pp. 38-45, *In* L.L. Triplett (ed.) *The Great Plains Symposium 1998: The Ogallala Aquifer, Determining the Value of Water*, Proceedings of the 1988 Great Plains Symposium, March 10-12, 1998, Lubbock, TX, the Great Plains Foundation, Overland Park, KS.

USING THE PET NETWORK TO IMPROVE IRRIGATION WATER MANAGEMENT [1/]

T.A. Howell [2/]

INTRODUCTION

I want to acknowledge the contributions to this presentation by all the PET team at Amarillo and Bushland. I'll try to point many of their individual contributions during the presentation. But in particular, I want to recognize Thomas Marek's and Leon New's dedication that made the North Plains PET Network a reality.

Benjamin Franklin said

"When the well's dry, we know the worth of water."

... Poor Richard's Almanac, 1746.

This quotation seems appropriate to the Ogallala Aquifer situation and especially this conference today despite its being more than 250 years old now. Figure 1 is a well hydrograph from our research farm that shows a decline rate > 3 ft/year for the first 20 years but a decline rate < 1 ft/year for the last 20 years. This well has been re-bowled twice since it was drilled. It pumped more than 1,000 gpm in 1957 and declined to around 280 gpm by 1980 due to the decrease in saturated thickness. We haven't made any recent flow rate and drawdown readings, but Dr. Schneider (who makes the measurements and maintains these data) believes it is still flowing around 230 to 250 gpm after it was re-bowled in 1982. More important, the "estimated" area this well could serve, assuming 10 gpm/ac for furrow irrigation, would have been 100 ac in 1957, and now it could still serve nearly 60 ac using the latest LEPA technology, assuming a reduced capacity of 5 gpm/ac. The Ogallala Aquifer, or perhaps more correctly the High Plains Aquifer, is facing areas of severe declines in Kansas and in the Texas High Plains. In many of these areas, considerable water remains but it may be deep. The key to any sustained pumping, I feel, is tied more to the availability of "cheap" energy than to the actual shortage of water in many areas, like the Northern Texas High Plains. So, the "GOOD NEWS" is that in most areas the problems are not eminent, but the "BAD NEWS" is that for many areas the day is just around the corner when they will face a critical problem.

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It never hurts to turn to the BIBLE for answers, and Solomon's writing in Proverbs 15:22 says

> *"Plans fail for lack of counsel, but with many advisors they succeed."*
>
> ... (NIV, the Holy Bible).

This verse emphasizes the importance of "WISE COUNSEL," and this is the very reason we are at this meeting to utilize the collective wisdom from many advisors to develop a rational plan to sustain our precious water resource. Essentially, this verse embodies in twelve words the intent of the Texas Senate Bill 1 (SB 1) that required many more words.

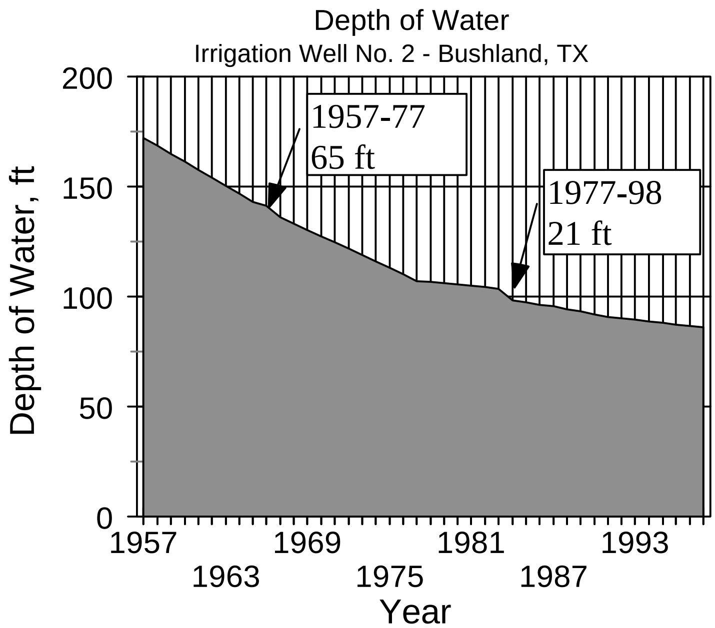

Figure 1. Hydrograph for irrigation well number 2 at Bushland, TX. Data are from Dr. Arland D. Schneider (personal communication).

Agriculture is an industry that sells one basic commodity – WATER. Water is the "fuel" that powers agriculture (whether irrigated or dryland agriculture). We know that no one here can create WATER. So, our purpose is to make sure we obtain the greatest return for any water that is consumed in agriculture and not immediately available elsewhere. Also, a great concern is that agricultural practices do not contribute to degrading our finite land and/or water resources. Irrigation requires huge quantities of water, and it must be water of "good" to "high" quality. Fortunately, the Ogallala aquifer water is very high quality water, or we would have been out of the irrigation business long ago here.

First, irrigation enhances and stabilizes the return to labor, land, and capital. Groundwater is a property that really only has value when used. Right now there is no "future's market" for water except that for crops or livestock that can be produced from the water. I'm sure the economists on the panel can explain this better, but other economists that I've heard say that income is "TURNED OVER" typically 3 to 7 times. But I feel that the social stabilizing feature in rural communities is far more important. All you have to do is drive through some of our small towns in areas where water is "WEAK" to observe this social deterioration.

VALUE OF WATER IN IRRIGATION

You can get a perspective of the productive value of water by examining the association between crop yield and evapotranspiration (ET). I've plotted all the Bushland corn data that I could find from a variety of experiments (tillage, fertility, irrigation scheduling, irrigation method, etc.) in Fig. 2. Of note, you should observe the wide scatter and erratic nature for the lower yield levels. But it shows consistently around 10 bu/ac per inch of ET after around 10-11 inches of ET. Since water pumping costs for an inch of water are roughly equivalent to a bushel of corn, this is a 10:1 gross return. Factoring in other irrigation pumping costs, a "gross return" of about 5:1 still seems likely over a fairly wide range of conditions.

The corn line can be compared with similar lines for other crops (Fig. 3). I've plotted the corn line from Bushland with another line from Bushland for wheat from Musick et al. (1994) and a sorghum line by Stewart and Steiner (1990) that contains much Bushland data, but also it has data from around the world. Corn and sorghum have C4 photosynthetic pathways while wheat has a C3 photosynthetic pathway. C4 crops have higher water use efficiencies (yield per unit ET) than C3 crops. For lower yield levels, sorghum has a consistent yield advantage over corn. But at higher yields, corn has much greater yield potential than sorghum and will require more water. For comparison, if cotton yields are expressed as seed cotton (total of lint and seed), I think that cotton will fall fairly close to the wheat line too (both are C3 crops). Because these functions are relatively linear and have significant X-axis intercepts (negative Y-axis intercepts), the water use efficiency (crop yield per unit ET) will increase with yield or ET. However, because ET is not a direct function of irrigation, greater irrigation water use efficiency will occur substantially below maximum yield or maximum ET.

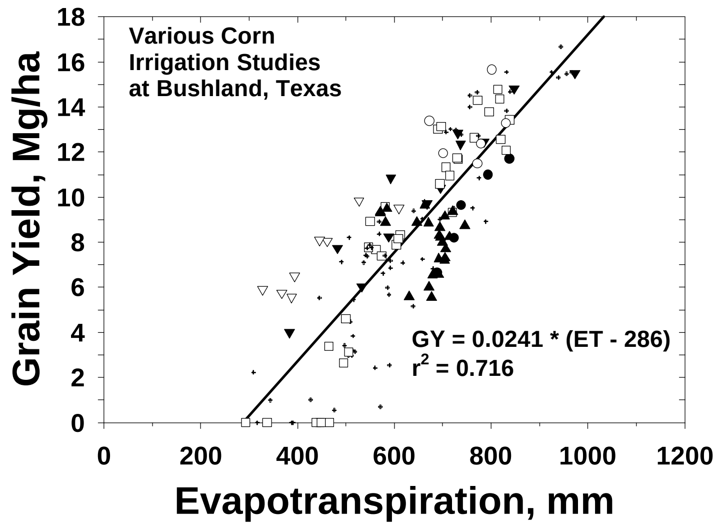

Figure 2. Relationship between grain yield and evapotranspiration water use for corn at Bushland, TX. Data from various published studies. To convert mm to inches, divide mm by 25.4; and to convert Mg/ha to bu/ac, multiply it by 15.9.

Production goals are to achieve yields at as least as high as these lines or the upper envelope of data points. This requires avoiding water deficits at critical growth stages like heading, pollination, or bloom; spreading water deficits evenly; and scheduling irrigations to meet the crop water needs.

PET NETWORK

The PET Networks are aimed at providing data to improve irrigation scheduling. They provide a "UNIFORM" and "DEPENDABLE" source of information on crop water use

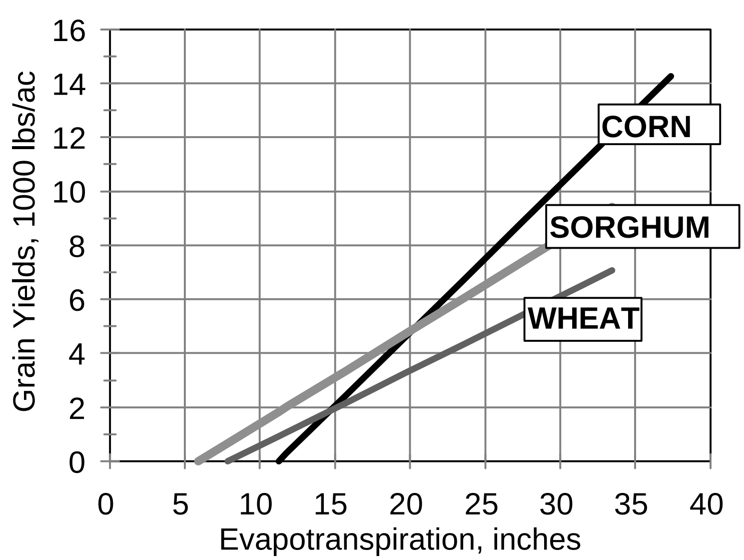

Figure 3. Example crop yield-ET relationships.

(Marek et al, 1997, and Seymour et al., 1994). They provide an excellent tool to advance continuing education on crop water needs to both irrigators and the public. They fill a critical void in our agricultural climate records as well.

The Oklahoma Mesonet (Brock et al., 1995) is one of the most sophisticated and uniform state-wide networks anywhere in the U.S. Plans are being pursued to develop a Texas Mesonet, but it is a long way from being funded and many years away from being in place. Fortunately, the Texas High Plains is one region in the state with fairly good weather network coverage now, despite the fact that NO DIRECT State or Federal monies have been designated for these purposes.

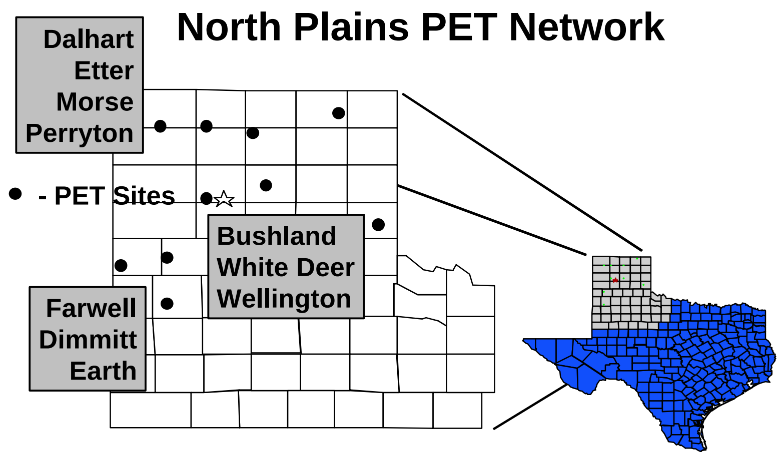

Figure 4. Map illustrating weather station sites for the North Plains PET Network.

We call our state-wide PET Network the TxPET Network, and it has three main branches the South Plains network in Lubbock, the North Plains network in Amarillo, and the TAMU Network in the Brazos Valley, Edwards Region, and Lower Rio Grande Valley. The Coastal Bend network, operated from Corpus Christi, isn't designed to serve irrigation, but rather to serve the dryland cotton industry. The North Plains PET Network operates 10 station sites now, placed in three tiers across the northern Texas High Plains (Fig. 4), from its headquarters in Amarillo. The South Plains PET Network operates 3 station sites (at Lamesa, Lubbock, and Halfway) from its Lubbock headquarters. If you drove to the North Plains sites, you would travel more than 1,200 miles making a circuit trip.

The PET Network is a group of meteorological stations to acquire weather data to compute "potential evapotranspiration" (PET) and to disseminated it in an automated process providing timely, accurate data on ET (and other factors) for a variety of crops to be used for improved irrigation scheduling, improved water management, and for water conservation. PET stands for "potential evapotranspiration" which is the amount of water that a well-watered crop that fully covers the soil might use. Reference ET (Allen et al., 1994) is a more widely used term nowadays, but we chose to stay with the word PET to maintain continuity in our technology transfer programs. Usually reference ET is designated to simulate water use from alfalfa or grass. The TxPET networks have standardized on a grass reference ET equation that specifically is designed to match water use rates from a "cool season" grass about 4-5 inches tall after the methods described in Allen et al. (1994). The PET Network acquires the weather data nightly from each station, computes the various parameters including estimating the crop stage of development, its Kc (or crop coefficient), and its estimated water use rates.

We have focused on the main crops of corn, sorghum, cotton, wheat, and soybean at the present. We're trying to add peanut soon and maybe alfalfa. We no longer plan to add sugar beet because the processing plant in Hereford closed. We bracket normal planting dates with 4 sowing dates. We estimate water and development for full-season and for short-season corn and sorghum and "normal" type cultivars for cotton, wheat, and soybean (mid group IV type).

We only simulate “well-watered” and “normal” crops. We do provide ET data for each day, for the previous 3 days, the previous 7 days, and the whole season to date. We include daily and season sums for GDDs (growing degree days) and estimates of the crop development stage. Included is a “mini summary” with rainfall, temperatures and soil temperatures along with the PET values. We also send out periodic alerts and messages. Although one of our primary audiences is farmers and irrigators, we hope we can meet needs for a diverse clientele. Our main goal is to deliver a product with consistently high quality and dependability.
We feel these products can enhance the ability of consultants to better serve their clients. We can’t and don’t intend to provide farm or field specific data that may be needed to accurately manage irrigation water in a specific situation. We are running some experimental models on insects (mainly corn root worms) and for peanut disease condition predictions that can provide some regional forecasts.

Our main method of dissemination is a daily fax (Table 1) sent to a subscriber. We send out more than 325 faxes each night. We’re using three PCs to get these faxes out before 7:00 a.m. each morning. The complete data and fax sheets can be retrieved from our WEB site at **http://amarillo2.tamu.edu/nppet/petnet1.htm**. Faxes are sent nightly to subscribers for a

Table 1. Example fax sheet for the Bushland, TX station (ARS site) sent on the morning of August 29, 1997.

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        North Plains PET Network   Weather Station, Bushland (ARS)

                 Temperatures (F)
   Date   PET  ---Air--  Soil Min  Prec.   Growing Degrees Days (F)
          in.  Max  Min  2in. 6in.  in.  Crn Srg Pnt Cot Soy Bet Wht
08/26/97  .29   90   62   65   77  0.00   24  26  21  16  28  36  39
08/27/97  .29   89   58   61   75  0.00   22  23  18  15  26  33  36
08/28/97  .30   91   61   62   78  0.00   23  26  21  16  27  36  38
10-day avg min soil temp  66   78

CORN       Short Season Var. Water Use     Long Season Var. Water Use
Seed  Acc  Growth   Day 3day 7day  Seas.  Growth   Day 3day 7day  Seas.
Date  GDD  Stage    -----in/d-----  in.   Stage    -----in/d-----  in.
04/01 2638 Blk lyr  .21  .20  .21  28.8   Dent     .30  .29  .29  30.2
04/15 2574 Blk lyr  .21  .20  .22  27.6   Dent     .30  .31  .31  29.0
05/01 2438 1/2 mat  .27  .26  .25  25.8   Dough    .35  .35  .33  26.8
05/15 2270 Dent     .30  .29  .27  23.5   Milk     .38  .38  .36  24.0

SORGHUM    Short Season Var. Water Use     Long Season Var. Water Use
Seed  Acc  Growth   Day 3day 7day  Seas.  Growth   Day 3day 7day  Seas.
Date  GDD  Stage    -----in/d----   in.   Stage    -----in/d----   in.
05/01 2584 H Dough  .27  .26  .25  21.5   S Dough  .28  .28  .26  20.6
05/15 2416 S Dough  .28  .28  .26  19.2   S Dough  .28  .28  .27  18.3
06/01 2166 Flower   .30  .29  .27  16.4   Flower   .30  .29  .28  15.5
06/15 1901 Flower   .30  .30  .29  13.5   Boot     .32  .32  .30  12.7

SOYBEANS   Late Group 4-Var. Water Use
Seed  Acc  Growth   Day 3day 7day  Seas.
Date  GDD  Stage    -----in/d----   in.
05/15 2689 R_6      .30  .29  .29  22.2
06/01 2376 R_5      .34  .34  .32  18.6
06/15 2057 R_4      .33  .33  .31  15.1
07/01 1635 R_3      .33  .32  .30  10.4

WHEAT                    Water Use
Seed  Acc  Growth   Day 3day 7day  Seas.
Date  GDD  Stage    -----in/d----   in.
08/15  540 Emerged  .15  .15  .13   1.5

NEW -- ARS-BUSHLAND WEB ADDRESS --  http://www.cprl.ars.usda.gov/

Field Day: 7/24/97 - North Plains Research Field @ Etter.
Call Pam Dillard or Thomas Marek @ 806-359-5401 for more info.
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particular weather station. These include growers and irrigators and crop consultants. Several faxes are sent to agricultural industries (like irrigation companies, farm cooperatives, equipment suppliers, etc.). Faxes are sent to local newspapers and radio and television stations. For instance, some data for lawn water needs are published on page 2 in the *Amarillo Globe News* each day from May through November in the Water Smart column from the Randall-Potter County Master Gardener project sponsored by the Texas Agricultural Extension Service. They use crop coefficients to estimate daily water use for bluegrass, Bermuda grass, and buffalo grass. Radio stations, like KGNC in Amarillo give the PET numbers daily on the morning agricultural weather news too. The fax sheet (Table 1) contains data for the previous three days for PET, daily max and min air temperatures, daily min soil temperatures at 2 and 6 in., daily precipitation, and GDDs for several crops. Then for each crop and seeding date, the accumulated GDDs, predicted growth stage, and water use for the previous day, previous 3 days, previous week (7 days), and for the season are given. At the bottom of a fax sheet, as room permits, notices or alerts are provided.

Several sectors need more detailed data to run their own models. All the hourly data can be acquired for any weather station from the Web site. We're working with the TAMU Meteorology Dept. to include the NP-PET data into the Texas Mesonet without compromising our service to our clients, but this has not been finalized yet.

A key part of our success is that our data are based on local research. We're measuring ET from irrigated grass to verify and improve the TxPET equations. We use a weighing lysimeter that is a 5 ft by 5 ft box containing an "undisturbed" soil core of our Pullman soil that is 8 ft deep. This box sets on a sensitive scale that measures the mass change of this box. The grass is SDI (subsurface drip irrigated) and regularly mowed to the 4-5 inch height. Our preliminary research indicates that the TxPET equation slightly under estimates well-watered grass water use rates in the Texas High Plains. The accurate estimation of PET information is important for estimating grass ET that is used for the lawn watering guidelines. That's why we are doing the research to improve the TxPET equation for the Texas High Plains. All the crop water use estimates are based upon research conducted using four large weighing lysimeters that are 10 ft by 10 ft with "undisturbed" soil cores that are 8 ft deep. These actual ET measurements were used to develop the crop coefficients (Kc) values needed to accurately predict crop ET.

Figure 5 shows a graph of the daily and accumulated ET data for the 1995 soybean crop that yielded 72 bu/ac. The maximum daily ET rate was 12 mm/d or 0.5 inch/d. The crop consumed about 770 mm or 30 inches of water. ET rates from the two lysimeters agreed well. Figure 6 shows the previous data transformed into a crop

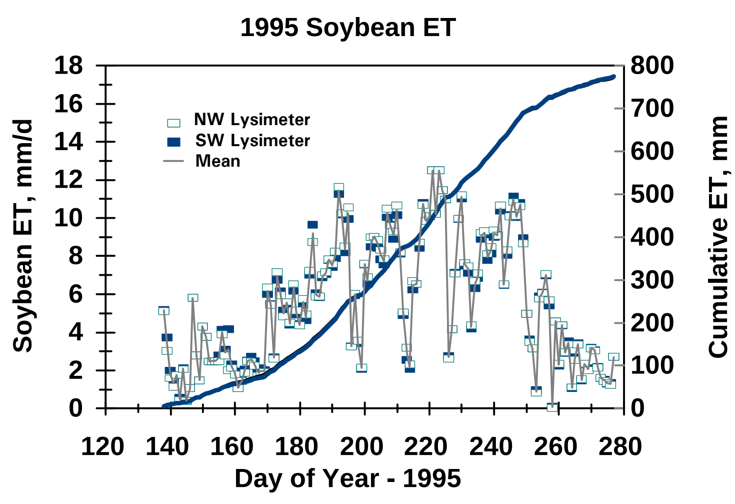

Figure 5. Daily and accumulated soybean evapotranspiration for 1995 at Bushland, TX. To convert mm to inches, divide mm by 25.4; and to convert mm/day to inches/day, divide mm/day by 25.4.

coefficient graph. The curve represents the "mean" crop coefficient for soybean. You can see how wetting from rains and irrigations greatly affect the Kc early in the season. Similar Kc curves have been developed from our research for wheat, corn, and sorghum. Our curve for cotton has been estimated, and we hope to verify it more thoroughly in the future along with developing a more accurate curve for peanut for this region.

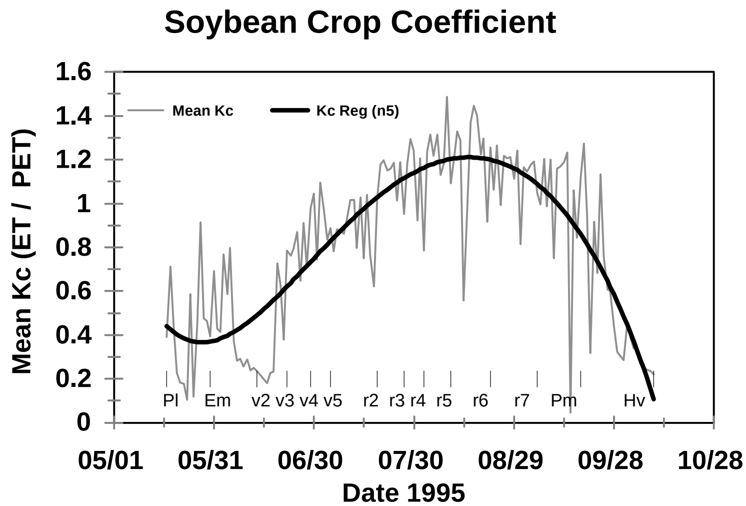

Figure 6. Daily and mean crop coefficient (Kc) curve for soybean in 1995 at Bushland, TX.

To be able to use this information, considerable training and/or continuing education will be needed. TAEX, TAMU, and WTAMU all extensively use the PET data in training and education. Local data on field rainfall and irrigation are needed at a minimum. Some critical data include the field system capacity (flow rate per unit area) and/or the gross flow rate and an estimate of "application efficiency." Crop data on sowing date and hybrid types are needed as well. It is probably better to match your actual crop development status (in your field) with the fax sheet crop growth stage rather than relying solely on your sowing date.

Figure 7 gives an example for the 1995 soybean data. Only three significant rain events occurred for the whole season through August although many smaller and less significant rains occurred. The difference between the rain and ET curves must be made up from 1) previously stored soil water or 2) irrigations. Irrigations should be applied when the ET rates are lower to keep the soil water in the root zone replenished and so a "relatively full" soil profile can be available when the crop growth reaches the critical periods like flowering and pod development for soybean. I will focus on the 3 weeks in

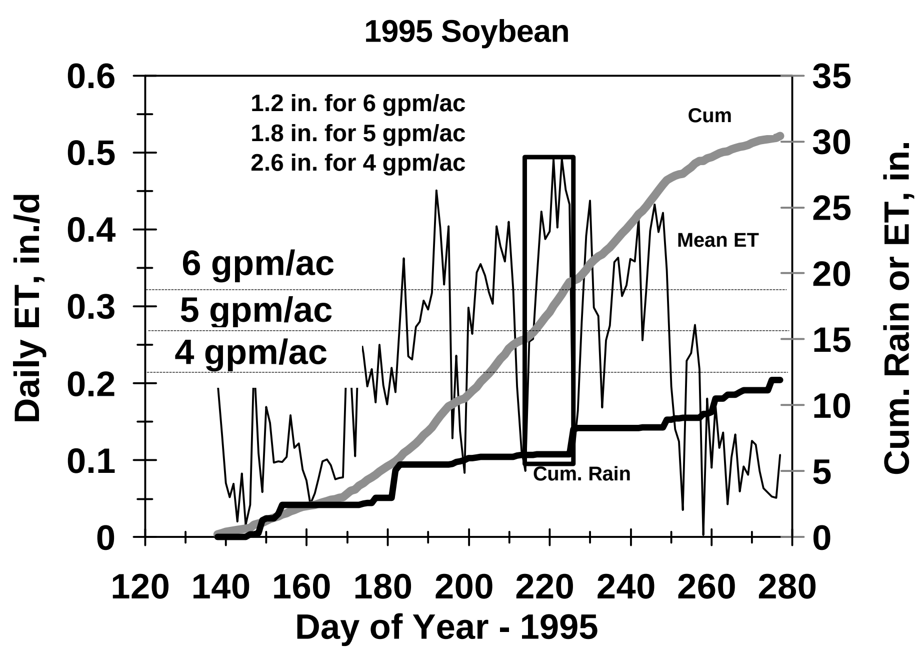

Figure 7. Daily ET and accumulated seasonal rain and ET for soybean in 1995 at Bushland, TX.

August within the box. If 6 gpm/ac irrigation capacity was available, a deficit of 1.2 in. would develop during this period. And if the irrigation capacity was reduced to 5 or 4 gpm/ac, then the deficit would increase to 1.8 in. and 2.6 in., respectively, during this one period. These deficits would have to be drawn from soil water or the crop would suffer water deficits and reduced yields. This simple example illustrates the critical importance that maintaining an irrigation capacity that can meet the majority of the ET demand so some flexibility in irrigation management can be achieved. If a marginal irrigation capacity is used, then a producer is always trying to catch up and needing timely rains to "hope" to achieve an acceptable yield. By knowing the crop ET needs, growers are in a much better position to make those critical strategic irrigation decisions and determine their acceptable levels of risk.

These networks provide a useful regional information resource as well. They give rainfall, soil temperature, climatic data, and water use data not previously available. Although much of these data is site specific, they do begin to provide a regional climatic picture. In particular, the soil temperature data, themselves, can greatly aid the crop planting decision making.

Several growers have documented water savings of 1 to 2 inches of irrigation besides achieving better crop performance. For example for a 1,000 ac irrigated farm, a 1 in. water savings might be valued at near $3-5,000 and any enhanced receipts from higher yields further increase profits. The network weather data also provides timely information to evaluate sudden weather events like late spring freezes or early fall freezes.

The PET data are not intended to be a stand alone resource but to compliment ongoing irrigation management tools. The PET information can be used to update and modify decisions in a timely manner. It should provide crop consultants with a better product that can be used to customize and meet exact needs of their various clients.

SUMMARY

I've emphasized the great value that water has to the Texas High Plains especially through irrigated agriculture and that the PET networks are being supported by solid research to make improvements and refinements to develop accurate products. These Texas High Plains networks serve the Southern High Plains region and compliment programs in New Mexico, Oklahoma, Colorado, and Kansas. In the future, the Texas Mesonet may provide an opportunity to improve these networks and gain even broader coverage. It is imperative that we strive to obtain the highest value for our water resources. I feel that the PET networks serve as a valued contribution toward advancing this goal.

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