

Water Optimization through Applied Irrigation Research

Matt Yost, Niel Allen, Warren Peterson, and Jody Gale

Irrigation, insurance, and life often do not end up in the same sentence. Irrigation provides essential insurance, even the lifeblood on irrigated farms. During the past 75 years, irrigation has brought people and prosperity to rural areas throughout the world. Given adequate water resources, irrigation ensures water essential to economic production of high quality food, fuel, feed, and fiber in needed quantities. Agriculture has become the largest user of extracted or diverted water on the planet and, consequently, the forefront of efforts to conserve and optimize water use.

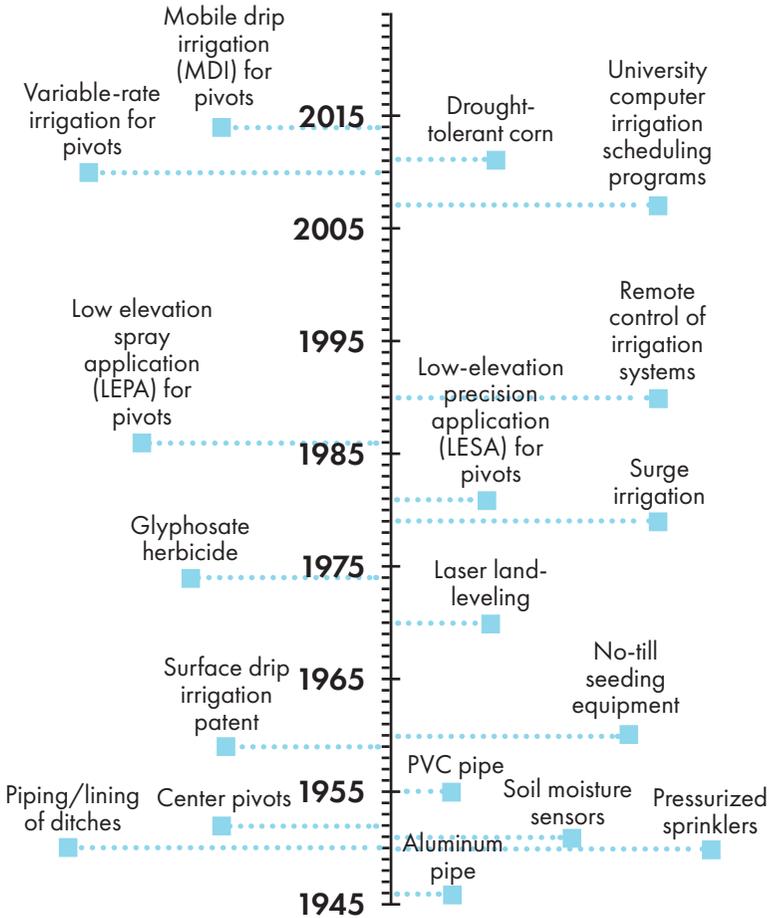
As competition for limited water resources increases across the world, water scarcity rises as a sustainability concern for irrigated agriculture. Rapid urban growth, increased food demands, groundwater depletion, soil and water salinity, and water supply shortages drive this competition. Competition will also increase due to projected climate trends toward less frequent, more variable, and different types (rainfall versus snow) of precipitation.

To address these water scarcity concerns, policymakers, scientists, engineers, practitioners, educators, farmers, and many others have and are working to optimize agricultural water use. Numerous technologies, developments, and policies have brought tremendous advancements in agricultural water optimization. For the sake of brevity, this article highlights only a few major changes of the last 75 years (figure 1) and a few needed efforts for the future. This discussion focuses on three central areas impacting water

Matt Yost is an agroclimate extension specialist and **Niel Allen** is an extension irrigation specialist, Utah State University, Logan, Utah. **Warren Peterson** (retired) was land and natural resources vice president, Farmland Reserve, Inc., Salt Lake City, Utah. **Jody Gale** is extension associate professor, Utah State University, Richfield, Utah.

Figure 1

Timeline of some of the major advances in water conservation from 1945 to 2020. Dates for many technologies are when they were first widely commercially available, unless otherwise noted.



optimization—irrigation, crop, and soil management—while acknowledging that complex interactions of these and other factors influence water optimization in agriculture.

■ Irrigation Management

A comprehensive view of irrigation management begins from the point of first diversion through delivery to the field, continues to water application, and evapotranspiration (ET) through the crop, and ends with return flow and

soil water storage. Major advancements in the first two areas are described briefly below.

Diversion and Delivery to the Irrigation System. Artificial irrigation relies on diversion from surface and groundwater sources. Greater access to and utilization of groundwater has reduced losses incurred during surface water delivery. Lining and piping of delivery systems have also been a major water optimization advancement (Schaible and Aillery 2012). Lined ditches and piping catalyzed by developments of improved materials (concrete, polyvinyl chloride [PVC], high-density polyethylene [HDPE], etc.; figure 1) have greatly reduced water losses during delivery from diversion to the field. Other major advances in delivery systems include technologies to monitor and remotely control flow through headgates, valves, weirs, and other devices (Stubbs 2016). Planned diversions through water orders from developed irrigation institutions (Bretsen and Hill 2007) instead of set diversions have also reduced system losses.

Application to the Crop. Irrigation has three major interacting components: method, amount, and timing. Surface irrigation systems efficiencies have benefited from advancements in laser-leveling, high-head, level basin irrigation, surge irrigation, and other related approaches (figure 1). One of the largest impacts in irrigation methods has been the development and widespread adoption of pressurized irrigation systems (USDA ERS 2019), namely center pivots and laterals. Massive transitions from gravity to pressurized irrigation systems have occurred, and still continue to occur, in the United States (USDA NASS 2018) and other countries. In many cases, this has enabled greater irrigation application uniformity and efficiency, and more precise and real-time control of irrigation. It has also significantly reduced farm labor requirements. In some cases, however, sprinkler systems have also increased evaporative losses, reduced return flows, and disrupted downstream water allocations (Grafton et al. 2018).

Center pivot technology rapidly advanced during the late 1990s and continues to date. Center pivots can now be remotely controlled and programmed to apply precise amounts of water throughout a field, enabling variable-rate irrigation approaches. To reduce evaporative losses and improve application uniformity, sprinkler systems, especially center pivots, have largely transitioned from sprinklers at high elevations (including on top of pivot) to mid- (~1.5 m [4.9 ft]) and low-elevation (0.5 m [1.6 ft]) systems. Most center pivots in the last two decades have utilized some form of mid-elevation spray application (MESA), but adoption of three more efficient pivot sprinkler technologies (low-elevation spray application [LESA], low-energy precision application [LEPA], and precision mobile drip irrigation [PMDI or MDI])

Figure 2

Four pivot/linear irrigation packages including mid-elevation spray application (MESA), low-energy precision application (LEPA), low-elevation spray application (LESA), and mobile drip irrigation (MDI).



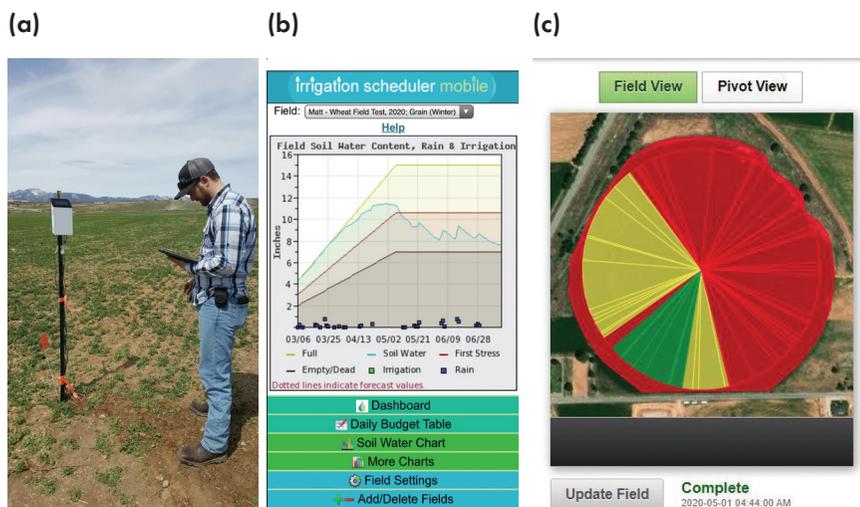
systems; figure 2) is increasing as the industry, irrigators, and scientists have documented their benefits (Schneider et al. 2000; Peters et al. 2016; Kisekka et al. 2017). These advanced irrigation systems have been appealing because they can be installed on existing pivots at much lower investment costs than subsurface drip irrigation.

Subsurface drip irrigation equipment and techniques have also advanced greatly in the last 75 years. This irrigation method has among the highest potential irrigation application efficiency (upwards of 97%) but has been impractical for many operations due to large capital investments and logistical concerns (Neibling 1994; Amossen et al. 2011). Subsequently, its growth has been the greatest in high value crops.

Simple and inexpensive management methods have allowed irrigators to improve water management, such as modifying irrigation amounts and timing. Irrigation rates have easily been modified by changing flow rates, irrigation set lengths, nozzle size, and other methods. These adjustments match irrigation rates to soil intake rates, maximum soil water depletion between irrigations, and ET demand, which in turn reduces or prevents unnecessary runoff or other losses (Andales 2014). The approach has been adjusted to account for inadequate water supplies and has included various forms of deficit or partial irrigation (Lindenmayer et al. 2011; Putnam et al. 2017).

Figure 3

Examples of advanced irrigation scheduling approaches: (a) soil moisture sensing system with telemetry, (b) weather station data used to estimate evapotranspiration and create irrigation schedule programs (e.g., Irrigation Scheduler developed by Washington State University), and (c) a commercial scheduling product called FieldNet Advisor developed by the Lindsay Corporation.



Several methods developed to determine ideal irrigation schedules include the following:

- Monitoring soil moisture by hand using the “feel” method, or with a variety of soil moisture sensors (Maughan et al. 2015; figure 3).
- Irrigation scheduler systems that utilize weather data to estimate ET, calculate water balances, and recommend irrigation rates according to maximum allowable depletion (Leib et al. 2002).
- Canopy temperature sensors to detect crop water stress (Stockle and Dugas 1992).
- Commercial programs that utilize crop growth models, soil characteristics, and ET estimated from satellite or aerial imagery. In some cases, these programs have the ability to send prescriptions directly to pivot controls for autonomous irrigation.

Although adoption of advanced irrigation scheduling techniques has been slow in the United States (USDA NASS 2018), interest from irrigators has grown each year as more growers realize benefits associated with improved scheduling.

■ Crop Management

Water optimization can be achieved when crops are better able to utilize water. This has occurred in many ways, but only three will be discussed here:

- Improved weed control has been a major advancement in crop management that has improved crop water utilization. Weeds often extract water in greater amounts per unit of dry matter than crops. Modern herbicides such as glyphosate have greatly reduced water competition from weeds for a large variety of crops.
- Improved crop varieties and hybrids have been another important advancement. The yield potential of most crop varieties has dramatically increased during the last 75 years. In tandem with yield increases, crop water use efficiencies have also improved. In some crops, advanced breeding and genetic techniques have led to more drought-tolerant varieties. Drought-tolerant corn hybrids such as AquaMax developed by DuPont Pioneer and DroughtGard developed by Monsanto are a couple of examples (McFadden et al. 2019).
- Alternative crops with lower and/or different timing of water requirements has been a third common advancement toward better water optimization. Alternative crop lists are lengthy, but some of the major gains in acreage have occurred with sorghum and related species, pearl millet, triticale and other various small grains, and some oilseeds like canola and safflower.

■ Soil Management

Another approach to water optimization is improving the soil's ability to retain water and make it available to plants. While many management practices influence soil water dynamics, a few have shown promise across wide geographies. These include proper nutrient management; reduced or eliminated tillage; residue management (up to 25% to 40% improvements in water productivity [Hatfield et al. 2001]), and soil amendments with high carbon organic materials such as manure, compost, cover crops, and/or biochar to help increase soil organic matter and improve water holding capacity (Khaleel et al. 1981; Ali and Talukder 2008; Karhua et al. 2011; Hunter et al. 2017).

■ Looking Forward

For the sake of brevity, this chapter has only scratched the surface of water optimization efforts during the last 75 years. Technology advancements of water delivery and application systems, coupled with irrigation, crop, and soil management have made large strides. Volumes have (Stubbs 2016; Nurzaman

2017) and could be written about the numerous policies, technologies, science, education, and adoption that have positively influenced water optimization.

Some of the major challenges going forward will be to discover, prioritize, and incentivize long-term economic and environmental ways to best optimize water use. Because it is impractical and unaffordable for all water-optimizing practices to be simultaneously implemented, advanced tools will be necessary to help farmers, policymakers, and other stakeholders identify the suites or combinations that produce the greatest water efficiencies. These tools and investments should be guided by ongoing and innovative long-term irrigation research, which is currently sparse or nonexistent compared to other agricultural research.

Acknowledgements

The authors would like to acknowledge the assistance of Monty Teeter, CEO of Dragon-Line, Inc., and Dan Schueler, sales manager with Senninger Irrigation, for their contributions to this chapter.

References

- Ali, M.H., and M.S.U. Talukder. 2008. Increasing water productivity in crop production—A synthesis. *Agricultural Water Management* 95(11):1201–1213.
- Amosson, S., L. Almas, J. Girase, N. Kinney, B. Guerrero, K. Vimlesh, and T. Marek. 2011. *Economics of Irrigation Systems*. B-6113. College Station, Texas: Texas AgriLife Extension Service.
- Andales, A.A., T.A. Bauder, and N.J. Doesken. 2014. The Colorado Agricultural Meteorological Network (CoAgMet) and crop ET reports (4):10–12. Denver, CO: Colorado State University Extension. <http://extension.colostate.edu/docs/pubs/crops/04723.pdf>.
- Bretsen, S.N., and P.J. Hill. 2007. Irrigation institutions in the American West. *UCLA Journal of Environmental Law and Policy* 25:289-331.
- Grafton, R.Q., J. Williams, C.J. Perry, F. Molle, C. Ringler, P. Steduto, B. Udall, S.A. Wheeler, Y. Wang, D. Garrick, and R.G. Allen. 2018. The paradox of irrigation efficiency. *Science* 361:748-750.
- Hatfield, J.L., T.J. Sauer, and J.H. Prueger. 2001. Managing soils to achieve greater water use efficiency. *Agronomy Journal* 93(2):271-280.
- Hunter, B., G.E. Cardon, S. Olsen, D.G. Alston, and D. McAvoy. 2017. Preliminary screening of the effect of biochar properties and soil incorporation rate on lettuce growth to guide research and educate the public through extension. *Journal of Agricultural Extension and Rural Development* 9:1-4.
- Karhua, K.T., T. Mattila, I. Bergströma, and K. Reginac. 2011. Biochar addition to agricultural soil increased CH₄ uptake and water holding capacity – Results from a short-term pilot field study. *Agriculture, Ecosystems and Environment* 140:309-313.
- Khaleel, R., K.R. Reddy, and M.R. Overcash. 1981. Changes in soil physical properties due to organic waste applications: A review. *Journal of Environmental Quality* 10(2):133-141.

- Kisekka, I., T. Oker, G. Nguyen, J. Aguilar, and D. Rogers. 2017. Revisiting precision mobile drip irrigation under limited water. *Irrigation Science* 35:483-500.
- Leib, B.G., M. Hattendorf, T. Elliott, and G. Matthews. 2002. Adoption and adaptation of scientific irrigation scheduling: Trends from Washington, USA as of 1998. *Agricultural Water Management* 55(2):105-120.
- Lindenmayer, B.R., N.C. Hansen, J. Brummer, and J.G. Pritchett. 2011. Deficit irrigation of alfalfa for water-savings in the great plains and intermountain west: A review and analysis of the literature. *Agronomy Journal* 103(1):45-50.
- Maughan, T., L.N. Allen, and D. Drost. 2015. Soil moisture measurement and sensors for irrigation management. AG/Irrigation/2015-01pr. Logan, UT: Utah State University Extension. https://digitalcommons.usu.edu/extension_curall/778/.
- McFadden, J., D. Smith, S. Wechsler, and S. Wallander. 2019. Development, adoption, and management of drought-tolerant corn in the United States. EIB-204. Washington, DC: US Department of Agriculture, Economic Research Service.
- Neibling, H. 1994. Irrigations systems for Idaho. CIS 1055. Moscow, ID: University of Idaho Cooperative Extension Service.
- Nurzaman, F.P. 2017. Irrigation management in the western states. Master's thesis, University of California, Davis.
- Peters, R.T., H. Neibling, and R. Stroh. 2016. Low energy precision application (LEPA) and low elevation spray application (LESA) trials in the pacific northwest. *In* Proceedings of the 2016 California Alfalfa and Forage Symposium, Reno, Nevada, Nov 29-Dec 1. Davis, CA: University of California Cooperative Extension.
- Putnam, D.H., J. Radawich, D. Zaccaria and A. Montazar. 2017. Partial-season alfalfa irrigation: An effective strategy for a future of variable water supplies. Davis, CA: University of California Cooperative Extension Service.
- Schaible, G., and M. Aillery. 2012. Water conservation in irrigated agriculture: Trends and challenges in the face of emerging demands. *Economic Information Bulletin* No. 99. Washington, DC: USDA Economic Research Service. <http://dx.doi.org/10.2139/ssrn.2186555>.
- Schneider, A.D. 2000. Efficiency and uniformity of the LEPA and spray sprinkler methods: A review. *Transactions of ASAE* 43:937-944.
- Stockle, C., and W. Dugas. 1992. Evaluating canopy temperature-based indices for irrigation scheduling. *Irrigation Science* 13(1):31-37.
- Stubbs, M. 2016. Irrigation in U.S. Agriculture: On-farm technologies and best management practices. Congressional Research Service. R44158. <https://fas.org/sgp/crs/misc/R44158.pdf>.
- USDA ERS (Economic Research Service). 2019. Irrigation and Water Use. Washington, DC: USDA Economic Research Service. <https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/#trends>.
- USDA NASS (National Agricultural Statistics Service). 2018. Irrigation and Water Management Survey. Washington, DC: USDA National Agriculture Statistic Service. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/index.php.