Chapter 5- Technologies and Advances in Water Management

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TECHNOLOGIES AND ADVANCES IN WATER MANAGEMENT
The session focused on technological advances that enable producers to better manage limited water resources. Topics included research on models that measure crop stress and evapotranspiration, development of wireless underground sensor networks to measure soil moisture and other conditions, and advancements in irrigation technology since the early 1960s. Each panelist gave an overview of his subject area and the panel then responded to audience questions.
Suat Irmak, University of Nebraska–Lincoln

Farmers are challenged to use water more efficiently while maximizing net return, Suat Irmak said. Researchers at the University of Nebraska–Lincoln (UNL) are investigating ways to improve agricultural practices and minimize water loss.

Center pivot irrigation research is designed to measure and understand crop response to water and chemigation under limited and full irrigation settings with the goal of determining how much farmers can reduce irrigation while maintaining high yields.

Irrigation treatments investigated range from dryland conditions to 50 percent irrigated to fully irrigated, and measurements include biomass production, kernel weight and other grain quality parameters. Other research addresses the effect of irrigation frequency on crop yield, water use efficiency and soil evaporation for corn under subsurface drip irrigation. Four years of results indicate that, in most cases, high-frequency irrigation leads to higher yields than low- or medium-frequency irrigation.

Additional research on crop water stress aims to determine, in part, how much stress the crop can withstand without a reduction in economical yields. A crop water stress index is determined from continuous canopy temperature monitoring using infrared thermometers from a few days after emergence to physiological maturity, coupled with microclimate variables, such as temperature and humidity.

Irmak and his colleagues also are improving models to separate evapotranspiration (ET) into evaporation and transpiration. By obtaining field measurements of stomatal conductance, researchers can develop a model to estimate transpiration. Such measures could be used to better analyze water use efficiency and other agricultural production indices. “We can do a pretty good job estimating or measuring soil moisture, rainfall or snowfall, but I think we have a long way to go to accurately quantify evapotranspiration,” Irmak said.

Irmak established the Nebraska Water and Energy Flux Measurement, Modeling and Research Network to measure ET for a variety of vegetative surfaces, including irrigated and rainfed crops and grasslands, crops under different conservation practices and invasive species. Twelve network instruments have been collecting data continuously throughout Nebraska for several years. One finding showed that
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disk-tilled fields averaged 7 percent higher ET rates than no-till fields during the past 18 months.

Other research, led by UNL biologist Ayse Irmak, estimates ET using satellite remote sensing. By integrating information algorithms, such as surface temperature and net radiation, ET mass for large areas can be estimated. “I see great potential for this technology to be used for water resources management and assessment,” Suat Irmak said.

Another study investigates the effect of climate change variables, such as air temperature and solar radiation, on agricultural functions, particularly ET rates. Analyzing historical data (going back to 1893 at one site), Irmak found a slight decrease in ET rates, despite slight increases in air temperature.

Passing research results to farmers, crop consultants and other users is critical, Irmak said. Without adequate communication, conserving water resources – the ultimate objective – cannot be achieved. That’s why Irmak and his colleagues established the Nebraska Agricultural Water Management Demonstration Network to integrate research and the work of UNL Extension.

The network’s goals are to transfer high-quality research to farmers, increase water use efficiency, reduce input and energy use, and improve management practices. The network also brings together researchers, growers and others for collaboration and learning. A website and on-site demonstrations give farmers useful tools and technologies.

The project began in 2005 with 15 Nebraska farmers and now has 400 members. Participating farmers are saving about 2 inches of water per growing season. The network comprises about 340,000 acres and is growing. “The network is an excellent example of university, farmers and state agency personnel coming together … to improve the productivity of agriculture,” Irmak concluded.
Wireless Underground Sensor Networks: A New Perspective for Automated Water Management

M. Can Vuran, University of Nebraska–Lincoln

Wireless sensor networks are one of 10 technologies that will change the world, according to *MIT Technology Review*. M. Can Vuran is taking the technology a step further by developing wireless underground sensor networks to gather information about the soil, which he believes could revolutionize agriculture.

A wireless sensor network consists of autonomous sensor nodes that gather environmental information and relay it wirelessly. The nodes are essentially tiny computers with limited processing capabilities and memory. They are powered by only two AA batteries and are inexpensive to produce.

Wireless sensor networks already play a large role in energy efficiency, Vuran said. His goal is to apply the technology to precision agriculture using nodes buried in the field. He is creating sensors that gather real-time information from the soil and crop conditions and transmit the information to personal computers or cell phones, enabling farmers to make immediate, informed decisions. “We want to let the soil tell us what to do,” Vuran said. “And we want to achieve a complete autonomy on the fields. We basically want farmers that are walking around their farms with iPads.”

Vuran’s experiments using off-the-shelf sensor nodes demonstrated that underground communication quality is highly stable over time, but soil moisture is the most important parameter affecting quality. A 9 percent increase in soil moisture resulted in a decrease in channel quality of 20 decibels per milliwatt. Increasing transmission power, however, minimizes the adverse effects of moisture. Therefore, it is necessary to establish environment-aware networking, in which the environmental information is exploited to provide networking solutions that can withstand the effects of the weather and other changes.

Based on these empirical studies, Vuran and his colleagues developed the Soil Subsurface Wireless Communication channel model. Three signals are
involved in the network: direct waves, reflected waves and lateral waves, which propagate through the air-to-soil boundary before reaching the receiver, increasing reliability. “We’re exploiting this third component,” Vuran said. “We can actually improve the communication range that will lead to the realization of underground sensor networks.”

The team also experimented with above-ground-to-underground communication, important for node maintenance. Researchers discovered that sending a 400-megahertz signal from the air to the soil requires an antenna tailored to a 1-gigahertz signal in the soil because of the change in wavelength. Using the ultra-wideband antenna significantly increased the range for above-ground-to-underground communication, and vice versa.

To test the system in the field, Vuran deployed eight underground nodes, buried 40 centimeters deep (the depth at which nodes are considered safe from agricultural machinery), and an above-ground node connected to a center pivot system. The system achieved nearly 100 percent communication reliability as the center pivot circled the field. The corn canopy and a 6.1 percent increase in volumetric water content each increased attenuation 3 decibels.

Soil irregularities appear to cause high space-time variability of signal strength. Combating the problem will require developing adaptive real-time protocols that provide multiple levels of temporal guarantees, Vuran said. For example, irrigation and rain can affect communication within hours, while soil moisture changes may impact communication over days. “We basically have information about the models that have been developed for these agricultural phenomena,” he said. “Already we can tie this information with developing real-time protocols that can combat these effects and can still provide information despite the adverse effects in communication.”

Many research challenges remain, but Vuran’s study has provided a proof of concept of the ability to deliver autonomous agricultural solutions by feeding environmental information collected underground to above-ground devices.
Irrigation has been an essential component of a global strategy for increasing yields to feed a growing world population. Steven R. Evett described new technology and future trends in irrigation in the U.S. and around the world.

Despite a booming global population, worldwide nutrition has improved largely because of increasing yields. Irrigation and the synergistic effect between irrigation and nitrogen in advanced varieties have played large roles.

Worldwide, irrigation has doubled since 1960, but in many important regions, irrigators have reached the limit of water availability. South Asia, the Middle East and North Africa are extracting half of the available water for human resources – an untenable situation, Evett said. “We need greater crop-water productivity in order to deal with this situation. Yield growth in resource-limited regions is going to be critical, but it depends on technology development,” he said.

In the U.S., irrigation has allowed production to more than double since 1960. At the same time, cultivated land and the amount of water applied per acre have decreased because vapor pressure deficits (VPDs) decrease from west to east. Lower VPDs indicate higher moisture levels on the plant surface; therefore, less irrigation is needed. Studies also have shown that irrigation increases crop-water productivity; as yield goes up, water use efficiency goes up.

Advances in irrigation technology and management have been critical. Pressurized irrigation decreases conveyance loss and improves the ability to manage irrigation systems. By 2000, about half of U.S. irrigated areas were served by pressurized irrigation, but more is needed. Other advances include weather station networks coupled with irrigation scheduling systems, improvements in crop-water use predictions, and scheme- and region-wide water demand predictions using satellite and aerial data.

Evett discussed examples from his work in Jordan and Uzbekistan. Jordan’s irrigated area is small but economically and socially critical. Irrigation is 95 percent pressurized and 30 percent of the irrigated area is covered by plastic houses, increasing productivity to high levels. A new weather station network, text messaging to farmers and a weighing lysimeter to determine crop-cover effect on water use are improving irrigation scheduling. In addition, the Middle East Regional Irrigation Management Information...
System has achieved successes in conducting research, establishing technological infrastructure and developing human resources.

Uzbekistan, in contrast, has inefficient surface irrigation. In field studies using drip irrigation, corn yields increased only slightly, but 35 to 43 percent of irrigation water was saved and crop-water productivity increased 64 to 78 percent. Cotton yields increased about 22 percent and crop-water productivity increased 76 to 103 percent.

Evett described the results of using the Temperature-Time Threshold method of automated irrigation for controlling water use efficiency in Texas. The method was successfully automated for drip and center pivot irrigation systems. Water use efficiency was controllable, and yields were equal to or larger than the most accurate manual irrigation scheduling method.

New technology is allowing mapping of yield potential so farmers can abandon fields identified to have low yield potential. If the technology sends the feedback information to the irrigation system, areas that are diseased or dying can be excluded from irrigation.

Despite these advances, many constraints to improving agricultural water use efficiency exist. Economic, regulatory and social impacts, such as water pricing, technological availability, land tenure issues and fair markets, are critically important and must be addressed in many regions.

The picture is always changing, Evett concluded. “We have to keep expanding our thinking about how we can improve crop-water productivity and how that can tie into profitability for farmers. Because if it doesn’t tie in with profitability, it’s not going to happen in the end.”

Center pivot irrigation in Saudi Arabia
Questions and Answers

**Audience question:** What would Suat Irmak consider the major challenges and barriers for adoption of no-till agriculture in Nebraska?

Irmak said the major challenges are the unknown factors, such as how yield changes with no-till, the amount of water saved and the effects of various parameters, such as soil type and management practices. In addition, no-till increases weed and disease challenges, which have yet to be addressed.

**Audience question:** What soil texture and clay types were involved in M. Can Vuran’s field soil experiments? How do soil type and texture affect wireless underground sensor networks?

Although clay soil is dry, clay particles have significantly higher attenuation because they hold moisture, Vuran said. While soil type is important, it cannot yet be modeled well. His model incorporates existing models that capture some soil properties. Before deploying an underground sensor network, site-specific studies will be necessary to understand soil properties.

Irmak added that the soil texture at some of Vuran’s field experiments is 20 percent clay, 14 percent sand, 64 percent silt and 2 percent organic matter.

**Audience question:** What is the underground nodes’ battery life?

Vuran said the lifespan of the two AA batteries that power the nodes depends on the information gathered and how frequently it is sent. The nodes consume little power when asleep, so minimizing information exchange will prolong the communication lifetime to one or two years.

**Audience question:** What is the role and adoption of partial-root drying in irrigation management?

Steven R. Evett replied that he had not done experiments on partial-root drying. Evidence suggests that it can improve plant efficiency, and Australian vintners believe it improves grapes. However, Evett said he doubts that efficacy translates to corn.

**Audience question:** What is the difference between conductances at night compared to daytime?

Irmak responded that UNL has a unique dataset to measure stomatal resistance. Resistance increases significantly at night; therefore, conductance decreases. At night, corn measures from 300 seconds to 3,000 seconds per meter, while daytime measures are 30 seconds to 300 seconds per meter.

Although long doubted, transpiration does occur at night. Evett added that in the Texas Panhandle, 20 percent of total evapotranspiration (ET) occurs at night. He believes it comes from transpiration, not soil evaporation.

**Audience question:** Given the closure errors and footprint uncertainty with eddy covariance, how is Irmak correcting eddy covariance flux to get true ET?

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Irmak said he uses the Bowen ratio-energy balance system, which doesn’t have closure errors.

In the Jordan Valley, Evett has collected eddy covariance data, which underestimate ET by 30 percent and are dangerously misleading in places where scientists don’t have direct measurements from a weighing lysimeter.

Audience question: Is there utility in deficit-irrigation schemes based on growth state? If so, is there research available using that scheme?

The data exist, and Irmak suggested that Tom Trout of USDA-ARS in Fort Collins, Colo., would have extensive data.

Evett said the Food and Agriculture Organization (FAO) recently released a water-productivity model called AquaCrop that he ran on cotton for both full and deficit irrigation to get accurate results. *Agronomy Journal* published those results about two years ago. After the root zone is established, deficit irrigation during one stage followed by full water in the next is a viable option.

Irmak said FAO publication No. 33 is an excellent resource that researchers have relied on for decades, but a revision is needed to account for advances made in the past 30 years.

Audience question: What is Evett’s opinion about the new soil moisture sensors that can be interrogated down to the hour, etc.? What would it take to schedule irrigations that way?

Evett based manual irrigations on neutron probes, which is not a tool farmers can use. Studies have concluded that electronic sensors designed to replace neutron probes do not work well enough for research or irrigation scheduling. Soil bulk electrical conductivity changes with water and clay content and is unpredictable *a priori*. Evett described fundamental problems with capacitance sensors and microstructural soil influences that create spatial variations. “What that means in terms of actually using these things is that we can’t,” Evett said. “We can’t rely on them because we don’t know *a priori* where to put them.”

Audience question: If crop prices are high and water is scarce, what technologies will producers adopt to adjust?

Irmak said he believes increasing productivity in that setting would require integrating advanced irrigation management technology with other technologies, such as soil management and enhanced drought-tolerant crops.

Evett said farmers in the Texas Panhandle and southern Kansas and Colorado are facing that situation. Rather than buying new irrigation
systems, farmers compensate by switching from low-value crops to corn. However, center pivot irrigation is used for more than 75 percent of the land because it’s more efficient. Drip irrigation also is becoming more widely adopted as a way to eke out more production for the same amount of water.

Irmak stressed that optimizing crop production with available water is extremely important. Robust tools are available to optimize production under deficit irrigation settings.

Vuran said as food prices increase and water becomes scarce, farmers have greater incentive to adopt newer technologies. Precision agricultural techniques and integration of information technology into agriculture would be important advances.

**Audience question:** *To what extent should we consider redesigning plant root systems, particularly for no-till management?*

Evett responded that roots are critically important to water uptake. For example, soil type directly affects how well crops take up water. Understanding how specific crops fare in different soil types would help farmers. Roots also are important in plant breeding because stronger roots that reach deeper into the soil will provide more water for the plant.

**Moderator Gary Hergert:** *Closing comments?*

Evett described the changes he has observed since he began working in Africa in the 1970s. The world is becoming smaller, he said. “We shouldn’t be bound by the perceptions of the agricultural system we see today. ... We shouldn’t be bound by our expectations and our experiences of the past.”

Vuran stressed the importance of interdisciplinary research to tackle complex problems. Solutions already exist that are directly applicable to some of these problems, and combining multiple disciplines will lead to additional solutions.

Irmak emphasized the need to invest in agricultural research, education and information transfer. To open the door for cooperation with international partners and researchers, his presentation highlighted some of UNL’s capabilities and experiences. Much remains to be understood about these complex problems, and he invited researchers to collaborate with UNL to address the issues facing irrigated agriculture in the U.S. and around the world.