

ADVANCES IN IRRIGATION: SELECT WORKS FROM THE 2010 DECENNIAL IRRIGATION SYMPOSIUM

M. D. Dukes, D. L. Bjorneberg, N. L. Klocke



ABSTRACT. *This article is an introduction to the “Advances in Irrigation” Special Collection in this issue of Transactions ASABE and the next issue of Applied Engineering in Agriculture, consisting of 14 articles selected from 88 papers and presentations at the ASABE 5th Decennial National Irrigation Symposium, which was held in December 2010 in Phoenix, Arizona. This symposium followed the objectives of the previous four decennial events to provide a forum to assess the progress of research endeavors to advance the effectiveness of irrigation practices during the past ten years, leading to further research priorities in light of future challenges. The articles in this Special Collection address a wide range of topics grouped into broad categories: microirrigation, center-pivot irrigation, crop water use for improved irrigation management, and smart irrigation controllers for landscape irrigation. While these articles are not inclusive of all irrigation work since the last decennial symposium, they provide an example of work considered important by researchers, funding agencies, and other stakeholders. Many aspects of irrigation have changed since the first symposium in 1970. Although microirrigation is a small proportion of irrigated acreage, it will continue to increase in highly technical commercial food and fiber production as well as in subsistence farming. Center-pivot irrigation systems have been an important tool to deliver water more efficiently in diverse settings. Advanced telemetry and control systems, developed during the past ten years, are now common options for center pivots, but challenges remain in integrating these hardware developments into crop management practices. Possibilities are emerging for adding monitoring devices to center pivots to match crop water needs with water delivery. Energy balance models continue to be refined as tools to estimate crop water use from both ground-based and satellite-based data. Evapotranspiration estimates are evolving from single-location weather stations to whole-field or regional scopes. Finally, smart irrigation controllers have coupled evapotranspiration estimation or soil water sensing with automated irrigation system water delivery. These controllers can increase the precision of irrigation to match crop or landscape water needs. Irrigation will continue to be an important practice for producing the world’s food. The irrigation research and education professions will need to respond to food production challenges with even more refined irrigation systems and water management in the next ten years. However, research investment in irrigation continues to decline while important issues exist, such as maintaining agricultural profitability with declining water supplies, integrating sensor-based information for real-time autonomous or semi-autonomous management, competition for limited water supplies between agriculture and other sectors, increasing energy cost, environmental impacts of irrigation, and use of alternative (i.e., lower quality) water sources for irrigation.*

Keywords. *Evapotranspiration, Irrigation, Plant Water Requirements, Water Management.*

Every ten years since 1970, ASABE has held a National Irrigation Conference to present the state of the art of U.S. irrigation research, reflect on progress during the past ten years, and look ahead to future issues. The Fifth Decennial National Irrigation Symposium was held in 2010 and was jointly sponsored by ASABE and the Irrigation Association, as it has been since

the 1990 conference. The conference proceedings contained 88 papers with contributions from 170 coauthors. Fourteen of these papers were subsequently submitted and selected for publication in the “Advances in Irrigation” Special Collection in this issue of *Transactions of the ASABE* and the next issue of *Applied Engineering in Agriculture*.

Since the first irrigation symposium was held in 1970, the U.S. population has increased 50% (fig. 1), and the world population has doubled. Irrigated agriculture has played a large role in feeding the growing population. In the U.S., farms with all cropland irrigated account for only 8% of the total cropland and about half of the total irrigated land (USDA-NASS, 2012). These farms produce 33% of the market value of crops and 12% of the market value of livestock. Over half of the crop value (55%) is produced on farms with some irrigated land, and these farms account for only 26% of the total cropland in the U.S. (USDA-NASS, 2012). Total irrigated area has increased nearly 50% in the last 40 years, with the types of irrigation used changing from less efficient to more efficient systems (USDA-

Submitted for review in March 2012 as manuscript number SW 9676; approved for publication by the Soil & Water Division of ASABE in April 2012.

The authors are **Michael D. Dukes, ASABE Member**, Professor, Department of Agricultural and Biological Engineering, University of Florida, Gainesville, Florida; **David L. Bjorneberg, ASABE Member**, Agricultural Engineer, USDA-ARS Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho; and **Norman L. Klocke, ASABE Member**, Professor, Southwest Research and Extension Center, Kansas State University, Garden City, Kansas. **Corresponding author:** Michael D. Dukes, Department of Agricultural and Biological Engineering, 205 Frazier Rogers Hall, P.O. Box 110570, University of Florida, Gainesville, FL 32611; phone: 352-392-1864; e-mail: mddukes@ufl.edu.

NASS, 2012). Most of the growth in irrigated area is due to expansion of sprinkler and center-pivot irrigation, with small gains in microirrigated areas (fig. 2). Surface-irrigated area peaked in 1980 but has steadily decreased since then.

In some areas, irrigation provides essentially all of the water necessary for crop growth. In other areas, irrigation only provides a small portion of the total crop water requirement but reduces the potential for water stress during critical periods. Many of the irrigation management topics have remained the same over the past 40 years, but the sophistication of the technology used for managing irrigation, controlling irrigation delivery, and predicting crop water use, such as wireless sensors and satellite-based information, continues to increase.

The First National Irrigation Symposium, sponsored jointly by ASAE (now ASABE) and the University of Nebraska, was a forum to bring together irrigation researchers, industry representatives, farmers, and extension specialists to review and discuss irrigation practices and to challenge all professions to strive for better irrigation system capabilities and improve management recommendations. The program consisted of 43 invited presentations that included drip and trickle irrigation, sprinkler irrigation, surface irri-

gation, and water supply automation topics. Papers that dealt with irrigation system automation reported on improvements of gates, valves, and flow control for surface water distribution systems. Improvements in evapotranspiration estimates and irrigation scheduling were already emerging as tools for irrigation management. One session, entitled “Environmental Considerations in Irrigation Scheduling,” appears in hindsight to have been ahead of its time, as it focused on environmental modification in addition to concerns about irrigation impacts on water quality and quantity. Environmental modification topics included frost protection, crop cooling, and capture of waste heat from energy generation for warming water for agriculture.

All 26 presentations at the Second National Irrigation Symposium in 1980 were invited. The program covered irrigation development, advances in irrigation systems and management, and the future of irrigation. Presenters frequently mentioned energy conservation. A rapid rise in energy costs in the late 1970s increased the desire to improve irrigation water management to reduce pumping costs. Richard Wenstrom, a farmer from west central Kansas, shared a quote from a magazine that center-pivot irrigation would be extinct in a few years due to dwindling water supplies and escalating energy costs (Wenstrom, 1980). Thirty years later, center pivots deliver water to more than 80% of the sprinkler-irrigated land and almost half of the total irrigated land in the U.S. (fig. 2). In fact, high-efficiency center-pivot machines continue to displace surface irrigation, particularly in areas where water supplies have become limited. Most irrigation management in the 1970s was based on observations and judgment rather than scheduled events from measured weather and soil water factors, but electronic sensors, computerized computations, and data management held the potential to greatly change irrigation management and control (Duke et al., 1980). Personal computers, or “microcomputers” as they were called in 1980, were just coming onto the market and offered new options for collecting and processing information to better manage irrigation. Improved irrigation water management was also needed to conserve current water resources rather than relying on new sources. Jan van Schilfhaarde noted that augmenting current water supplies with interbasin transfers, iceberg harvest, or desalination may be technically possible, but these methods were unlikely to come to fruition (van Schilfhaarde and Hoffman, 1980). Although desalination is currently a viable option for freshwater production, it accounted for less than 0.4% of the total U.S. water supply in 2005, and 75% of this water was for municipal and industrial uses (NRC, 2008).

In 1990, the Third National Irrigation Symposium had a larger program developed from a call for papers and invited presentations. Turf and landscape irrigation was included for the first time due to the first joint sponsorship with the Irrigation Association, which hosted the meeting at the 11th Annual International Irrigation Exposition in Phoenix, Arizona. The fourth and fifth symposia were also conducted during the Irrigation Association’s annual show. The final program that year had 88 oral presentations and 39 posters. It is difficult to briefly summarize the 127 presentations from 22 different sessions; a general focus of the third

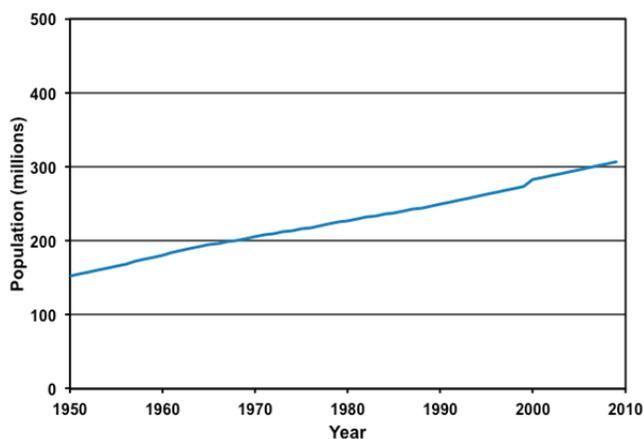


Figure 1. U.S. population 1950 through 2010 (data from U.S. Census Bureau, www.census.gov).

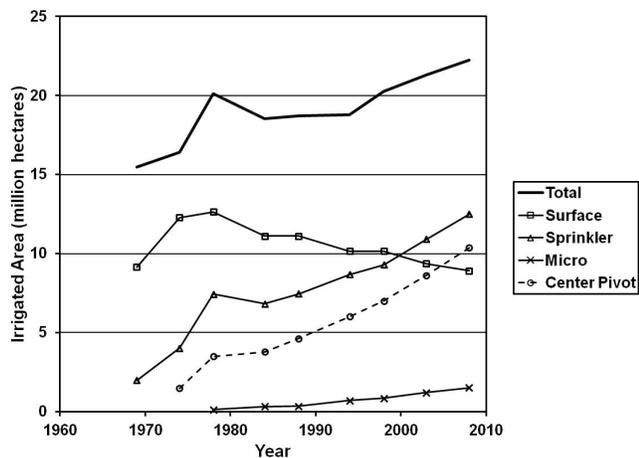


Figure 2. Trends in irrigated acreage 1960-2010 (after USDA-NASS, 2012).

symposium was optimum use of water resources through irrigation management and system design. In addition, there was a distinct theme related to reducing environmental impacts related to irrigation and a strong theme related to efficient use of irrigation water. Twenty-two papers had descriptions or evaluations of irrigation scheduling methods, system designs, or tillage practices to conserve water. Early indications of groundwater declines due to irrigation withdrawals and escalating energy costs during the 1980s led researchers to devise more water-saving management practices and commercial manufactures to design sprinklers with lower energy requirements. More papers described using microirrigation with row crop production. Spurgeon and Manges (1990) and Camp et al. (1990) discussed the advantages of microirrigation for corn and cotton. At the second symposium, Howell et al. (1980) noted that microirrigation was economical mainly for orchard, vine, and vegetable crops. While microirrigation is still primarily used for high-value crops, its use continues to gradually increase (fig. 2), with subsurface drip irrigation (SDI) as a key strategy for maintaining productivity in water-limited areas (Lamm et al., 2012). At the 1990 symposium, more topics reported on the use of sensors to provide feedback from the plant or soil to optimize irrigation practices with limited supplies, manage salinity, and measure weather factors collected from remote locations. Phene et al. (1990) predicted that sensors placed in the soil or on plants would provide information to determine precisely when to irrigate. These sensors would be “connected to computers which will not only calculate an index of stress, but will automatically activate the irrigation system to apply the correct amount of water and fertilizer” to high-value crops where water costs are high and supplies are limited. Others predicted that it may be common for airplanes to fly over agricultural regions once or twice a week to collect reflected and emitted radiation from the crops below. Following these predictions and challenges, systems are now available that provide affordable control for landscape irrigation (Dukes, 2012) and use remote sensing by satellites to estimate ET over large areas (Allen et al., 2010).

The Fourth National Irrigation Symposium in 2000 continued the theme of optimum use of irrigation water. Improved methods were presented to calculate crop water use built upon the concept of reference crop evapotranspiration presented at the second symposium (Burman et al., 1980). A standardized reference evapotranspiration (ET) equation (Walter et al., 2000) had been developed, and automated weather stations could provide data to calculate ET (Elliot et al., 2000; Yoder et al., 2000). Marvin Jensen noted that nearly a century was needed for U.S. scientists and engineers to develop sound, physically based equations for estimating reference crop ET (Jensen and Allen, 2000). Site-specific irrigation management was a new topic, as researchers were evaluating the potential benefits of varying irrigation amounts within a field (Sadler et al., 2000). In addition to applying water, the center pivot provides an excellent platform for collecting site-specific soil and plant information (Evans et al., 2000). Subsurface drip irrigation was a more prominent part of the microirrigation program, as research was showing the potential for SDI to reduce ir-

rigation while maintaining productivity (Camp et al., 2000). Ominously, there was continuing evidence of groundwater depletions from irrigation withdrawals from major aquifers like the Ogallala Aquifer (Postel, 2000), leading to targeted research reported in several papers at the 2010 symposium.

The Fifth Decennial Irrigation Symposium in 2010 continued with a strong theme of improved techniques for delivering and managing water for more effective irrigation practices. There were a total of 88 presentations and papers. The program included topics that were relatively new, such as remote sensing for regional ET estimation and smart irrigation controllers for landscape irrigation, and topics that were presented at all prior symposia, such as irrigation scheduling, ET estimation techniques, and surface irrigation management. Of the 88 papers, 25 dealt with ET estimation, plant water use, site-specific irrigation, and irrigation scheduling, which had a common theme of enhancing water use efficiency. Eight papers reported on research conducted in the central and southern Great Plains with the goal of extending the regional economic impact of irrigation from the Ogallala Aquifer. These papers described advances in deficit irrigation, SDI, and sprinkler application techniques. Decision support tools to assist producers in choosing crop rotations, predicting crop yields, and scheduling irrigation were discussed. Other sessions included topics on deficit irrigation, irrigation management in humid regions, center-pivot irrigation, surface irrigation, and microirrigation. Irrigation of turf and landscapes were the topics of 12 presentations primarily covering estimation of irrigation requirements, smart irrigation controllers, and other efforts to promote irrigation efficiency. This was also the first symposium without a hardcopy proceedings document; instead, the proceedings were provided to authors on CD-ROM and were made available at the ASABE Technical Library (<http://elibrary.asabe.org/>).

No matter how much technology changes, irrigation continues to be an essential aspect of agricultural production and urban landscapes. As competition for limited water resources increases, the need for sound irrigation research becomes more important. The following sections summarize the articles in this Special Collection.

MICROIRRIGATION

Microirrigated area in the U.S. continues to grow (fig. 2). In particular, the primary use of microsprinklers is in the irrigation of trees and some vine crops (Boman et al., 2012). Use of this irrigation type is dominant in the Pacific Northwest, California, and Florida. Microsprinkler is primarily used on fruit and nut crops, such as apple, almonds, citrus, pecan, and peach. Advantages associated with microsprinklers include: less total water applied compared to overhead sprinklers or surface irrigation, freeze protection, capability for more frequent applications, larger wetted area compared to drip systems, compatibility with chemigation, reduced evaporation compared to sprinkler systems, lower plant disease issues compared to systems that wet foliage, improved weed control due to unirrigated areas, lower cost compared to overhead sprinklers, and lower run times

compared to drip systems. Disadvantages include: increased knowledge and level of management required, increased maintenance compared to overhead sprinklers, frequent operation required, higher losses than drip systems, and higher initial cost than drip systems.

Similar to the microsprinkler review article by Boman et al. (2012), the current status of SDI is summarized by Lamm et al. (2012), focusing on the latest in applied research. SDI is the most common type of drip irrigation used on commodity crops such as corn and cotton in the central Great Plains of the U.S. Lamm et al. (2012) point out that SDI grew 59% (97,000 ha) from 2003 to 2008, whereas surface drip irrigation only increased 23% (128,000 ha). In contrast, center-pivot irrigation grew 20% (1.75 million ha) in the same period (USDA-NASS, 2012). Challenges remaining for adoption of SDI include: uncertainty about when it is best (i.e., profitable) for a grower to adopt SDI, uncertainty associated with operation and management, and lack of visual clues to system operation. Contemporary SDI topics include drip tubing orientation and spacing. Bordovsky and Mustian (2012) found that cotton yield differences over five years in the Texas High Plains were not significant between 0.76 and 1.02 m spacing. In addition, they provide results on yield effects due to drip offset from rows and due to drip spacing when oriented perpendicular to crop rows at various irrigation capacities.

CENTER-PIVOT IRRIGATION

The biggest single change since the first irrigation symposium is the amount of land irrigated with center-pivot and linear-move irrigation machines. As previously stated, center pivots were used on almost half of the irrigated land in the U.S. in 2008 (USDA-NASS, 2012). Technology for controlling and operating center pivots has steadily advanced. Kranz et al. (2012) describe how operators can now communicate with irrigation machines by cell phone, satellite radio, and internet-based systems. New sensors are being developed to collect soil or crop information that can be used for managing irrigation. As Evans and King (2012) note, integrating information from various sensors and systems into a decision support program will be critical to highly managed, spatially varied irrigation. Technology has allowed irrigators to precisely control irrigation. However, technology to precisely apply irrigation water is wasted if the water does not infiltrate into soil where it was applied. King and Bjorneberg (2012) characterize the kinetic energy applied to the soil from common center-pivot sprinklers and relate this energy to runoff and soil erosion to improve center-pivot sprinkler selection. Finally, Martin et al. (2012) describe the wide variety of sprinkler packages available for mechanical-move irrigation machines and how those sprinkler packages are selected.

CROP WATER USE FOR IMPROVED IRRIGATION MANAGEMENT

Making the best use of limited irrigation water supplies has been a common theme at all five irrigation symposia. A

general conclusion has been that irrigation was more beneficial when applied during the growing season rather than preseason. As Schlegel et al. (2012) point out, many irrigation systems no longer have the capacity to meet peak crop water demands and must rely on stored soil water to meet crop water needs. They found that preseason irrigation was profitable for the well capacities tested (2.5 to 5 mm d⁻¹) near Tribune, Kansas, and water use efficiency was not significantly affected by preseason irrigation. The ability to manage irrigation timing and amounts requires knowledge of crop water use, and site-specific management requires specific knowledge about each field and locations within fields. Evett et al. (2012) note that crop coefficient values are sensitive to local climate conditions and are not transferable. Using two surface energy balance models to calculate reference evapotranspiration, they demonstrate the types of errors that can occur when stomatal resistance changes due to weather conditions and when assuming constant daytime and nighttime surface resistances. Accounting for these errors may improve site-specific ET estimations. Aiken and Klocke (2012) used sap flow heat gauge measurements on corn to calculate transpiration and compared the results with transpiration calculated by the Penman-Monteith method. They found that the uncertainty in stomatal behavior caused similar variability in transpiration calculated by Penman-Monteith method as the potential bias in transpiration calculated from sap flow heat gauges. Remotely sensed thermal and reflectance information from the crop canopy can be used to calculate site-specific water use. Colaizzi et al. (2012) used a two-source energy balance model to predict daily ET of corn, cotton, grain sorghum, and wheat. Their technique, combined with wireless sensors, may allow the center pivot to be a remote sensing platform for collecting real-time information for calculating site-specific ET.

SMART IRRIGATION CONTROLLERS FOR LANDSCAPE IRRIGATION

As early as the 1990 symposium, the first that included turf and landscape irrigation, at least two presentations were specific to soil moisture-based control of landscape irrigation, and one presentation was on weather-based control via commercially available central control systems. Since then, many smart controllers using ET principles or soil moisture measurements have been developed and commercialized for landscape irrigation. The concept is not new, but new robust and relatively inexpensive sensors and electronic technologies now make these controllers affordable for small sites such as single-family homes and small commercial properties. In the past decade, the market has been flooded with these devices, mostly from small startup companies. At this point, fewer of those startup companies exist; however, all major landscape irrigation manufacturers have a line of smart controllers. Dukes (2012) gives a brief history of smart controller commercialization and summarizes a number of applied demonstration projects as well as research projects focusing on the water conservation potential of the controllers. In general, large-scale

demonstration projects have resulted in much lower irrigation savings (10% or less) compared to research projects (40% to 70%). Reasons suggested for this observation include: demonstration projects were on sites with less potential for savings, lack of contractor education, and lack of followup. Davis and Dukes (2012) compiled and synthesized ET controller research in humid conditions. They found that while ET controllers often had potential to reduce landscape irrigation amounts, they also may have resulted in greater irrigation on sites that were historically deficit irrigated. In contrast, soil moisture sensor (SMS) controllers have been shown to consistently reduce irrigation (27% to 54% in dry weather and 42% to 72% in wet weather) compared to time-based schedules used in landscapes (Cardenas-Lailhacar and Dukes, 2012).

SUMMARY AND CONCLUSIONS

Heerman (2000) stated, “The buzz words of the 70s (water conservation, xeriscape, water reclamation, resource management, water quality, and product quality) became serious business in the 80s and became words of wisdom and the price of admission in the 90s.” In the first decade of the 21st century, it is apparent that the water quantity and quality issues associated with irrigation are intensifying. Thus, the “buzz words” that Heerman talked about are more relevant than ever, particularly water conservation and water quality. In contrast, the term “xeriscape” has been rebranded in many cases so as not to give the negative connotation resulting from early incarnations of xeric landscapes, which were often desert-like landscapes.

Considerable progress in irrigation technology and management has been made since 1970. Areas that will pose challenges in the next ten years include:

- Profitable production with declining water supplies.
- Further integration of sensor-based data for real-time autonomous or semi-autonomous management.
- Competition for limited water resources between agriculture and other sectors.
- Impact of declining investment in irrigation research.
- Energy cost and the influence on irrigation type and management.
- Environmental impacts of irrigation.
- Using alternative water sources or degraded water for irrigation.

ACKNOWLEDGEMENTS

This article is one of 15 articles in the “Advances in Irrigation” Special Collection in this issue of *Transactions of the ASABE* and the next issue of *Applied Engineering in Agriculture*. The authors wish to thank the ASABE publications staff, associate editors, and reviewers for their contributions to and timely management of the review process, and the authors and co-authors of articles in this collection for their contributions to the research literature represented by this collection. In particular, the authors would like to thank SW Division Editor Kyle Douglas-Mankin for his invaluable assistance in encouraging and shepherding this collection through the submission and review process.

REFERENCES

- Aiken, R. M., and N. L. Klocke. 2012. Inferring transpiration control from sap flow heat gauges and the Penman-Monteith equation. *Trans. ASABE* 55(2): 543-549.
- Allen, R. G., J. Hendrickx, W. Bastiaanssen, J. Kjaersgaard, A. Irmak, and J. Huntington. 2010. Status and continuing challenges in operational remote sensing of ET. In *Proc. Fifth Decennial National Irrigation Symposium*. Paper No. IRR109971. St. Joseph, Mich.: ASABE.
- Boman, B., B. Sanden, T. Peters, and L. Parsons. 2012. Current status of microsprinkler irrigation in the USA. *Applied Eng. in Agric.* 28(3): (in press).
- Bordovsky, J. P., and J. T. Mustian. 2012. Cotton response to crop row offset and orientation to subsurface drip irrigation laterals. *Applied Eng. in Agric.* 28(3): (in press).
- Burman, R. D., J. L. Wright, P. R. Nixon, and R. W. Hill. 1980. Irrigation management: Water requirements and water balance. In *Proc. 2nd National Irrigation Symposium*, 141-153. St. Joseph, Mich.: ASAE.
- Camp, C. R., W. M. Thomas, and C. C. Green. 1990. Scheduling irrigation for cotton in humid areas. In *Proc. 3rd National Irrigation Symposium*, 275-280. St. Joseph, Mich.: ASAE.
- Camp, C. R., F. R. Lamm, R. G. Evans, and C. J. Phene. 2000. Subsurface drip irrigation: Past, present, and future. In *Proc. 4th Decennial National Irrigation Symposium*, 363-372. St. Joseph, Mich.: ASAE.
- Cardenas-Lailhacar, B., and M. D. Dukes. 2012. Soil moisture sensor landscape irrigation controllers: A review of multi-study results and future implications. *Trans. ASABE* 55(2): 581-590.
- Colaizzi, P. D., S. R. Evett, T. A. Howell, P. H. Gowda, S. A. O’Shaughnessy, J. A. Tolck, W. P. Kustas, and M. C. Anderson. 2012. Two-source energy balance model: Refinements and lysimeter tests in the Southern High Plains. *Trans. ASABE* 55(2): 551-562.
- Davis, S. L., and M. D. Dukes. 2012. Landscape irrigation with evapotranspiration controllers in a humid climate. *Trans. ASABE* 55(2): 571-580.
- Duke, H. R., H. L. Manges, and R. H. Evelyn-Veere. 1980. Future of irrigation: Processors and controllers. In *Proc. 2nd National Irrigation Symposium*, 233-241. St. Joseph, Mich.: ASAE.
- Dukes, M. D. 2012. Water conservation potential of landscape irrigation smart controllers. *Trans. ASABE* 55(2): 571-580.
- Elliot, R. L., K. G. Hubbard, M. D. Brusberg, J. J. Hattendorf, T. A. Howell, T. H. Marek, and R. L. Snyder. 2000. The role of automated weather networks in providing evapotranspiration estimates. In *Proc. 4th Decennial National Irrigation Symposium*, 243-250. St. Joseph, Mich.: ASAE.
- Evans, R. G., and B. A. King. 2012. Site-specific sprinkler irrigation in a water-limited future. *Trans. ASABE* 55(2): 493-504.
- Evans, R. G., G. W. Buchleiter, E. J. Sadler, B. A. King, and G. B. Harting. 2000. Controls for precision irrigation with self-propelled systems. In *Proc. 4th Decennial National Irrigation Symposium*, 322-331. St. Joseph, Mich.: ASAE.
- Evett, S. R., R. J. Lascano, T. A. Howell, J. A. Tolck, S. A. O’Shaughnessy, and P. D. Colaizzi. 2012. Single- and dual-surface iterative energy balance solutions for reference ET. *Trans. ASABE* 55(2): 533-541.
- Heerman, D. F. 2000. Where have we been, what have we learned, and where are we going. In *Proc. 4th Decennial National Irrigation Symposium*, 40-51. St. Joseph, Mich.: ASAE.
- Howell, T. A., D. A. Bucks, and J. L. Chesness. 1980. Advances in trickle irrigation. In *Proc. 2nd National Irrigation Symposium*, 69-94. St. Joseph, Mich.: ASAE.
- Jensen, M. E., and R. G. Allen. 2000. Evolution of practical ET estimating methods. In *Proc. 4th Decennial National*

- Irrigation Symposium*, 52-65. St. Joseph, Mich.: ASAE.
- King, B. A., and D. L. Bjornberg. 2012. Droplet kinetic energy of moving spray-plate center-pivot irrigation sprinklers. *Trans. ASABE* 55(2): 505-512.
- Kranz, W. L., R. G. Evans, and F. R. Lamm. 2012. A review of center-pivot irrigation control and automation technologies. *Applied Eng. in Agric.* 28(3): (in press).
- Lamm, F. R., J. P. Bordovsky, L. J. Schwankl, G. L. Grabow, J. Enciso-Medina, R. T. Peters, P. D. Colaizzi, T. P. Trooien, and D. O. Porter. 2012. Subsurface drip irrigation: Status of the technology in 2010. *Trans. ASABE* 55(2): 483-491.
- Martin, D. L., W. R. Kranz, A. L. Thompson, and H. Liang. 2012. Selecting sprinkler packages for center pivots. *Trans. ASABE* 55(2): 513-523.
- NRC. 2008. *Desalination: A National Perspective*. Washington, D.C.: National Research Council.
- Phene, C. J., B. Itier, and R. J. Reginato. 1990. Sensing irrigation needs. In *Proc. 3rd National Irrigation Symposium*, 429-443. St. Joseph, Mich.: ASAE.
- Postel, S. 2000. Redesigning irrigated agriculture. In *Proc. 4th Decennial National Irrigation Symposium*, 1-12. St. Joseph, Mich.: ASAE.
- Sadler, E. J., R. G. Evans, G. W. Buchleiter, B. A. King, and C. R. Camp. 2000. Design considerations for site-specific irrigation. In *Proc. 4th Decennial National Irrigation Symposium*, 304-315. St. Joseph, Mich.: ASAE.
- Schlegel, A. J., L. R. Stone, T. J. Dumler, and F. R. Lamm. 2012. Managing diminished irrigation capacity with preseason irrigation and plant density for corn production. *Trans. ASABE* 55(2): 525-531.
- Spurgeon, W. E., and H. L. Manges. 1990. Drip line spacing and plant population for corn. In *Proc. 3rd National Irrigation Symposium*, 217-222. St. Joseph, Mich.: ASAE.
- USDA-NASS. 2012. Farm and ranch irrigation survey. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: www.agcensus.usda.gov. Accessed 11 January 2012.
- van Schilfgaarde, J., and G. J. Hoffman. 1980. Future sources of water. In *Proc. 2nd National Irrigation Symposium*, 222-232. St. Joseph, Mich.: ASAE.
- Walter, I. A., R. G. Allen, R. L. Elliott, M. E. Jensen, D. Itenfisu, B. Mecham, T. A. Howell, R. Snyder, P. Brown, S. Echings, T. Spofford, M. Hattendorf, R. H. Cuenca, J. L. Wright, and D. Martin. 2000. ASCE's standardized reference evapotranspiration equation. In *Proc. 4th Decennial National Irrigation Symposium*, 209-215. St. Joseph, Mich.: ASAE.
- Wenstrom, R. J. 1980. Irrigation prospects and perspectives: A farmer's view. In *Proc. 2nd National Irrigation Symposium*, 213-221. St. Joseph, Mich.: ASAE.
- Yoder, R. E., T. W. Ley, and R. L. Elliot. 2000. Measurement and reporting practices for automated agricultural weather stations. In *Proc. 4th Decennial National Irrigation Symposium*, 260-265. St. Joseph, Mich.: ASAE.