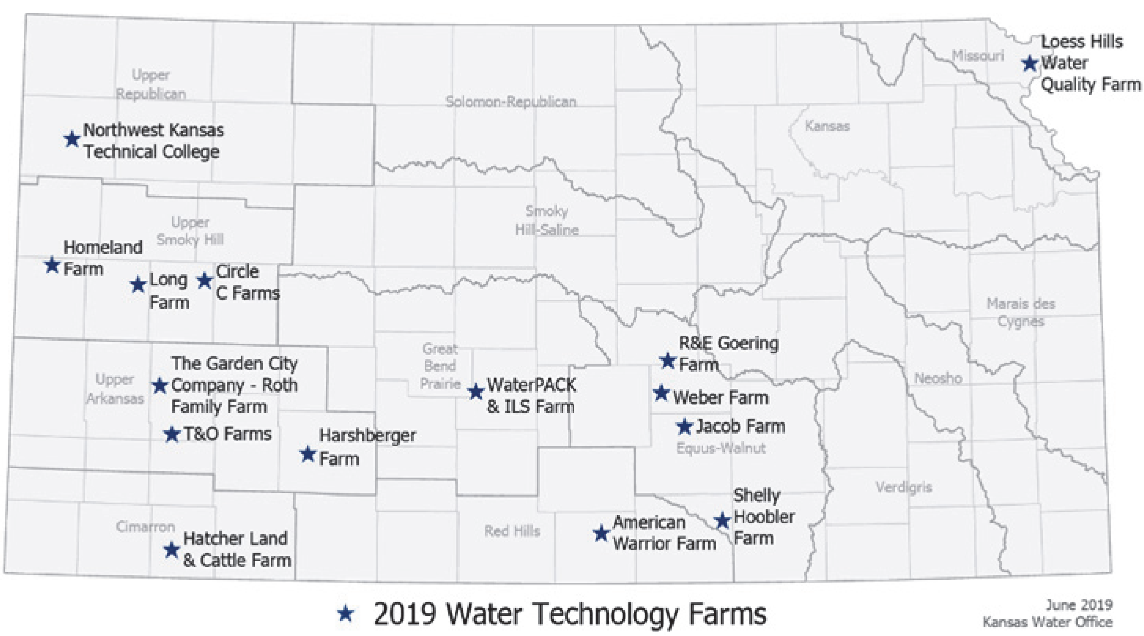

Figure 4. Distribution of 2019 Water Technology Farms (WTFs) across Kansas (source: https://kwo.ks.gov/projects/water-technology-farms).

their water use by a certain percentage (typically 10% to 20%), and of the three farms that reached their three-year participation, all achieved or surpassed their reduction goals.

Alabama Participatory Demonstration Network

In recent years, Alabama producers have invested in irrigation due to the increased frequency of prolonged droughts. To broaden their reach and to address spatial challenges, university extension faculty moved from conducting irrigation demonstrations at university research and extension centers to on-farm demonstrations of irrigation scheduling and variable-rate irrigation. The irrigation demonstration sites constituted a network of farms that represented different agroecologic conditions and management methods. A participatory approach was established to foster co-learning and exchange knowledge among multiple actors: farmer to farmer, farmer to scientist, farmer to industry, and scientist to industry. Adoption of best irrigation practices is a process, not a unilateral decision. The co-learning process facilitated by this participatory approach involved several steps: (1) identification of farmers' expectations, needs, and current practices, (2) farmer and extension team agreements on how the demonstrations were to be conducted and definitions of roles, responsibilities, and activities, (3) identification of possible partners, (4) identification of outputs and outcomes, (5) establishment of the demonstrations and monitoring of the learning process, and (6) frequent meetings to discuss the data collected during the growing season and agreement on irrigation decisions based on the data. At the demonstration sites, different IWM methods (e.g., soil water sensors, smart phone apps, crop growth simulation models) were evaluated under a variable-rate center pivot irrigation system. During the group meetings, data collected from the sensors were discussed, such as the impact of irrigation or rainfall on soil water dynamics and how to interpret data from sensors, apps, and models to prescribe irrigation. The producers were encouraged to present their data and share their knowledge with other interested producers. Coaching (one-to-one interaction) and reiteration of concepts were often necessary for the participating producers to understand, accept, and adopt these sometimes-complex irrigation practices.

Mid-South IWM Demonstrations

Faculty at land grant institutions in Arkansas and Mississippi identified four IWM practices, i.e., computerized hole selection (CHS), surge irrigation, soil water monitoring, and multiple inlet rice irrigation, that were not fully used in the mid-south region (i.e., Arkansas, the boot heel of Missouri, Mississippi, and Louisiana). CHS determines the correct hole size for each individual furrow in a lay-flat irrigation pipe system by accounting for row length, inlet and required individual furrow flow, pipeline pressure and hydraulics, and crown elevation. Two software programs exist for CHS: Pipe Hole and Universal Crown Evaluation Tool (PHAUCET) (Burch, 2012) and a commercial product, Pipe Planner™, developed and maintained by Delta Plastics (2020). From 2013 to 2017, the four IWM practices were evaluated in the region using paired field comparisons (Bryant et al., 2017; Spencer et al., 2019). The paired field comparisons consisted of one field receiving the demonstration of IWM practices while the other field was the producer-managed field, holding other management practices (e.g., cultivar selection) constant. Bryant et al. (2017) implemented these practices on 20 paired furrow-irrigated soybean fields and found no significant difference in yield between IWM and the control ($p = 0.67$), while IWM reduced water use by 21% ($p = 0.0198$) and increased irrigation water use efficiency by 36% ($p = 0.0194$). Spencer et al. (2019) conducted 18 paired on-farm maize demonstrations in Arkansas and Mississippi and found that IWM improved water use efficiency by 51% ($p = 0.0062$), increased maize grain yield by 0.41 Mg ha^{-1} ($p = 0.0137$), and increased net returns above irrigation costs by \$62 to \$69 per hectare. The collective findings showed that growers can adopt IWM practices and can recover the IWM investment costs through reduction in energy by applying less irrigation.

The demonstration results were used to motivate growers to adopt IWM and were disseminated through irrigation schools and county production, irrigation, and conference meetings. In Mississippi, the program was called the Row-crop Irrigation Science and Extension Research (RISER) program. In Arkansas, it was facilitated by county agents through an existing initiative to conduct on-farm demonstrations with growers. The demonstration and supporting extension programs appeared to be effective, as adoption of soil water monitoring increased by 52% in Arkansas and by 114% in Mississippi from 2012 to 2017 (USDA-NASS, 2013, 2019). However, the effectiveness of this type of large-scale demonstration program was likely underestimated due to the observer effect, also known as the Hawthorne effect (Roethlisberger, 1941). In other words, individuals under study may alter their response due to their knowledge of being observed; thus, demonstration programs may need to be modified to fully account for their impact.

North Plains Water Conservation Center

In the fall of 2014, the North Plains Groundwater Conservation District (NPGCD, 2020) officially took over management of the North Plains Water Conservation Center (WCC) at Etter, Texas, formerly known as the Texas Agricultural Experiment Station. The NPGCD had owned the facility since 1987 and leased it to Texas A&M AgriLife Research and Extension. Beginning in 2014, the WCC refocused on demonstration of practical water conservation technologies that were readily available to growers and could be executed at production scale. The WCC was re-tooled with state-of-the art farming infrastructure and irrigation systems to reflect the systems commonly used by the most progressive farmers in the district. These improvements included two new low-energy precision application (LEPA) center pivots as well as 15 ha of subsurface drip irrigation (SDI). The SDI project was funded through an agreement with the USDA-NRCS that required previously irrigated area be converted to a cover crop. The NPGCD collaborated with a local grower to demonstrate a wide array of conservation technologies at the WCC, including LEPA and SDI systems as well as soil water monitoring, center pivot monitoring and control systems, and on-farm weather stations. An innovative component of the WCC was the integration of irrigation management tech-

nologies with conservation practices such as hybrid selection, residue management, cover crops, and optimized planting dates to present a multi-dimensional resource management system. The WCC used traditional dissemination techniques to engage growers and has also used social media and hosted virtual field days to enhance reach to the more electronically oriented audience. In 2019, the WCC was one of multiple locations across the district to host the first season of an on-line educational program called "Cotton and Conservation" in cooperation with Texas A&M AgriLife Extension.

Urban Water Conservation

Similar to agriculture, urban and suburban areas can be subjected to diminishing freshwater quality and quantity and often compete with agriculture for water resources. This concern can be exacerbated by increased urbanization, along with the unprecedented hydrological changes resulting from climate change (McDonald et al., 2011). To address this concern, the Florida-Friendly Landscaping (FFL) program was developed to provide research-based training and educational services on efficient landscape management (e.g., water, nutrients, etc.) to homeowners, landscape professionals, and green industries. The FFL program operates under nine principles: (1) right plant and right place, (2) water efficiently, (3) fertilize appropriately, (4) mulch, (5) attract wildlife, (6) manage pests responsibly, (7) recycle, (8) reduce stormwater runoff, and (9) protect the waterfront (IFAS, 2009).

To support the FFL program and provide guidance to users, Boyer and Dukes (2015) developed a technical guide to predict the impact of implementing various water conservation measures based on prior research. This technical guide directly addressed a primary barrier of water conservation adoption, which is inadequate information about available water conservation strategies and their associated benefits (Borisova et al., 2017). This technical guide served as an example of a traditional program through its integration of research and extension; however, it was developed into an innovative system that allowed extension agents to estimate the impact and value of their teachings. As described by Borisova et al. (2017), estimating the benefit and value of water conservation programs can improve overall extension accountability, enhance program marketing and promotion, and ensure broader engagement of community members. In addition, it provides an opportunity to educate the public on the importance of irrigation and the role of water conservation practices in water security, which was identified by Porter et al. (2010) as a key attribute of an irrigation extension program. The FFL program has estimated that more than 1,461 million liters of water, equivalent to more than $2 million, have been saved by utilities and their customers (IFAS, 2019).

Technology Adoption Infrastructure

In the modern era of digital and precision agriculture, producers are seeking near real-time site-specific information to guide their irrigation and agronomic decisions. Consequently, an appropriate system and data infrastructure must be developed to allow sensor integration and modeling at a spatial extent. Development of this infrastructure will also allow new extension programming. For example, since the early 1990s, irrigation extension efforts in Colorado have included ET-based irrigation scheduling using data collected from automatic weather stations. Initially, the fledging network of less than ten stations in Colorado limited the spatial relevancy of ET-based scheduling in parts of Colorado. The Colorado Agricultural Meteorological Network (CoAgMet, 2017) now has a greater spatial reach and increased producer relevancy, as it operates more than 90 stations as of 2020. With expansion of the CoAgMet network, along with the advent of cloud services and smartphones, the development of a statewide irrigation scheduling tool called Water Irrigation Scheduler for Efficient Application (WISE App) was possible (Andales et al., 2014; Bartlett et al., 2015). The WISE App has expanded the utility of ET-based irrigation scheduling because it accounts for field-specific attributes, such as soil water holding capacity, applied irrigation, crop development, and soil water deficits.

The integration of sensor data can improve the accuracy of model-based irrigation schedulers (Andales, 2019) as well as other agronomic models. The internet of things (IoT) has been developing rapidly and may be a perfect match for agricultural applications due to its highly interoperable, scalable, pervasive, open nature and its capability of providing near real-time monitoring (Liang et al., 2020). Furthermore, deployment of IoT, along with its accompanying communication technology (e.g., LoRa), can connect large numbers of sensors, which creates the potential for cluster networks (i.e., groups of producers working together). In other words, the infrastructure that promotes sensor connectivity may also allow new extension programming that fosters a community of growers working together to manage their resources.

Summary

The programs highlighted in this article are just a snapshot of current IWM extension efforts across the U.S. that have been designed, modified, and shaped to address local issues while working within specific institutional and regulatory frameworks. However, each of the highlighted programs shared the idea of extending beyond traditional programming to connect and engage producers with IWM. A few commonalities across the programs included transitioning away from lectures or field tours as a primary knowledge transfer mechanism and focusing instead on experiential learning, development of practitioner networks, and participation from industry.

Fostering a community or peer network that supports and promotes IWM technology can further increase as well as sustain adoption of IWM. The TAPS program built comradery through a competition that hosted annual banquets where the participants discussed their strategies and built relationships. The on-farm demonstration programs fostered networks of producers, and the research-based demonstration sites served as local hubs where participating and neighboring producers, along with researchers, industry representatives, and agricultural service providers, could experiment with technology. The Master Irrigator program provided a

cohort of participants with an intensive four-day training, followed by technical support, and cost-share funding for adoption of IWM technology. On-farm paired comparison of IWM practices in the mid-south and other regions also demonstrated significant benefits. Other efforts, such as technology infrastructure development, also have potential to foster peer-to-peer and community sharing of data to improve adoption of IWM.

An important component of each of these programs was the involvement of experiential learning. Whether through a competition, demonstration site, or workshop, these programs recognized the value of putting technology and methods into the hands of users. The TAPS program allowed farmers to evaluate new technologies and management strategies as well as learn from others who used different options. It also gave technology providers an opportunity to highlight their products and learn how their products can be improved. The on-farm demonstration programs were similar but focused their experiential learning on producer-owned farms, which can be more effective for evaluating site-specific (i.e., tailored to their location) irrigation application technologies and management options. A drawback of demonstration sites is that typically fewer producers are directly engaged in the program, unless the program is accompanied by other extension efforts, such as training sessions and workshops. The Master Irrigator programs started with intensive four-day training, followed by experiential learning facilitated through cost-share programs and follow-up meetings.

The effectiveness and long-term impact of IWM extension programs will rely on the ability of the programs to evolve and modify their delivery of products and resources. In addition, recruiting and engaging younger producers will be important because they have an acute short-term interest in farm profitably and a long-term interest in keeping their farms viable, especially in areas where water availability is dwindling. Younger producers may also be more amenable to management changes and system upgrades, including adoption of IWM. Similarly, younger landscape irrigation managers, whether they are homeowners or landscape professionals, are assumed to be more amenable to water conservation practices and management upgrades. Lastly, the effectiveness and impact of IWM extension programs will benefit from enhanced communication among irrigation extension specialists as well as transparent and accessible documentation of program strengths, weaknesses, and impacts. In addition, as older extension staff retire and are replaced by younger professionals, training programs for new extension personnel (many of whom may not have farming experience) will be essential to maintain the momentum.

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