

# NEBRASKA AGRICULTURAL WATER MANAGEMENT DEMONSTRATION NETWORK (NAWMDN): INTEGRATING RESEARCH AND EXTENSION/OUTREACH

S. Irmak, J. M. Rees, G. L. Zoubek, B. S. van DeWalle, W. R. Rathje, R. DeBuhr,  
D. Leininger, D. D. Siekman, J. W. Schneider, A. P. Christiansen

**ABSTRACT.** *Maximizing the net benefits of irrigated plant production through appropriately designed agricultural water management programs is of growing importance in Nebraska, and other western and Midwestern states, because many areas are involved in management and policy changes to conserve irrigation water. In Nebraska, farmers are being challenged to practice conservation methods and use water resources more efficiently while meeting plant water requirements and maintaining high yields. Another challenge Nebraska experiences in its approximately 3.5-million-ha irrigated lands is limited adoption of newer technologies/tools to help farmers better manage irrigation, conserve water and energy, and increase plant water use efficiency. In 2005, the Nebraska Agricultural Water Management Demonstration Network (NAWMDN or Network) was formed from an interdisciplinary team of partners including the Natural Resources Districts (NRD); USDA-NRCS; farmers from south central, northeast, west central, and western Nebraska; crop consultants; and University of Nebraska-Lincoln faculty. The main goal of the Network is to enable the transfer of high quality research-based information to Nebraskans through a series of demonstration projects established in farmers' fields and implement newer tools and technologies to address and enhance plant water use efficiency, water conservation, and reduce energy consumption for irrigation. The demonstration projects are supported by the scientifically-based field research and evaluation projects conducted at the University of Nebraska-Lincoln, South Central Agricultural Laboratory located near Clay Center, Nebraska. The Network was formed with only 15 farmers as collaborators in only one of the 23 NRDs in 2005. As of late 2009, the number of active collaborators has increased to over 300 in 12 NRDs and 35 of 93 counties. The Network is impacting both water and energy conservation due to farmers adopting information and newer technologies for irrigation management. The NAWMDN is helping participants to improve irrigation management and efficiency by monitoring plant growth stages and development, soil moisture, and crop evapotranspiration. As a result, they are reducing irrigation water application amounts and associated energy savings is leading to greater profitability to participating farmers. This article describes the goals and objectives of the Network, technical and educational components, operational functions, and procedures used in the NAWMDN. The quantitative impacts in terms of water and energy conservation are reported.*

**Keywords.** *Water conservation, Irrigation management, Reference and Crop evapotranspiration, Soil moisture.*

**W**ater is the life support of irrigated and rainfed agriculture and economy of Nebraska and other Central Plains and mid-western states. Nebraska's approximately 3.5 million ha of irrigated lands are extremely vital to the state's economy with

approximately 5 billion dollars/year of revenue. Withdrawal of fresh water resources for irrigation in Nebraska represents the largest of the state's water pumping demands. Irrigated agriculture consumes more than 90% of the groundwater pumped in Nebraska (USGS, 2000). In the United States, approximately 26 million ha are now being irrigated and about 13.5% of this total is located in Nebraska alone. Total land area under irrigation in Nebraska has increased from about 1.7 million ha in 1970 to 3.5 million ha in 2007.

Efficient use of water resources in Nebraska and Central High Plains is becoming crucial to the sustainability of agro-ecosystems and economy of the region more than ever as the farmers are being challenged to practice conservation methods and use water resources more efficiently. Currently irrigated agriculture in Nebraska faces ever-increasing pressure to do its part to conserve water and protect water quality. Concern about the sustainability of available irrigation water in Nebraska is growing. As Nebraska's industrial and agricultural development increase, use of water supplies have come under increased scrutiny. The long-term viability of this resource is threatened by several consecutive years of drought and over-pumping of groundwater supply. These have resulted in reduced well-output and falling groundwater tables in much of the Ogallala aquifer. Litigation between "downstream" and "upstream" users has placed restrictions on the amount of water available to farmers in some major watersheds. In Nebraska, these

---

Submitted for review in September 2009 as manuscript number SW 8208; approved for publication by the Soil & Water Division of ASABE in April 2010.

The mention of trade names or commercial products is solely for the information of the reader and does not constitute an endorsement or recommendation for use by the authors or the University of Nebraska-Lincoln.

The authors are **Suat Irmak**, ASABE Member Engineer, Associate Professor, Department of Biological Systems Engineering, University of Nebraska-Lincoln (UNL), Lincoln, Nebraska; **Jennifer M. Rees**, Extension Educator, UNL, Clay Center, Nebraska; **Gary L. Zoubek**, Extension Educator, UNL, York, Nebraska; **Brandy S. VanDeWalle**, Extension Educator, UNL, Geneva, Nebraska; **William R. Rathje**, Engineering Research Technician, Department of Biological Systems Engineering, UNL, Lincoln, Nebraska; **Rodney DeBuhr**, Water Resources Department Manager, Upper Big Blue Natural Resources District, York, Nebraska; **Dan Leininger**, Water Conservationist, Upper Big Blue Natural Resources District, York, Nebraska; **Darrel D. Siekman**, Extension Educator, UNL, Central City, Nebraska; **James W. Schneider**, Extension Educator, and **Andrew P. Christiansen**, Former Extension Educators, UNL, Aurora, Nebraska. **Corresponding author:** Suat Irmak, Department of Biological Systems Engineering, University of Nebraska-Lincoln (UNL), 241 L.W. Chase Hall, Lincoln, Nebraska 68583; phone: 402-472-4865; fax: 402-472-6338; e-mail: sirmak2@unl.edu.

constraints will require limits on the amount of irrigation water that can be pumped by farmers, restrict or more closely regulate drilling of new irrigation wells, and require flow meters on existing wells in some parts of the state. The new regulations will also require Natural Resource Districts (NRD) to monitor and record groundwater withdrawals within watersheds. More importantly, in some districts, farmers are limited to pump only 60% to 70% of the full water requirement for maximum yield.

Increased energy costs are also threatening the sustainability of irrigation in the state. Energy costs for irrigation rose over 80% for typical Nebraska irrigators from the spring of 2003 to the spring of 2008 and predictions are that it will rise again in the coming years. The rising cost of fuel and the limited availability of water make producing maximum grain yield with minimal input imperative. Farmers in Nebraska and neighboring states, who have similar farming practices and challenges, need scientifically-based and practical management strategies that can aid them in their decision making process to enhance plant water use efficiency to achieve maximum profitability. Farmers are seeking aid on how to maximize use of limited irrigation water and how to efficiently manage it to reduce pumping cost in this new era. These challenges also make it imperative for farmers to use some kind of plant water use monitoring method or device to make better-informed irrigation management decisions. Another issue that contributes to reduction in available water resources is practicing poor irrigation management strategies. All these aforementioned challenges can be encountered through well-designed, large scale, coordinated, and effective irrigation water management programs. These programs can be delivered to the user via variety of dissemination tools, including one-on-one interactions with field demonstrations, seminars and courses, web resources, etc.

Currently, there are numerous web-based irrigation management applications that provide decision support information/tools to farmers, their advisors, and other professionals. Most web-page applications are designed to provide only climate (evapotranspiration, ET)-based irrigation management aids and some of them are more comprehensive and combine several indices, including ET and soil moisture, for irrigation management. For example, The California Irrigation Management Information System (CIMIS) (<http://www.cimis.water.ca.gov/cimis/welcome.jsp>) is a program in the Office of Water Use Efficiency, California Department of Water Resources that manages a network of over 120 automated weather stations. CIMIS was developed in 1982 (Snyder and Pruitt, 1985; 1992) by the California Department of Water Resources and the University of California at Davis to assist California's irrigators manage their water resources efficiently. Since the beginning of the CIMIS weather station network in 1982, the primary purpose of CIMIS was to make available to the public, free of charge, information that will be useful in estimating crop water use for irrigation management. Although irrigation management continues to be the main use of CIMIS, the uses have been constantly expanding to other disciplines over the years. At present, there are approximately 6,000 registered CIMIS users from diverse backgrounds accessing the CIMIS data and information directly.

The Irrigation Management Climate Information Network (IMCIN) (<http://www1.agric.gov.ab.ca/general/>

[progserv.nsf/all/pgmsrv149](http://www1.agric.gov.ab.ca/general/progserv.nsf/all/pgmsrv149)) in Alberta, Canada, is intended to provide the irrigation industry with up-to-date information on crop water use and agro-climatic conditions throughout southern Alberta. IMCIN web page provides up-to-date information on current conditions and provides a forecast for irrigation requirements throughout the major irrigated areas of southern Alberta. The data collected and posted on IMCIN web page include primary climate variables (rainfall, solar radiation, air temperature, wind speed, relative humidity) as well as irrigation management information for various crops. The web site is designed to be a guide to irrigators and is specific to each reporting station. The posted soil moisture depletion values for various crops are calculated based on recorded climate parameters and are updated along with the climate conditions. The site also provides projected average crop water use information based on historical data.

A Site Specific Irrigation Scheduling Tool web site as a part of North Dakota Agricultural Weather Network (NDAWN) web site (<http://ndawn.ndsu.nodak.edu/irrsched-crop-view-form.html>) has been developed at the North Dakota State University to track soil water content and crop water use for various agronomical crops, including barley, canola, maize, potato, sugar beet, sunflower, wheat and other small grains, in field conditions. The web site is designed to aid farmers to make site-specific irrigation management decisions and utilizes soil characteristics information from the USDA-NRCS's digitized web soil survey database and aerial images. Crop evapotranspiration for various agronomical crops and supporting climate data are provided on a daily basis.

The Texas High Plains ET Networks (North Plains and South Plains Networks) were established in the 1990's to provide convenient and timely access to agriculturally-based meteorological data for use by producers, agricultural researchers, and others interested in agriculturally-relevant meteorological data. The Texas High Plains Evapotranspiration (TXHPET) Network (<http://txhigh-plainset.tamu.edu/>) is a partnership between engineers and scientists of the North Plains ET (NPET) Network, based at Amarillo, Texas, and the South Plains ET (SPET) Network, based at Lubbock, Texas. The network depends upon agricultural research and extension personnel to provide the best estimates of water use for reference and field crops grown in the region. The respective networks are maintained and supported internally by Texas Agricultural Experiment Station and Texas Cooperative Extension. The information is made available principally for agricultural irrigation management purposes. However, many other applications and user groups have supported and utilized the data since the TXHPET's inception. Data on this site are currently utilized by a variety of clientele for various purposes. Over time, additional data features and applications (including lawn and turf water use estimates) have been added to the network site, significantly expanding the clientele base (Marek and Michels, 1986; Porter et al., 2005; Marek et al., 2008).

The Irrigation Management-Online (<http://oiso.bioe.orst.edu/RealtimeIrrigationSchedule>) is a decision support system for use in water resources planning and irrigation management. The tool was developed as a partnership effort between USDA-NRCS and Oregon State University. The system downloads weather data from local weather stations and uses the data, in combination with farm-specific information about fields, crops, and actual irrigation

practices provided by irrigators, to estimate soil moisture conditions and to forecast irrigation schedules. There are numerous other online irrigation management tools. While the functions, content, design, and complexity of the web-based tools differ, they all have a common goal of providing timely irrigation management decision support information.

While the aforementioned and similar web-based water management decision support applications can provide vital information to farmers and their advisors in specific location or state, there is a need for these types of applications to increase in number and intensity due to great diversity in cropping patterns, climatic, and soil conditions and also due to great diversity in management practices between the states. Thus, providing local climate and/or soil moisture-based decision support information is a key for the increased accuracy and efficiency of irrigation management. Providing these types of information locally can also enhance the adoption of the information/tools provided by the local professionals. Also, it is critical for web-based water management programs to have enough connections to the field conditions to increase the accuracy of the water management recommendations. One difference between the NAWMDN and other similar web-based programs is that while the NAWMDN also has a significant web-based information dissemination component, the core members of the Network are continuously in contact/communication with almost all cooperators, which makes it challenging, but a unique Network. This paper describes a coordinated Network (Nebraska Agricultural Water Management Demonstration Network, NAWMDN) that is designed to provide information to farmers, crop consultants, and water resources management agency personnel on irrigation management and transfer research-based information and knowledge to make better-informed management decisions to increase water use efficiency through extensive field demonstrations. The Network couples the web and ground-based information to disseminate the water management information to the users. Also, extensive ground truth observations for the procedures and recommendations used are significant components of the Network.

#### **TRANSFERRING RESEARCH-BASED INFORMATION THROUGH EXTENSION/OUTREACH**

One of the challenges Nebraska experiences in irrigated agriculture is limited adoption of newer technologies/tools for irrigation management. Adoption of accurate, practical, durable, and economical tools can help farmers to make better decisions and improve irrigation efficiencies through best irrigation timing and amount. Proper irrigation management also aids in reducing nutrient leaching and other chemicals below the plant root zone. In early 2005, the NAWMDN was formed from an interdisciplinary team of partners including the Natural Resources Districts (NRD), United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), farmers from south central, north east, west central and western Nebraska, consultants, and University of Nebraska-Lincoln Extension faculty. The main goal of the Network is to enable transfer of high quality research-based information to Nebraskans through a series of demonstration projects established in farmers' fields and implement newer tools and technologies

to enhance plant water use efficiency and water conservation, and reduce energy consumption for irrigation. The demonstration projects are supported by the scientifically-based field research and evaluation projects conducted at the University of Nebraska-Lincoln, South Central Agricultural Laboratory (SCAL) located near Clay Center, Nebraska, by senior author. The specific goals and objectives of the NAWMDN are to:

- enable transfer of research-based information to farmers and their advisors to make better-informed irrigation management decisions,
- foster adoption of newer irrigation management technologies and methods,
- provide one-on-one training/education to users to teach how to install the instrumentation, interpret and incorporate the data/information into decision-making process,
- disseminate information, data, and knowledge gained on the NAWMDN web site to share the information with other users,
- establish and/or improve communication, exchange ideas, enhance collective learning to achieve a common goal of conserving and protecting precious water resources.

## **MATERIALS AND METHODS**

### **TOOLS AND METHODS IMPLEMENTED**

Initially, two primary tools that were adopted in the NAWMDN collaborators' fields are Atmometers (evapotranspiration gage,  $ET_{\text{gage}}^{\text{TM}}$ ) to monitor reference evapotranspiration ( $ET_{\text{ref}}$ ) and Watermark<sup>TM</sup> granular matrix sensors to monitor soil water status. The  $ET_{\text{gage}}$  is used to estimate plant water use from reference evapotranspiration and plant coefficient information. The tools/technologies are not limited to these two initial tools implemented and the Network core members are continuously researching and demonstrating other economical, durable, accurate, and practical tools/sensors to incorporate into the Network. Every year, numerous educational and in-service programs are held to educate cooperators about the objectives of the Network; procedures used; instrumentation; how to read, interpret, and utilize the data; troubleshooting of the instrumentation; how to obtain help; and other functions. In the first year (2005), the  $ET_{\text{gages}}$  and Watermark sensors were installed and read by the farmers and core Network members on a weekly basis. Farmers read their sensors and gages by themselves after they felt confident with the tools. They used the sensors and gages for irrigation management as they were taught in the Network in-service educational programs. The core members are continually in touch with the cooperators throughout the growing season. The following section provides a brief description of these tools, how they function, and how they are installed in the cooperator fields.

### **MEASUREMENT OF SOIL WATER STATUS IN COLLABORATORS' FIELDS: PROCEDURES**

One of the electrical resistance type sensors to measure soil water status is the 200SS Watermark<sup>®</sup> Granular Matrix sensor (Irrometer, Co., Riverside Calif., [www.irrometer.com](http://www.irrometer.com)) (fig. 1). The Watermark sensor operates on the same principles as other electrical resistance-based sensors to

measure soil matric potential (SMP). Water conditions inside the Watermark sensor change with corresponding variations in water conditions in the soil. Resistance between the electrodes decreases with increasing soil water. These changes within the sensor are reflected by differences in resistance between two electrodes imbedded in the sensor. The range of SMP that can be measured with the Watermark is from 0 to 200 kPa which covers the range of soil water contents that are usually sufficient for irrigation management in most soils. In sandy soils, however, the measurement range is from 10 to 200 kPa (Irmak and Haman, 2001).

Watermark sensors have been used to measure soil water status for irrigation management and other purposes for more than two decades (Armstrong et al., 1985; Thomson and Threadgill, 1985; Thomson and Armstrong, 1987; Eldredge et al., 1993; Bausch and Bernard, 1996; Mitchell and Shock, 1996; Shock et al., 1996). The performance and calibration functions of the Watermark sensors have been the subject of research. Armstrong et al. (1985), Thomson and Threadgill (1985), and Thomson and Armstrong (1987) developed calibration curves for the Watermark model 200, and Shock et al. (1996) did the same for the model 200SS. Yoder et al. (1998) compared eight different soil water sensors performance representing eight sensor types and reported that the Watermark sensors were one of the four sensors that performed best when accuracy, reliability, durability, and installation factors were considered. Bausch and Bernard (1996) evaluated the validity of the Watermark SMP values calculated using Thomson and Armstrong (1987) and Shock et al. (1996) calibration equations with the tensiometer-measured SMP. They reported that calculated SMP values using both equations showed the same trend as measured SMP throughout six wetting and drying cycles for irrigated corn. Thomson and Threadgill (1985) derived a calibration equation for Watermark sensors using a pressure plate apparatus and a water bath to control temperature. The authors found a non-linear temperature effect which was greater than that suggested by the manufacturer. The sensitivity of Watermark sensors in coarse-textured soils is more important than those in fine-textured soils because irrigation trigger points (based on the SMP) are much narrower in coarse-textured soil than fine-textured soils.

Irmak and Haman (2001) studied several different published calibration curves for Watermark 200SS series in two sandy soils against mercury manometer-tensiometer-measured SMP. They observed a linear resistance versus SMP within the ranges of approximately 10 to 80 kPa and 11.5 to 23 kPa for loamy fine sand and fine sand soils, respectively. They observed that the Watermark sensors did not respond to changes in SMP at potentials lower than approximately 10 and 11.5 kPa in the loamy fine sand and fine sand, respectively. Optimization results showed that calibration equations with optimized parameters can successfully be used to estimate SMP for the soil in which the parameters were optimized. However, applying the same equation with the optimized parameters to estimate SMP in the other soil type resulted in poor estimates.

In the NAWMDN project, one  $ET_{\text{gage}}$  and four to eight Watermark sensors were installed at each collaborator's field. In the initial years, most of the sensor and  $ET_{\text{gage}}$  installations were done by the core members with the assistance of cooperators. The Watermark sensors were installed every 0.30 m up to 1.20 m in the soil profile. During the installation, extra precautions were taken not to damage the plants as damaged plants would have different water uptake rates than the healthy ones and this may result in non-representative soil moisture measurements. To avoid plant damage, sensors were installed early in the season after plant emergence. Farmers showed more confidence in early season installation as they had a month or longer period prior to the first irrigation to get familiar with the sensors. Sensors were installed in representative areas of the field and installation in low spots or areas with excessively steep slopes was avoided. The representative areas for each field were selected based on uniform plant emergence, average field slope, and soil type. In the case where the field had more than one soil type, the dominant soil type was chosen as the location to install the sensors. Locations that were low areas, tops of hills, beneath the coverage of the end gun of a center pivot, under the first tower of a center pivot, near the edges of fields that may get uneven irrigation, or any other area that is not representative of the field was avoided. One Watermark sensor was installed in between two plants on the plant row (fig. 2). In most cases, collaborators used hand-held meters

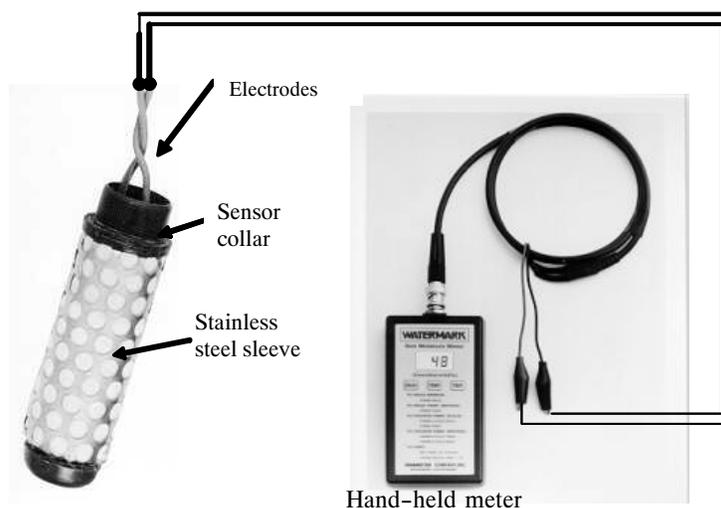


Figure 1. Basic components of the Watermark granular matrix sensor and a hand-held meter.



**Figure 2.** Watermark sensors installed at 0.30-, 0.60-, and 0.90-m depths between two maize plants in collaborator's field.



**Figure 4.** Watermark Monitor installed in a collaborator field to log the soil matric potential data on an hourly basis. Eight Watermark sensors can be attached to the monitor.



**Figure 3.** University of Nebraska-Lincoln (UNL) Extension Educator Brandy van DeWalle is teaching one of the NAWMDN collaborators about how to read the Watermark sensors and interpret the data for making irrigation management decision.

to read the Watermark sensors once or twice a week with assistance of the core members (fig. 3). Some collaborators installed Watermark monitors to record the SMP data on an hourly basis (fig. 4).

#### **SOIL-WATER RETENTION CURVES FOR WATERMARK SENSORS IN DEMONSTRATION FIELDS**

Saxton's model (Saxton et al., 1986) was used to create soil water retention curves for the demonstration fields using soil particle size distribution and organic matter content determined from the soil samples that were taken from the demonstration fields. The soil samples were analyzed in a private soil laboratory for soil texture, including, particle size distribution, field capacity, permanent wilting point, and organic matter content. From the soil analyses data, the organic matter content of the topsoil ranged from 1.5% for sandy soils to 3.5% for other soils. The total water holding capacity ranged from 25 mm/0.30 m for sandy soils to 60 mm/0.30 m for silt loam soils. An extensive educational/training campaign was conducted to educate each of the core extension educators and collaborator as to how to create the

retention curves and how to make the conversions from SMP to soil water content and available soil water for individual fields, how to interpret the data, and incorporate the results into the irrigation management practices. In many cases, these trainings were conducted for group of collaborators as well as through one-on-one trainings. The following section briefly describes the procedures used to create the soil-water retention curves.

Numerous soil-water retention curves were developed as the demonstration sites consisted of several different soil textures, including silty-clay loam, clay loam, silt loam, fine sandy-loam, loamy sand, and fine sand. Saxton et al. (1986) developed soil water characteristic equations for a variety of soil types from the USDA soil database using readily available variables of soil texture and organic matter content from many locations in the United States. The equations were combined with previously reported relationships for SMPs and conductivities and the effects of density, gravel, and salinity to form a comprehensive predictive system of soil water characteristics for agricultural water management and hydrologic analyses. The verification for the developed equations was performed by Saxton et al. (1986) using independent data sets for a wide range of soil textures. The equations were derived for SMPs of 0 to 1500 kPa and air-entry based on commonly available variables of soil texture and organic matter content. These were combined with equations of conductivity, effects of density, gravel, and salinity, to provide a water characteristic model useful for a wide range of soil water and hydrologic applications. In our study, to estimate the retention curves for soils that were commonly represented in the NAWMDN demonstration fields, the soil analyses results were entered as inputs to the Saxton's model. This process was done by entering the average percent sand, clay, and organic matter for each site based on soil sampling at each demonstration site. The salinity, gravel, and soil compaction inputs were left at the default values in the model. Thus, numerous soil-water retention curves were developed. Some of the estimated retention curves are presented in figure 5. Soil types shown in figure 5 are silt-loam, silty-clay loam, clay-loam, sandy loam, and sandy soils were represented in the demonstration sites based on the soil samples. These retention curves were

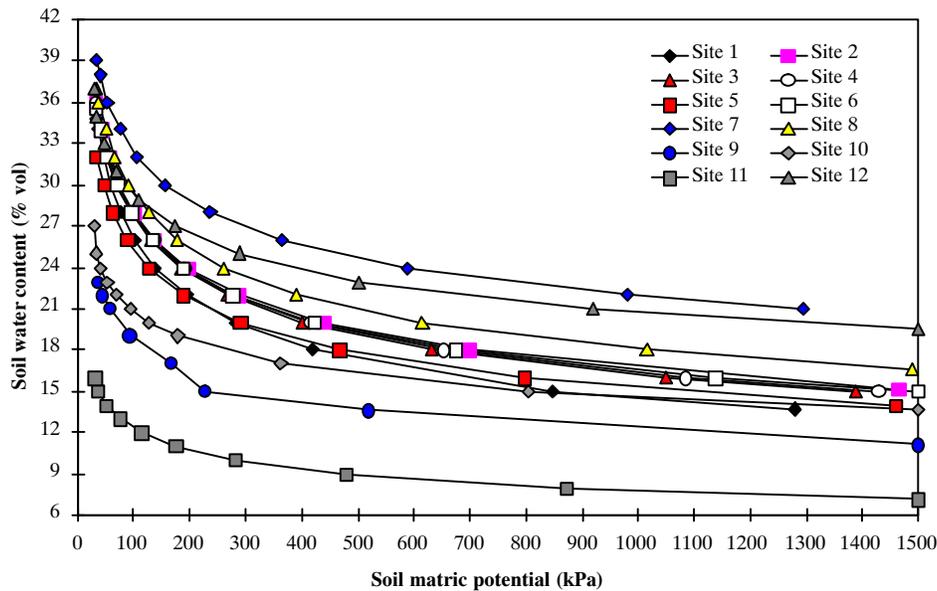


Figure 5. Some of the soil-water retention curves that were developed for the demonstration sites using Saxton's model. Measured soil texture and organic matter content data were used as inputs to the model.

used to convert Watermark SMP readings to volumetric soil water content and calculate available water (or depletion). Again, these processes were taught and explained to educators and collaborators through numerous educational in-service programs. The retention curves for various soil types were provide to the collaborators in a tabular format.

The collaborators had one of the three options to use the Watermark sensors and  $ET_{gages}$  to determine irrigation timings. The first option is to use the pre-determined Watermark-measured SMP threshold values, which were established through local research projects by the senior author, to trigger irrigations. For example, for field maize grown on a silt loam soil, the research findings indicate that when the average of top 0.30-, 0.60-, and 0.90-m Watermark sensors read between 90 and 100 kPa [35% to 38% depletion of available water holding capacity (AWHC) for typical silt loam soils], the irrigation should be initiated. This trigger point is lower than the traditional strategy of irrigating at 50% depletion of the AWHC because it accounts for the time it takes for a typical center pivot irrigation system to make one full circle, which usually takes between 3 to 5 days, depending on the well capacity, system hydraulic design, and other factors. The second option is to use a checkbook method to determine the initial available soil water during the initial stages of the growing season and use the  $ET_{gauge}$ -measured  $ET_{ref}$  and plant coefficients to determine the weekly plant water use to manage irrigations. The plant coefficients for a variety of agronomical plants are provided to the collaborators. The third option is to determine the first irrigation trigger point using Watermark sensors and start using the  $ET_{gauge}$  thereafter throughout the season. The user can use the Watermark sensors again at the end of the season to decide for the last irrigation date. One of the goals of the Network is to utilize as much off-season precipitation and dry down the soil profile near the end of the growing season. The trigger point strategy eliminates unnecessary early season irrigation before soil moisture reach a certain trigger point.

## QUANTIFICATION OF REFERENCE AND ACTUAL EVAPOTRANSPIRATION IN COLLABORATOR'S FIELDS: PROCEDURES

Measurement or estimation of the  $ET_{ref}$  to determine actual plant evapotranspiration ( $ET_a$ ) is one of the critical components of effective irrigation management and it was one of the main functions of the NAWMDN.  $ET_{ref}$  can be estimated from one or a combination of several climate variables such as solar radiation, air temperature, wind speed, and relative humidity. However, using climate variables and empirical equations for  $ET_{ref}$  estimations can be a difficult task for farmers, consultants, extension educators, and technicians who may not be familiar or comfortable with complex equations. In addition, the above-mentioned climate variables may not be readily available to use one of the combination-based equations for  $ET_{ref}$  estimations. Furthermore, if the field in which the plant water use is being determined for is far enough (i.e., >25-30 km) from the weather station, the station's climatic and plant water use information may not adequately represent the climatic conditions in a remote field. The station's climate data may be impractical for irrigation management due to spatial variability especially in rainfall pattern depending on the terrain characteristics. Therefore, farmers need practical, economical, simple, but accurate tools to monitor plant water use from their fields. Another tool that was implemented into the Network was the  $ET_{gauge}$  that is used to estimate  $ET_{ref}$  rates.

The simplicity of the use and interpretation of the  $ET_{gauge}$  data as well as the economical feasibility encourages farmers to monitor plant water use of their own fields. Currently available  $ET_{gages}$  are simple, practical, and accurate tools for irrigation management. Most of the current commercially available  $ET_{gages}$  are very similar in principle. The  $ET_{gauge}$  marketed by the  $ET_{gauge}$  Company (<http://etgauge.com>, Loveland, Colo.) is a modified atmometer that consists of a

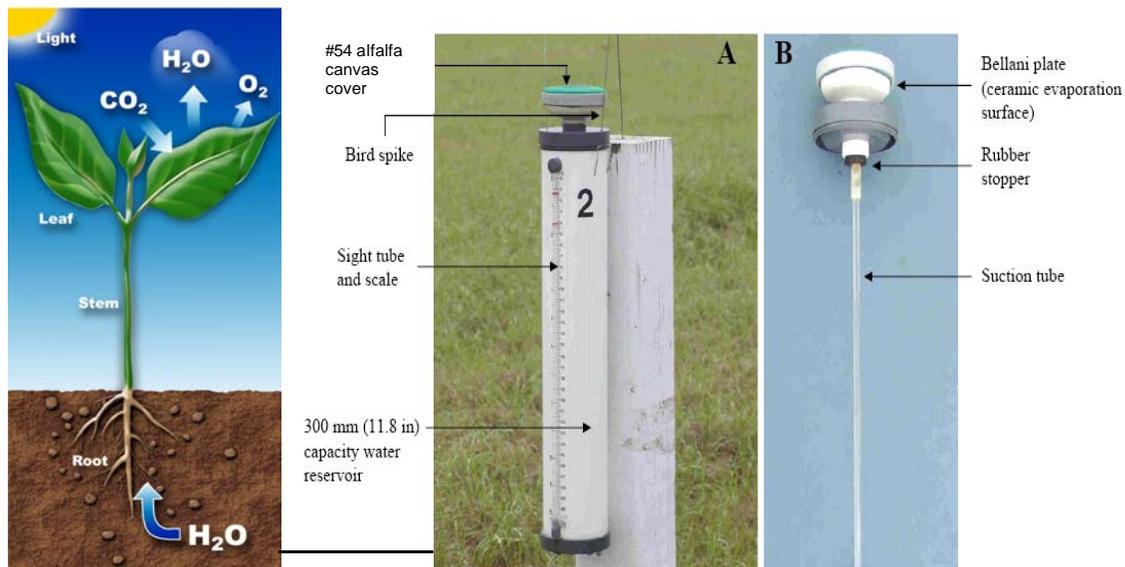


Figure 6. Various components of an evapotranspiration gage ( $ET_{gage}$ ) (right picture from Irmak et al., 2005) that mimics plant water uptake and evaporation from the plant leaves (left).

canvas-covered ceramic evaporation plate (Bellani plate) mounted on a distilled water reservoir (fig. 6). The fabric covering creates a diffusion barrier (resistance) that controls the evaporation rate similar to that found in healthy leaves in a well-watered plant community. The green canvas cover that surrounds the ceramic plate mimics the plant surface albedo so that solar radiation absorption by the  $ET_{gage}$  will be similar to the solar radiation received at the plant canopy (Altenhofen, 1985; Broner and Law, 1991; Irmak et al., 2005). The cover over the ceramic plate can be changed to simulate either the ET rate for alfalfa-reference ET ( $ET_r$ ) or grass-reference ET ( $ET_o$ ) (Irmak et al., 2005).

There have been numerous research results that suggest a good correlation between the reference ET estimated by the combination-based energy balance equations and the evaporation rate from the  $ET_{gages}$ . Wilcox (1963) reported a good correlation between #54 covered (alfalfa-reference)  $ET_{gage}$  evaporation rate and lysimeter-measured  $ET_r$  for alfalfa. Broner and Law (1991) evaluated the Bellani plate  $ET_{gages}$  and concluded that the  $ET_{gages}$  water loss to variations in weather conditions was similar to that predicted by the Penman equation (Burman et al., 1983) and they recommended that the  $ET_{gages}$  can be used to estimate reference ET for irrigation management. Crookston (1988), Blume et al. (1988), Broner and Law (1991), Hess (1998), Alam and Trooien (2001), and Irmak et al. (2005) have reported, in general, a good correlation between the  $ET_{gage}$ -estimated reference ET and reference ET computed from energy balance equations. One of the best examples of utilizing the  $ET_{gages}$  as a tool for large-scale irrigation management program was demonstrated by Altenhofen (1985) in the Northern Colorado Water Conservancy District where modified Bellani plate  $ET_{gages}$  for on-farm monitoring of crop ET has been developed and used by farmers.

The procedures used in the NAWMDN in terms of application of the  $ET_{gages}$  for irrigation management were tested and investigated at the UNL South Central Agricultural Laboratory (SCAL) (fig. 7). In the NAWMDN,

one  $ET_{gage}$  was installed in each collaborator's field to monitor  $ET_r$  with a #54 canvas cover since alfalfa-reference, rather than grass-reference, ET is more commonly used in Nebraska and other Midwestern states.  $ET_{gages}$  were usually installed in mid-May to mid-June and removed at the end of the season in late September-early October.  $ET_{gages}$  are usually placed at the edge of an irrigated field or service road for easy access. The  $ET_{gages}$  were mainly read by collaborators with assistance from the NAWMDN team. Collaborators were provided with the plant coefficient ( $K_c$ ) values to estimate  $ET_a$  (i.e.,  $ET_a = ET_{ref} \times K_c$ ) values for a specific field on a weekly basis to be used for irrigation management. Cooperators were provided alfalfa-reference  $K_c$  values in a tabular form and were taught through numerous educational in-service training programs about how  $K_c$  values are used, how they change with growth stage for each crop and the differences in  $K_c$  between different



Figure 7. Evapotranspiration gages ( $ET_{gage}$ ) with alfalfa and grass-reference canvas covers (#54 and #30, respectively) installed at the University of Nebraska-Lincoln, South Central Agricultural Laboratory (SCAL), Clay Center, Nebr., for research purposes. The research projects related to  $ET_{gage}$  and Watermark sensors conducted at SCAL are implemented into the NAWMDN functions.

agronomic plants. In the Network, each collaborator is required to send in his/her weekly total  $ET_{gage}$  data along with plant growth stage and plant type to the Network so that this information and data can be posted on the NAWMDN web site (<http://water.unl.edu/cropswater/nawmdn>) for others to use. The web site will be discussed in detail in the next section.

#### NAWMDN WEB SITE

In today's technological platform, educational programming must move beyond the "face-to-face program" paradigm. Instead of presenting information at a specific time and place, information must be made available for the user to access instantly. The NAWMDN web site is designed to increase the Network's strength and visibility in the areas of water use, management, research, and education. It aids to increase the awareness, enhances the delivery of water management-related information to key audiences, and integrates extension, research, and teaching components to strengthen each other. The web site was developed so that producers could update their own ET information in a timely manner to one statewide web site. It also allows anyone to view the ET data from participating cooperators throughout the state. One of the other main premises of the web site is to share the information with the users who are not collaborators of the Network so that they can implement the data into their irrigation management decisions, or simply monitor and learn the practices taught in the Network. As a result of this effort, an interactive web site (<http://water.unl.edu/cropswater/nawmdn>) was created for the NAWMDN in 2008 to inform producers and other clients about the Network and educate producers and industry professionals about using newer tools, technologies, and information to make better irrigation management decisions. The web site includes educational information, key publications, and other educational and practical materials. Video clips are also included in the web site to provide education and demonstrations to users on how to install, read, interpret, and maintain the irrigation management tools. An interactive Google map of Nebraska on this site allows producers to click on the site closest to their fields to obtain  $ET_{ref}$  information. The latitude and longitude of each demonstration site is also included on the map. The site also includes information on how to join the Network.

In the web site, users can click on the "online  $ET_{gage}$  tool" on the main page and on "View Weekly  $ET_{gage}$  Data" on the next page to track the  $ET_{ref}$  information provided by farmers, consultants, NRD personnel, and extension educators. To view the data, the user can click on any of the counties. The user then will see a Google<sup>™</sup> Map view of the county that has the  $ET_{gage}$  sites marked with balloon-shape map markers. Simply clicking on the marker near his/her field location (fig. 8) will allow the user to go to a page that includes the weekly total  $ET_{gage}$  data along with weekly rainfall amounts. The site lists the crop growth stages for a variety of crops as well. The growth stages for various crops are shown under the "Growth Stage Charts" tab. The  $ET_{ref}$  data along with the plant coefficients are automatically used to calculate the actual plant water use for maize, soybean, wheat, sorghum, sunflowers, sugar beets, dry beans, potatoes, and alfalfa, which are major agronomical crops grown in Nebraska. The actual plant evapotranspiration is listed under the "Weekly

crop water use" table. The NAWMDN web site uses the plant coefficients published by HPRCC. This interactive web site has engaged cooperating producers and enhanced learning by making them actively participate in reporting reference ET information on a weekly basis. In our initial year, ET information from over nearly 200 producers' sites was uploaded and updated to the web page on a weekly basis by core NAWMDN members, producers, and NRD personnel.

#### $ET_{gage}$ DATA AND PERFORMANCE ANALYSES: PROCEDURES

Extensive analyses were done to assess the performance of the  $ET_{gages}$  used in the demonstration sites as compared with the alfalfa-reference  $ET_{ref}$  reported by the High Plains Regional Climate Center (HPRCC). One of the main objectives of these comparisons was to provide information to the Network participants on the performance of the  $ET_{gage}$  to aid them to gain confidence in the tools implemented in the NAWMDN. The performance analyses were conducted between the  $ET_{ref}$  measured using  $ET_{gages}$  from 30 NAWMDN demonstration sites and the HPRCC  $ET_{ref}$ . For the comparison, the selected  $ET_{gage}$  sites ranged from southeastern Nebraska to the northwestern part of the state, representing a range of climatic and microclimatic zones. The data were downloaded from the NAWMDN site for the  $ET_{gage}$   $ET_{ref}$  and from the HPRCC web site for the HPRCC  $ET_{ref}$ . In the comparisons, the  $ET_{gage}$   $ET_{ref}$  values were compared to the HPRCC  $ET_{ref}$  values from the closest weather station to each  $ET_{gage}$  site. Analyses were done on a weekly total basis as most center pivot and gravity irrigators need weekly total ET data.

All  $ET_{gages}$  used in the NAWMDN were identical models (Model A) and the  $ET_{gage}$  sites that were well-maintained were selected for the analyses. The sum of  $ET_{ref}$  from the  $ET_{gages}$  and those obtained from the HPRCC web site covered the same period (7 days) and provided a data pair for evaluations. The HPRCC Penman equation is alfalfa-reference ET and was modified by Kincaid and Heermann (1974) for Mitchell, Nebraska, climatic conditions by modifying the wind function of the Penman (1948) equation for alfalfa surface. The HPRCC  $ET_{ref}$  values were selected to compare  $ET_{gage}$   $ET_r$  because HPRCC has been widely used in North Dakota, Nebraska, Kansas, South Dakota, and Colorado as part of the HPRCC automated weather network. Irmak and Irmak (2008) made extensive comparisons between HPRCC-Penman  $ET_{ref}$  and those calculated using the ASCE-EWRI standardized Penman-Monteith (American Society of Civil Engineers, Environmental and Water Resources Institute, ASCE-EWRI, 2005)  $ET_{ref}$  values on a daily basis for Nebraska conditions and found very good agreements between the two equations. Irmak et al. (2008) also made extensive analyses between the ASCE-PM  $ET_r$  and HPRCC  $ET_r$  on a daily basis and concluded that the HPRCC Penman equation  $ET_r$  estimates were in a very good agreement with those from the ASCE-PM  $ET_r$  and that the HPRCC Penman  $ET_{ref}$  estimates were with 5% of the ASCE-PM  $ET_r$  with root mean square difference (RMSD) of  $0.56 \text{ mm d}^{-1}$ . This RMSD value was also very comparable with those obtained by the 1948 and 1963 Penman equations when daily time step is considered. No corrections were applied to the HPRCC  $ET_{ref}$  data and none of the data were omitted from the analyses. The HPRCC has an automatic and routine procedure in place to fill-in and/or correct for days

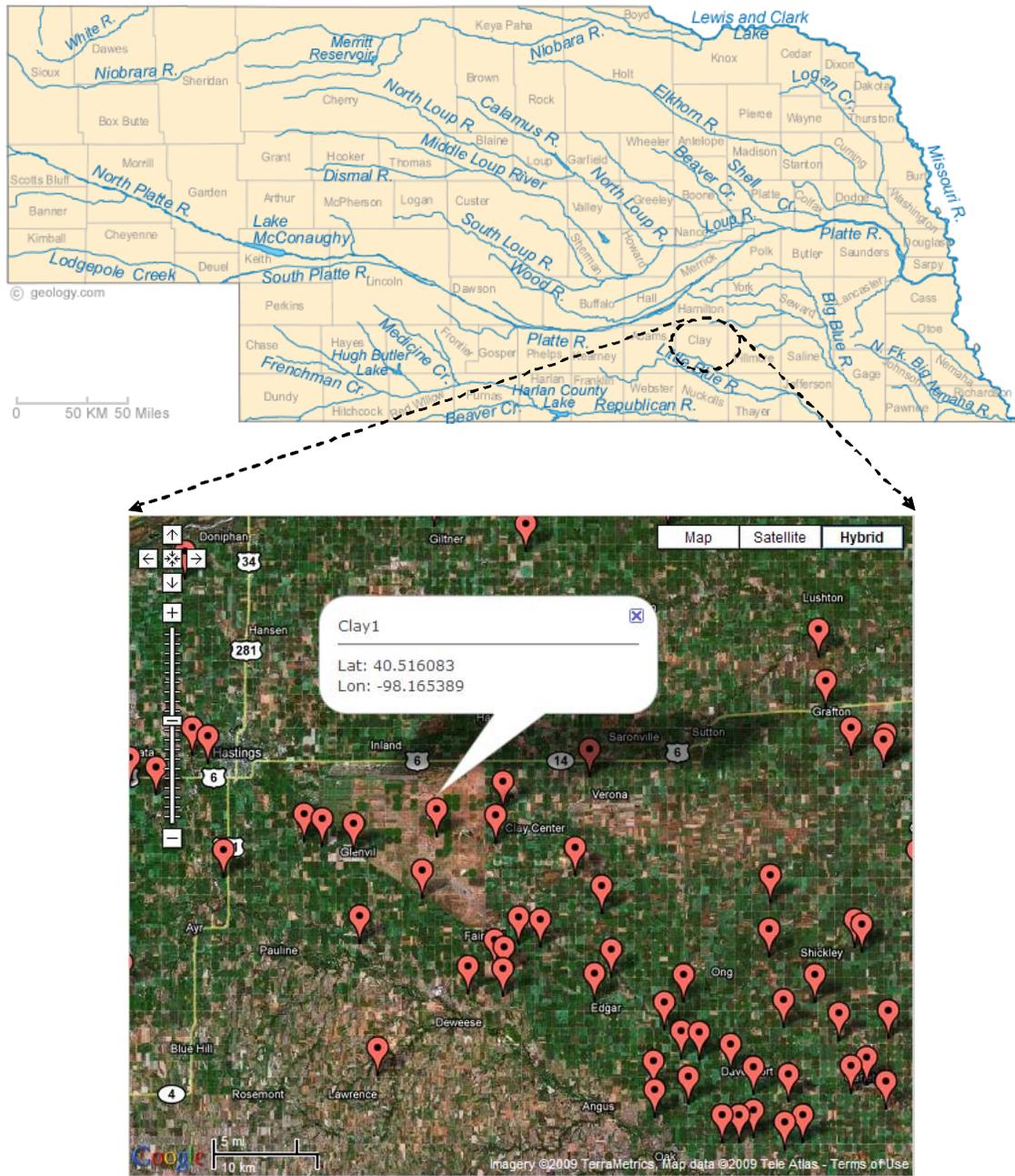


Figure 8. County map of Nebraska (top) and the locations of the demonstration sites marked in one of the counties (Clay) in south central Nebraska (bottom).

with erroneous and/or missing data. Thus, no additional procedures were applied for filling any data gap.

In the comparisons, the  $ET_{gages}$  that had a variety of range of distance from the weather station were selected. The data from the  $ET_{gage}$  locations that were less and more than approximately 15 km from the closest weather station were analyzed separately to assess the impact of the distance from the weather station on the  $ET_{gage}$  performance. Also, the data from all 30 sites and years were pooled together and analyzed. The  $ET_{gage}$  data from the demonstration sites from 2007, 2008, and 2009 were used. The RMSD and coefficient of determination ( $r^2$ ) were calculated to judge the accuracy and performance of the  $ET_{gages}$ . The intercept of the relationships between  $ET_{gage}$ ,  $ET_{ref}$  and HPRCC  $ET_{ref}$  was

forced to zero and percent over or underestimations by the  $ET_{gage}$  was quantified. The RMSD values were calculated as:

$$RMSD = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i^e - y_i^m)^2} \quad (1)$$

where  $n$  is the number of observations,  $y_i^e$  is the  $ET_{gage}$ -measured alfalfa-reference ET ( $ET_{ref}$ ), and  $y_i^m$  is the HPRCC-Penman-estimated  $ET_{ref}$ .

#### **$ET_{gage}$ DATA AND PERFORMANCE ANALYSES: RESULTS**

The regression comparisons and analyses between  $ET_{gage}$ -measured  $ET_{ref}$  and those from the HPRCC-Penman are presented in figures 9a-o and figure 10a-o for

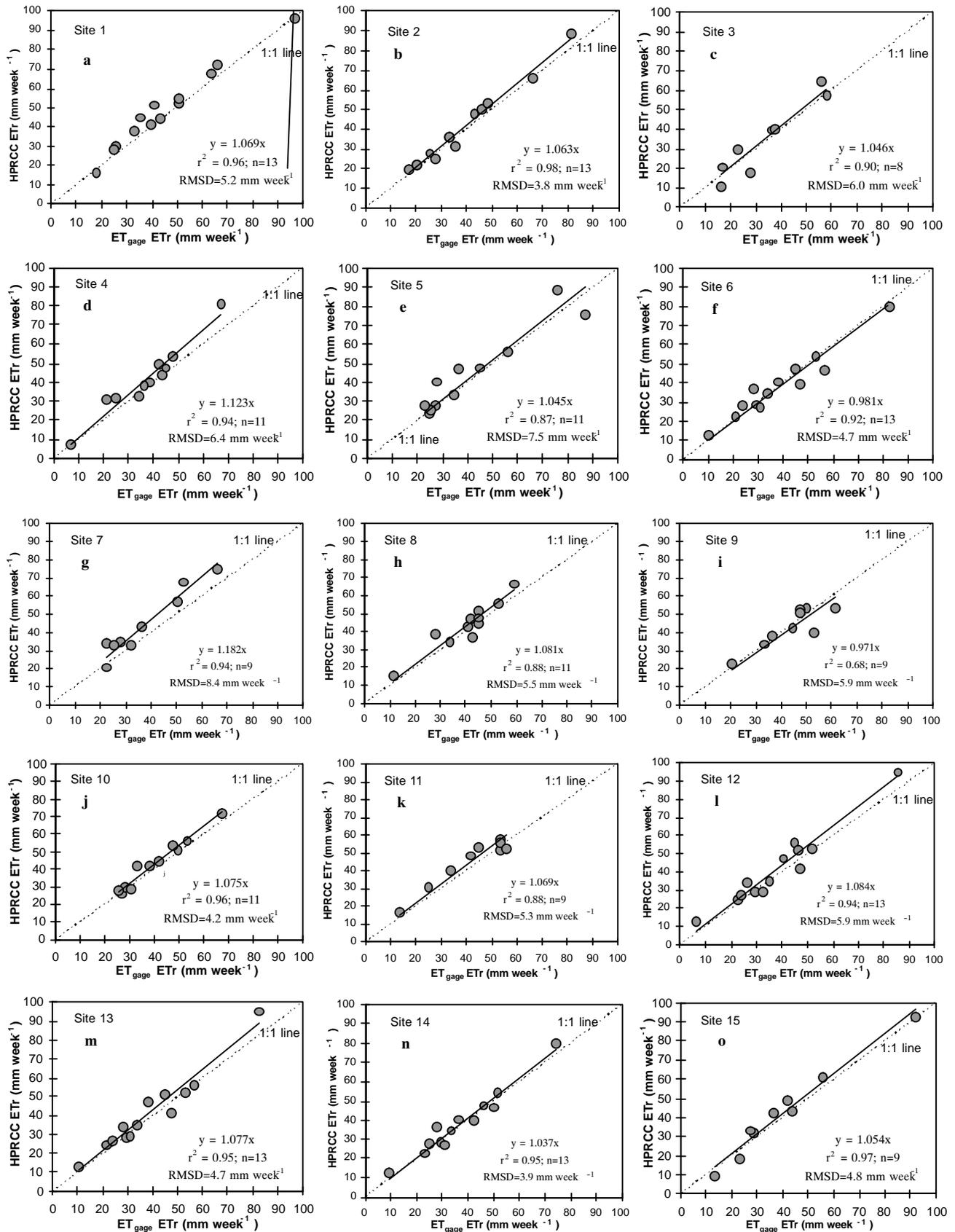


Figure 9. Comparison of weekly total alfalfa-reference evapotranspiration ( $ET_r$ ) obtained from the  $ET_{gage}$  and the High Plains Regional Climate Center (HPRCC) Penman equation (as reported by HPRCC) for 15 sites in Nebraska.

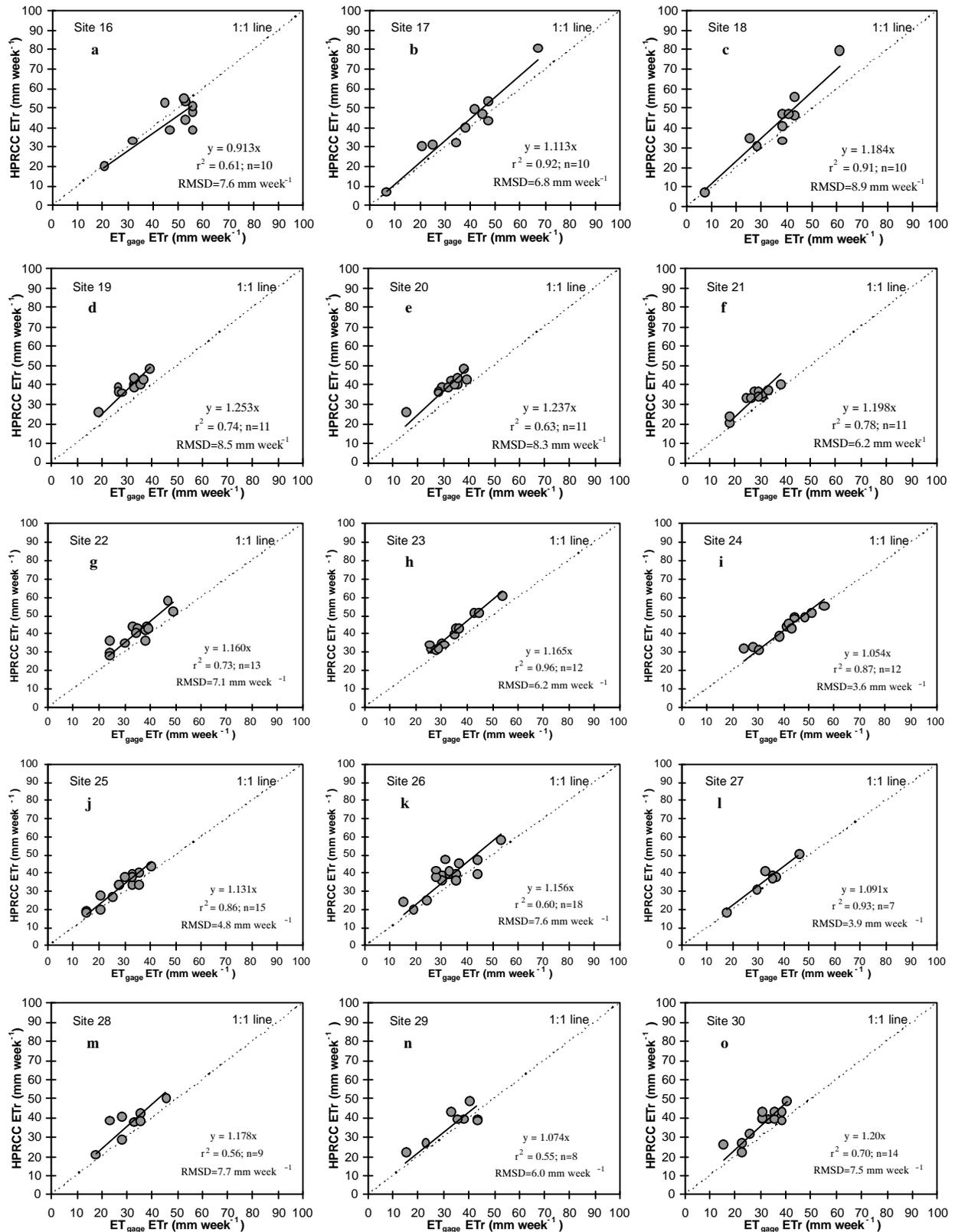


Figure 10. Comparison of weekly total alfalfa-reference evapotranspiration ( $ET_{ref}$ ) obtained from the  $ET_{gage}$  and the High Plains Regional Climate Center (HPRCC) Penman equation (as reported by HPRCC) for 15 sites in Nebraska.

30 NAWMDN demonstration sites. Overall, there were strong agreements between the two approaches in estimating weekly total  $ET_{ref}$ . The minimum and maximum weekly total

$ET_{ref}$  values recorded from the  $ET_{gage}$  over all sites and years were 6.6 and 96.5 mm week<sup>-1</sup>, respectively, and they were 7.1 and 96.0 mm week<sup>-1</sup> for the HPRCC.  $ET_{gage}$  underestimated

$ET_{ref}$  as compared with the HPRCC values at 27 out of 30 sites. The slope of the regression line ranged from 0.91 for site 16 to as high as 1.25 for site 19. The underestimation by the  $ET_{gage}$  ranged from 2% at site 6 to 9% at sites 16 and 27. Overestimations ranged from 3.7% at site 14 to 25.3% at site 19. Most  $ET_{gages}$  had reasonable RMSD values ranging from as low as 3.6 mm week<sup>-1</sup> at site 24 (fig. 10i) to 8.9 mm week<sup>-1</sup> at site 18 (fig. 10c). Twenty out of 30  $ET_{gages}$  had  $r^2$  values greater than 0.85. Site 2 had the highest  $r^2$  (0.98) and the second lowest RMSD (3.8 mm week<sup>-1</sup>) among all sites. Most RMSD values were within acceptable range for the  $ET_{gages}$  to be used for weekly irrigation management.

The distance between the  $ET_{gage}$  and the closest weather station varied for each demonstration site. Twenty-two out of 30  $ET_{gages}$  were located less than 15 km from the closest weather station. Sites 9, 16, 19, 20, 22, 26, 28, and 30 were located at 17, 20, 15, 16, 15, 32, 26, and 22 km from the closest HPRCC weather station. The distance from the weather station appeared to impact the correlation between the  $ET_{gage}$ ,  $ET_{ref}$  and the HPRCC  $ET_{ref}$  because all the  $ET_{gages}$  that were located more than 15 km from the weather station had high RMSD and low  $r^2$  values. However, the highest RMSD (8.9 mm week<sup>-1</sup>) obtained from the  $ET_{gage}$  site 18 which was located within 15 km of the closest weather station. The microclimatic characteristics, terrain and citing conditions and/or poor maintenance of the gage may have been factors contributed to the high RMSD value for site 18. To better assess the distance impact on the  $ET_{gage}$  performance, the data from all sites and years were pooled and presented in figure 11a. In figure 11b, pooled data from  $ET_{gages}$  that were located more than 15 km from the closest weather station were graphed against the HPRCC  $ET_{ref}$  values. Pooled data from the  $ET_{gages}$  that were installed within 15 km from the closest weather stations were compared with the HPRCC  $ET_{ref}$  data and the comparisons are presented in figure 11c. When all data were pooled (fig. 11a) the  $ET_{gage}$  showed a very good performance with a good  $r^2$  (0.87), and low RMSD (6.3 mm week<sup>-1</sup>) as compared with the HPRCC-Penman  $ET_{ref}$  values further confirming that the  $ET_{gages}$  is a viable tool for estimating  $ET_{ref}$  for irrigation management. Overall,  $ET_{gage}$  underestimated HPRCC  $ET_{ref}$  by 8.8%. The magnitude of underestimation increased at higher  $ET_{ref}$  range (i.e., >60 mm week<sup>-1</sup>) with low scatter in data points at <60 mm week<sup>-1</sup>  $ET_{ref}$  range. The pooled data from the  $ET_{gage}$  that were installed more than 15 km from the weather station had higher RMSD (7.0 mm week<sup>-1</sup>) and lower  $r^2$  (0.67) (fig. 11b) with underestimation increasing to 14.3%. The  $ET_{ref}$  obtained from the  $ET_{gages}$  that were within 15 km of the weather station had very good correlation with the HPRCC  $ET_{ref}$  with 7.6% underestimation (RMSD = 5.7 mm week<sup>-1</sup>;  $r^2 = 0.91$ ) (fig. 11c). These results indicate that as the distance between the  $ET_{gage}$  location and the closest weather station increased the correlation decreased. Thus, as the distance from the weather station increases, the  $ET_{gage}$  may provide more representative  $ET_{ref}$  values for a specific location than the weather station due to changes in microclimatic conditions, terrain characteristics, spatial distribution in rainfall amount and frequency, variations in wind speed, and other factors, given the  $ET_{gage}$  is well-maintained. However, even if the  $ET_{gage}$  was located more than 15 km from the closest weather station, on average the  $ET_{gage}$   $ET_{ref}$  values were within 14.3% of the HPRCC  $ET_{ref}$

values, thus they provide good information for estimating actual plant water use for irrigation management.

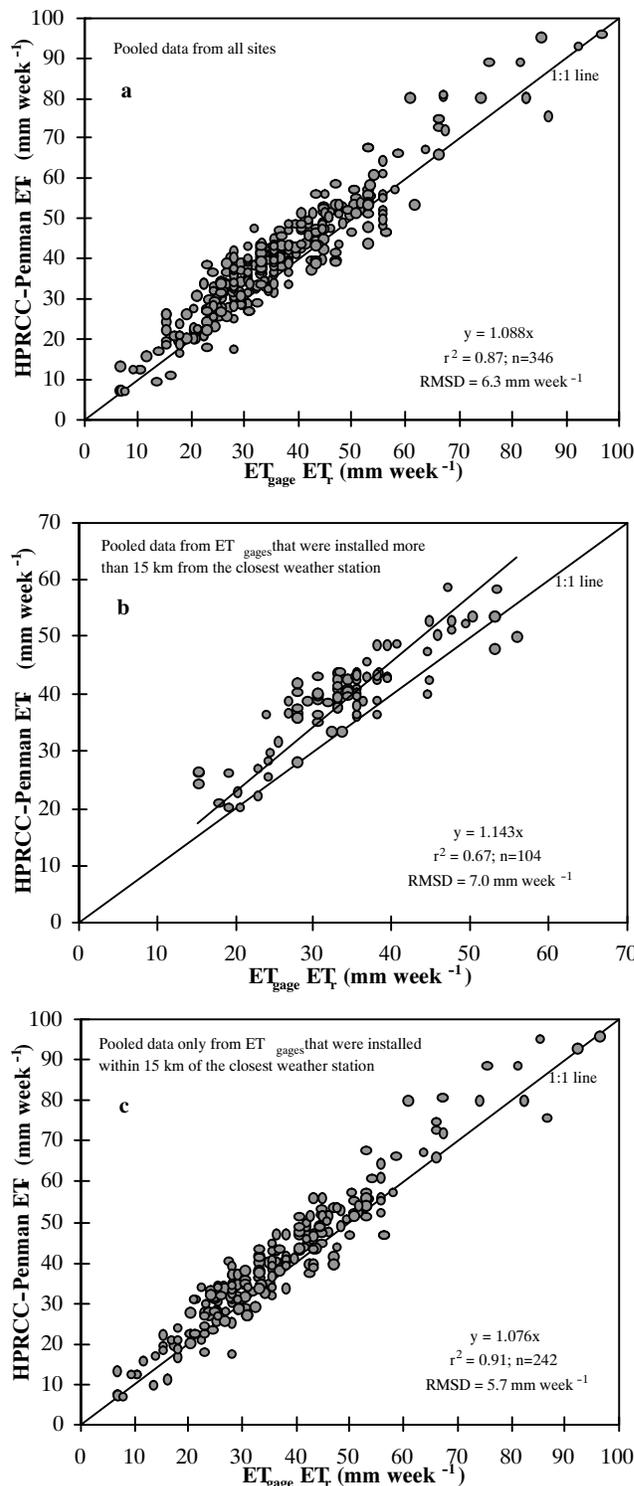


Figure 11. Comparison of alfalfa-reference evapotranspiration ( $ET_r$ ) from  $ET_{gages}$  vs.  $ET_r$  values obtained from the High Plains Regional Climate Center (HPRCC)-Penman equation (as reported by the HPRCC): (a) pooled data from all sites, (b) pooled data from  $ET_{gages}$  that were located more than 15 km from the closest HPRCC weather station, and (c) pooled data only from  $ET_{gages}$  that were located within 15 km of the closest HPRCC weather station.

## IMPACT ASSESSMENT

Based on the long-term observations and assessments of the core members, getting the farmers to use some kind of instrument for irrigation management is more difficult than teaching them how to interpret the readings and use it for decision making. Once they commit to incorporate soil water status or reference evapotranspiration measurement device into their practices, then they are more willing to learning the operation, interpretation and application of the instrumentation/sensor readings into their irrigation management practices. To evaluate the impact of the NAWMDN educational programs and receive feedback, the team members conduct surveys at the end of each calendar year. The surveys usually have 60% to 70% return rate. In the survey, the Network cooperators are asked to provide detailed information on many aspects of their irrigation and general farm practices and their involvements with the Network. The questions include, number of years that they have been involved with the NAWMDN, why they choose to be part of this effort, their county and occupation, how many acres of irrigated land they manage, irrigation method used, crop type, estimated water saving they achieved by being involved with the Network (the reduction of water applications were determined by cooperator based on cooperator's best estimate using his/her long-term irrigation application record), knowledge gained by being involved with the Network (this part of the survey is a separate part that asks ten additional questions to assess the behavior change of the cooperators in terms of water management), what did they like the best about the program, what they did not like about the program, what they suggest to improve the program, and whether they will continue to be part of the program in the next year. Since 2005, none of the cooperators has dropped out of the program.

The NAWMDN started with only 15 farmer collaborators in early 2005. As of September 2009, the number of active collaborators reached over 300. The Network was initiated with only one NRD (Upper Big Blue NRD). In 2008, 12 NRDs are currently active partners of the Network. The Network is having significant impacts on both water and energy conservation. The NAWMDN is helping participants to improve irrigation management and efficiency by monitoring plant growth stages and development, soil moisture, and reference ET. As a result, participants are reducing irrigation water applications and are achieving energy savings and this is leading to greater profitability to participating producers. Through conservation practices, the Network is also aiding in the conservation of water resources of the Ogallala aquifer, which is a vital source of freshwater supply for irrigation and other uses for several states extending from South Dakota to Texas and New Mexico. The first 4-year of results and collaborations with growers yielded positive feedback. The ET<sub>gage</sub> and Watermark data were analyzed and core members and producers learned about using both the ET<sub>gages</sub> and Watermark sensors and incorporated them into their irrigation management decisions. The NAWMDN team is regularly organizing several in-service education programs/meetings during and after the growing seasons to implement the project, review the results, assess the progress made, set future goals, and obtain feedback from the growers about the demonstration functions. The project progress, findings, accomplishments,

and future goals and objectives have been presented at over 231 meetings to over 8,650 producers, consultants, agriculture industry and government representatives. Some of the project functions have also been published in numerous regional magazines, and demonstrated in numerous radio and TV programs. Based on the survey results, some of the quantitative impacts can be summarized as:

- In 2005, the project participants represented a total of approximately 600 ha of cropland and reported water conservation due to reduced irrigation applications, ranging from 50 to 100 mm with an average of 60 mm per field per growing season.
- In 2006, the survey participants represented about 24,280 ha of cropland. The water conservation that was reported by the Network participants ranged from 25 to 90 mm for maize and soybean, respectively, with an average of 43 mm for both crops. With the diesel fuel prices of \$3.80 per 3.78 L in 2006, the water conservation range of 25 to 90 mm was associated with a dollar saving of \$22.72/ha and \$79.75/ha, respectively. The average water conservation of 43 mm was associated with a \$38.77/ha of increase in net benefit to the growers.
- In 2007, cooperating producers and consultants had approximately 48,000 ha of total irrigated land with approximately 33,000 ha in corn and 15,000 ha in soybean. Based on the survey results, the estimated water conservation for maize ranged from 0 to 190 mm with an average of 66 mm while soybean water conservation ranged from 0 to 122 mm with an average of 53 mm. With the diesel fuel prices of \$3.80 per 3.78 L in 2007, the water conservation of 66 and 53 mm that was achieved with the NAWMDN were associated with a savings of \$59.25/ha and \$47.90/ha, respectively. Using 2007 diesel prices, this resulted in total energy savings of \$2,808,000 and \$2,269,800 for corn and soybean over 48,000 ha.
- Surveys of 300 NAWMDN participants, which represented 12 of 23 NRDs and 35 of 93 counties, estimated water conservation for 2008 at an average of 66 mm for maize and 55 mm for soybean on 114,000 ha (58,000 ha of maize and about 56,000 ha of soybean). With 2008 diesel fuel prices, this water conservation was an equivalent of \$2,814,000 and \$2,270,000 for maize and soybean, respectively, in energy costs saved for the land area represented.
- Educational meetings were held before, during, and after the growing season each year to address questions and concerns and improve the Network for the following year. Since the beginning of the NAWMDN, over 8,650 producers, crop consultants, and agricultural industry personnel have been reached and educated at over 231 meetings. Producers had many positive comments about the NAWMDN efforts and indicated that it made them more aware of water use and that they have learned and gained confidence as a result of being involved with the Network. Another impact of our Extension method was that the NRDs are cost sharing the tools we implemented for the growers by 50%. As a condition of cost-share, the collaborators are required to report their weekly total reference ET readings from their ET<sub>gages</sub>, plant growth stages, and rainfall amounts to the NAWMDN members and the information for all demonstration sites is posted on the web site.

## CONCLUSIONS

The Nebraska Agricultural Water Management Demonstration Network (NAWMDN) was formed from an interdisciplinary team in early 2005 in partnership with the Natural Resources Districts (NRD), United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), farmers from south central, north east, west central, and western Nebraska, consultants, and University of Nebraska-Lincoln faculty. The Network initially utilized Watermark granular matrix sensors and atmometers ( $ET_{gates}$ ) to monitor soil water status and crop evapotranspiration to make better-informed irrigation management decisions.

This interdisciplinary demonstration project has been very effective in helping farmers to increase the adoption of appropriate newer technologies and methods to obtain higher water use efficiency and save water and energy resources. The Network has enhanced the communication and information exchange between farmers, researchers, NRCS, UNL Extension, NRDs, and other state and federal agencies. The first 4 years of results and collaborations with growers yielded excellent outputs and positive feedback from core members and producers. The  $ET_{gate}$  and Watermark data were analyzed and core members and producers learned about using both the  $ET_{gates}$  and Watermarksensors and incorporated them into their irrigation management decisions. Growers report water conservation and energy savings. For example, based on the survey conducted in 2008, estimated water conservation was averaged 66 mm for maize and 55 mm for soybean on 114,000 ha (58,000 ha of maize and about 56,000 ha of soybean). With 2008 diesel fuel prices, this water conservation was an equivalent of \$2,814,000 and \$2,270,000 for maize and soybean, respectively, in energy costs saved for the land area represented. The Network will continue to grow as new collaborators are expected to join the Network in 2009 and 2010. This interdisciplinary team effort has demonstrated that a well-coordinated team effort comprised of farmers, researchers, educators, and state and federal agency personnel is an effective approach to conserve water and energy resources through effective irrigation management.

## ACKNOWLEDGEMENTS

This project is supported, in part, by the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) under the project contract number 65-6526-6-284; University of Nebraska-Lincoln Extension, and Upper Big Blue Natural Resources District.

## REFERENCES

- Alam, M., and T. P. Trooien. 2001. Estimating reference evapotranspiration with an atmometer. *Applied Eng. in Agric.* 17(2): 153-158.
- Altenhofen, J. 1985. A modified atmometer for on-farm evapotranspiration determination. In *Proc. National Conf. Advances in Evapotranspiration*, 177-184. St. Joseph, Mich.: ASAE.
- Armstrong, C. F., J. T. Ligon, and S. J. Thomson. 1985. Calibration of the Watermark model 200 soil moisture sensor. ASAE Paper No. 852077. St. Joseph, Mich.: ASAE.

- ASCE-EWRI. 2005. The ASCE Standardized Reference Evapotranspiration Equation. Environmental and Water Resources Institute (EWRI) of the American Soc. of Civil Eng., ASCE, Standardization of Reference Evapotranspiration Task Committee Final Report. R. G. Allen, I. A. Walter, R. L. Elliot, T. A. Howell, D. Itenfisu, M. E. Jensen, and R. L. Snyder, eds. Reston, Va.: ASCE.
- Bausch, W. C., and T. M. Bernard. 1996. Validity of the Watermark sensor as a soil moisture measuring device. In *Evapotranspiration and Irrigation Scheduling*. C. R. Camp, E. J. Sadler, and R. E. Yoder, eds. St. Joseph, Mich.: ASAE.
- Blume, H. R., L. J. Kuder, D. R. Jantz, and A. D. Shaw. 1988. Methods in determining crop water usage. In *Proc. Conf. Planning Now for Irrigation and Drainage in the 21<sup>st</sup> Century*, 368-375. D. R. Hay, ed. New York, N.Y.: ASCE.
- Broner, I., and R. A. P. Law. 1991. Evaluation of a modified atmometer for estimating reference ET. *Irrig. Sci.* 12(1): 21-26.
- Burman, R. D., P. R. Nixon, J. L. Wright, and W. O. Pruitt. 1983. Water requirements. In *Design and Operation of Farm Irrigation Systems*. M. E. Jensen, ed. St. Joseph, Mich.: ASAE.
- Crookston, M. A. 1988. Canvas covered Bellani plate atmometer. In *Proc. Conf. Planning Now for Irrigation and Drainage in the 21<sup>st</sup> Century*, 716-723. D. R. Hay, ed. New York.
- Eldredge, E. P., C. C. Shock, and T. D. Stieber. 1993. Calibration of granular matrix sensors for irrigation management. *Agron. J.* 85(6): 1228-1232.
- Hess, T. 1998. Evapotranspiration estimates for water balance scheduling in the UK. Univ. Report. Silsoe College, Cranfield University, MK, UK.
- Irmak, S., and D. Z. Haman. 2001. Performance of the Watermark granular matrix sensor in sandy soils. *Applied Eng. in Agric.* 17(6): 787-795.
- Irmak, S., M. D. Dukes, and J. M. Jacobs. 2005. Using modified Bellani plate evaporation gauges to estimate short canopy reference evapotranspiration. *J. Irrig. Drain. Eng.* 131(2): 164-175.
- Irmak, A., and S. Irmak. 2008. Reference and crop evapotranspiration in south central Nebraska: II. Measurement and estimation of actual evapotranspiration. *J. Irrig. Drain. Eng.* 134(6): 700-715.
- Irmak, A., S. Irmak, and D. L. Martin. 2008. Reference and crop evapotranspiration in south central Nebraska: I. Comparison and analysis of grass and alfalfa-reference evapotranspiration. *J. Irrig. Drain. Eng.* 134(6): 690-699.
- Kincaid, D. C., and D. F. Heermann. 1974. Scheduling irrigations using a programmable calculator. USDA-ARS Report No. ARS-NC-12. Washington, D.C.: USDA.
- Marek, T., and G. J. Michels. 1986. Panhandle Agricultural Information System – A Bulletin Board (BBS) system. Amarillo, Tex.: Texas Agricultural Experiment Station. Amarillo Research and Extension Center.
- Marek, T., D. Porter, and T. Howell. 2008. Assessment of Texas Evapotranspiration (ET) Networks. Texas Water Development Board. Contract No. 0903580000. College Station, Tex.: Texas AgriLife Research-Amarillo, Texas A&M System.
- Mitchell, A. R., and C. C. Shock. 1996. A Watermark datalogging system for ET measurement. In *Evapotranspiration and Irrigation Scheduling*. C. R. Camp, E. J. Sadler, and R. E. Yoder, eds. St. Joseph, Mich.: ASAE.
- Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. *Proc. Royal Society of London A*193: 120-146.
- Porter, D., T. Marek, T. Howell, and L. New. 2005. The Texas High Plains Evapotranspiration (TXHPET) Network User Manual- v 1.02. Amarillo AREC #05-37. Texas AgriLife Research at Amarillo Publication No. 09-02. Amarillo, Tex.
- Saxton, K. E., W. J. Rawls, J. S. Romberger, and R. I. Papendick. 1986. Estimating generalized soil water characteristics from texture. *Trans. ASAE* 50(4): 1031-1035.

- Shock, C. C., E. Fibert, and M. Saunders. 1996. Malheur Experiment Station Annual Report. Special Report. 964. Ontario, Oreg.: Oregon State University.
- Snyder, R. L., and W. O. Pruitt. 1985. Chapt. VII: Estimating reference evapotranspiration with hourly data. In *California Irrigation Management Information System Final Report, Land, Air and Water Resources Paper #10013-A*, vol. 1. Davis, Calif.: Univ. of California.
- Snyder, R. L., and W. O. Pruitt. 1992. Evapotranspiration data management in California. In *Proc. ASCE Water Forum*, 128-133. Reston, Va.: ASCE.
- Thomson, S. J., and E. D. Threadgill. 1985. Calibration and adaptation of an improved low cost soil moisture sensor for automated irrigation scheduling. ASAE Paper No. 85207. St. Joseph, Mich.: ASAE.
- Thomson, S. J., and C. F. Armstrong. 1987. Calibration of the Watermark model 200 soil moisture sensor. *Applied Eng. in Agric.* 3(2): 186-189.
- USGS (United States Geological Survey). 2000. Ground Water Atlas of the United States. 730-D, Segment 3, Kansas, Missouri, Nebraska. Reston, Va.: USGS.
- Wilcox, J. C. 1963. Effects of weather on evaporation from Bellani plates and evapotranspiration from lysimeters. *Can J. Plant Sci.* 43(1): 1-11.
- Yoder, R. E., D. L. Johnson, J. B. Wilkerson, and D. C. Yoder. 1998. Soil water sensor performance. *Applied Eng. in Agric.* 14(2): 121-133.