

Precision Irrigators Network: On-Farm Research Demonstration to Evaluate Irrigation Scheduling Tools in the Wintergarden and Texas High Plains



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ACRONYMS, ABBREVIATIONS AND DEFINITIONS

ABA	Abscisic acid <i>A plant hormone that functions in many plant development processes</i>
ANOVA	Analysis of variance <i>A collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables</i>
°Brix	Degrees Brix <i>A measurement of the dissolved sugar-to-water mass ratio of a liquid</i>
Centibars	<i>The scale for the soil moisture monitoring tools is in centibars, which is one of the standard units for soil moisture measurements. A soil moisture value between 0 and 50 represents wet soil and plentiful moisture conditions. Soil moisture values near 150 to 200 represents extremely dry soil moisture conditions.</i>
CropMan	Crop Evapotranspiration and Crop Simulation Models <i>Located online at: http://cropman.brc.tamus.edu/</i>
DSS	Decision Support System
EPIC	Erosion-Productivity Impact Calculator model <i>A cropping system simulation model developed to estimate soil productivity as affected by erosion throughout the United States during the 1980's. EPIC simulates all crops with one crop growth model using unique parameter values for each crop. The processes simulated include leaf interception of solar radiation; conversion to biomass; division of biomass into roots, above ground mass and economic yield; root growth; water use; and nutrient uptake. EPIC is a field scale, daily time step model composed of physically-based components for soil and crop processes such as erosion, nutrient balance, crop growth and related processes. It is designed to simulate drainage areas that are characterized by homogeneous weather, soil, landscape, crop rotation and management. http://epicapex.brc.tamus.edu/</i>
ET	Evapotranspiration
ET _c	Crop Evapotranspiration
ET _{co}	Reference crop ET notation
ET _o	Reference Evapotranspiration
ET _{os}	Reference ET notation for meteorological stations

FAO	Food and Agriculture Organization
GDD	Growing Degree Day
Irrig-Aid	<i>A downloadable spreadsheet-based decision tool designed to assess the risk of various crop, soil and irrigation practices, as well as quantify economic trade-offs in allocating soil and water resources to various cropping alternatives. Online at: http://cropman.brc.tamus.edu/decision-aids.aspx</i>
Kc	Crop coefficients
kPa	Kilopascal
LPS	Low-pressure system
N	Nitrogen
NPET	North Plains Evapotranspiration
NPRF	North Plains Research Field
NRCS	United States Department of Agriculture–Natural Resources Conservation Service
NUE	Nitrogen use efficiency
PD	Planting date
PET	Potential Evapotranspiration
PIN I	Precision Irrigators Network: On-Farm Research Demonstration to Evaluate Irrigation Scheduling Tools
PIN II	Precision Irrigators Network: On-Farm Research and Demonstration to Evaluate Irrigation Scheduling Tools in the Wintergarden and High Plains
RUSLE	Revised Universal Soil Loss Equation <i>One of the equations used in the model to estimate water erosion. The RUSLE equation is a modification of the Universal Soil Loss Equation (USLE).</i>
RUSLE2	Revised Universal Soil Loss Equation, Version 2 <i>One of the equations used in the model to estimate water erosion. The RUSLE2 equation is a modification of the RUSLE equation.</i>
SAS	Statistical Analysis Software
SAM	Stage adjusted model

SDI	Subsurface drip irrigation
SE	Standard error
SPAD	<i>A chlorophyll meter used to measure chlorophyll content</i>
SPSS	Statistical Package for the Social Sciences <i>A computer program used for statistical analysis</i>
SSC	Soluble solid content <i>% brix by refractometry</i>
SSCy	Soluble solid content yield
TAIA	Texas Agricultural Irrigation Association
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
TXHPET	Texas High Plains Evapotranspiration
UAN	<i>A solution of urea and ammonium nitrate in water used as a fertilizer</i>
USDA-ARS	U.S. Department of Agriculture – Agricultural Research Service
CSREES	U.S. Department of Agriculture – Cooperative State Research, Education and Extension Service
WinEPIC	<i>A user-friendly windows interface version of the EPIC engine and is intended for users who have an understanding of crop growth and development. WinEPIC is designed for simulation of homogeneous single field applications. The model was constructed to evaluate various land management strategies considering sustainability, erosion, economics, water supply and quality, plant competition, weather and pests.</i>
WUE	Water use efficiency

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EXECUTIVE SUMMARY

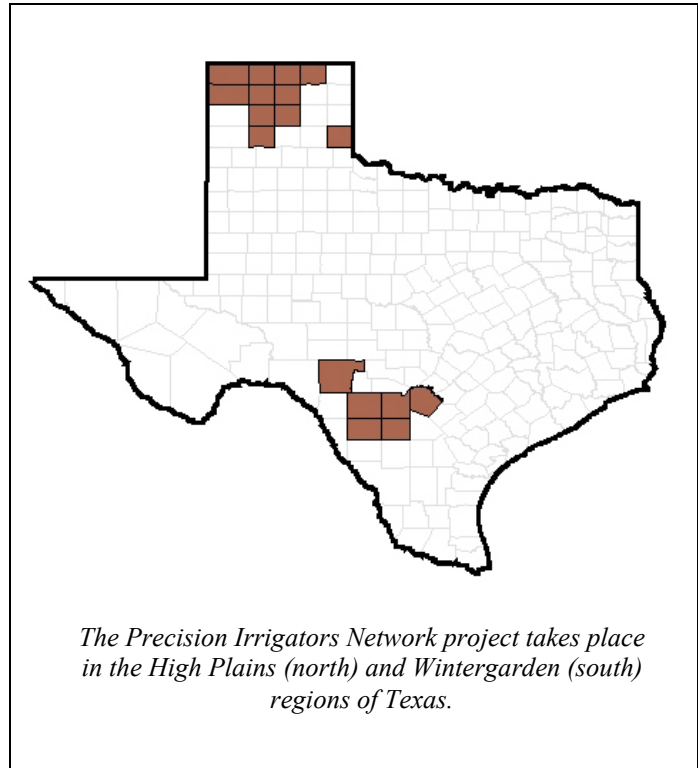
OVERVIEW

Proper management of irrigation water is increasingly important for growers in the High Plains and Wintergarden, two of the most important agricultural production regions in Texas. Water pumping and allocation limits imposed by the Edwards Aquifer Authority and local water districts constrain production in these areas.

Due to these constraints, the need arose for growers to shift their irrigation strategy from full/unlimited water application to a strategy where irrigation must be used to minimally supplement rainfall and available soil moisture. The Texas Water Development Board, recognizing the need for agricultural production to become more efficient in their water use and to foster adoption of precision irrigation practices, funded a project entitled *Precision Irrigators Network: On-Farm Research and Demonstration to Evaluate*

Irrigation Scheduling Tools in the Wintergarden and High Plains (known as the Precision Irrigators Network or PIN II). The project was developed by Texas AgriLife Research and Texas Water Resources Institute and was initiated February 14, 2006. Scientists in the High Plains and Wintergarden with Texas AgriLife Research and Extension Centers at Amarillo and Uvalde worked with growers to demonstrate the need for real-time knowledge of crop water use and the necessity for careful attention to the amount of water available to effectively irrigate and manage crops to optimize economical production.

Specific objectives of the PIN II project included: 1) encouraging producers to implement limited irrigation to alleviate excessive water use; 2) conducting on-farm demonstrations where growers were actively involved in evaluation of precision irrigation programs that best fit their farms; 3) educating growers about precision irrigation and use of tools such as potential ET, crop water requirements and soil water availability; and 4) determining the effectiveness of decision support systems, such as Crop Evapotranspiration (ET) and Crop Simulation Models (i.e., CropMan) and Crop ET, for optimizing timing and quantity of in-season irrigation. Throughout the two-year span of the project 21 grower fields were involved in demonstrations in the High Plains and 18 grower fields involved in the Wintergarden. An additional 5 growers were involved in vegetable crop demonstrations for monitoring soil moisture, but these growers were not subject to modeling.



Data collected from on-farm research demonstrations for row crops was used to validate the CroPMan model as these methods provide producers the ability to manage irrigation and production practices in a most water efficient manner.

This project built upon successes achieved through the *Precision Irrigators Network: On-Farm Research Demonstration to Evaluate Irrigation Scheduling Tools* project (PIN I) initiated December 1, 2005. The results of these projects continue to help High Plains and Wintergarden growers increase irrigation efficiency and improve irrigation strategies, as well as provide crop coefficients and water-use requirements of agronomic and vegetable crops.

PROJECT PARTNERS

Scientists from Texas AgriLife Research and Extension Centers at Amarillo, Temple (Blackland) and Uvalde joined together with the Texas Water Resources Institute (TWRI) to develop, submit and execute the deliverables of the PIN II project. Additional project partners included growers, crop consultants and Texas AgriLife Extension Service county agents in Bexar, Medina, Moore, Potter, Sherman and Uvalde counties. Additionally, cooperation of the USDA–Agricultural Research Service Water Management Unit (Bushland) and the North Plains Groundwater Conservation District (Dumas) is greatly appreciated for their support of the North Plains Evapotranspiration (NPET) network research and irrigation water conservation efforts at the North Plains Research Field.

PIN II project efforts were also coordinated with the TWDB-funded Irrigation Training Program, which was initiated July 1, 2006. That program provided irrigation water management training to farmers, consultants, educators and agency personnel in Texas. PIN growers were involved in these trainings, particularly at the Amarillo and Hondo training sites, and the PIN program was used as an example project within the context of the training.

In addition to PIN project partners and collaborators, we appreciate the support TWDB personnel gave for this demonstration project. By working together, we are helping the state's growers better manage their available water to efficiently irrigate their crops to provide the most yield while conserving water supplies.

ACCOMPLISHMENTS

On-Farm Demonstrations: Wintergarden

In the Wintergarden, on-farm demonstrations on growers' farms were successfully conducted and 18 growers were actively involved in the evaluation of limited irrigation programs that were custom fit to their farms. Each field was monitored weekly to record planting dates, plant density, stand establishment and survival, soil moisture availability, staging of the crop, fertility and tillage practices, heat units evaluation and calculation, monitoring of major insects, use of plant growth regulators in young or mature plants, and record final yields and profitability. This information was successfully collected and sent to scientists at the Blackland Center to input into their Decision Support System (DSS) models to record growth and development and evaluate producer practices.

At the Uvalde Center fields, scientists focused on stand establishment, yields, water use efficiency and product quality responses to deficit irrigation rates and irrigation systems of vegetable crops. Improved irrigation strategies were realized and new crop coefficients developed over the course of PIN I and PIN II. These developments significantly increased water savings for growers in the region. Specific crop coefficients developed for the Uvalde region included corn, cotton, onion, sorghum, spinach (PIN I only) and wheat. These are major contributions to guide precision irrigation in this region of Texas for the future.

Water savings for 2007 were difficult to document, as the Wintergarden region received 27 inches of rain during the approximate 5-month growing season, which exceeds the average annual rainfall of 23 inches. Therefore, substantial irrigation water savings were documented due to including rainfall in crop water requirements. Due to irrigation scheduling in 2008, growers used less water to irrigate, reducing water amounts and total number of irrigations.

On-Farm Demonstrations: High Plains

Over the two-year period in the northern Texas High Plains (Dumas area), producer evaluation of irrigation scheduling on a total of 21 fields and 4,055 acres showed less than full crop demand being applied by producers. Considering all acreage monitored, this project resulted in a water savings of 35,152 acre-inches, as compared to the crops full irrigation needs. The data also reflect that High Plains irrigated producers are using groundwater resources efficiently and at a level below that required for maximum yield production.

Decision Support System Validation and Calibration

Data from the Wintergarden and High Plains demonstrations were supplied seasonally to researchers at the Blackland Research Center to incorporate as input into the CroPMan model for model calibration and future decision-making and system management uses. Using this crop production and management information, the effectiveness of CroPMan and Crop ET for optimizing the timing and quantity of in-season irrigation was determined. In addition, analytical capabilities of CroPMan were assessed to pre-test alternative management scenarios that fit the individual grower's situation and identify practices and/or farming systems to optimize production and profit. Through this project, the accuracy of these methods was improved and became more reliable for the typical grower under various field situations. The models have been greatly improved to provide guidance to growers.

Project Administration

TWRI administration and project manager have served as a liaison between TWDB and the project scientists. TWRI compiled quarterly reports from data gathered from each scientist and submitted them to TWDB as per contract agreement. The TWRI project manager coordinated necessary meetings throughout the project life to bring project participants together with TWDB personnel. In addition, TWRI developed and/or edited publications, articles, factsheets and a brochure that was distributed to media, growers and TWDB officials.

OUTREACH EFFORTS

Outreach and education efforts are an integral part of demonstration projects. Events such as field days and workshops were held, presentations were given, publications were developed and articles and marketing materials were developed. Growers and agency personnel were trained. All of these efforts impacted growers and other researchers, providing them with a current demonstration project that is efficient and saves water while maintaining yields and profitability. See the Education and Outreach section of this report, page 89 for specific events that were held during the PIN 2 project period.

CONCLUSIONS AND RECOMMENDATIONS

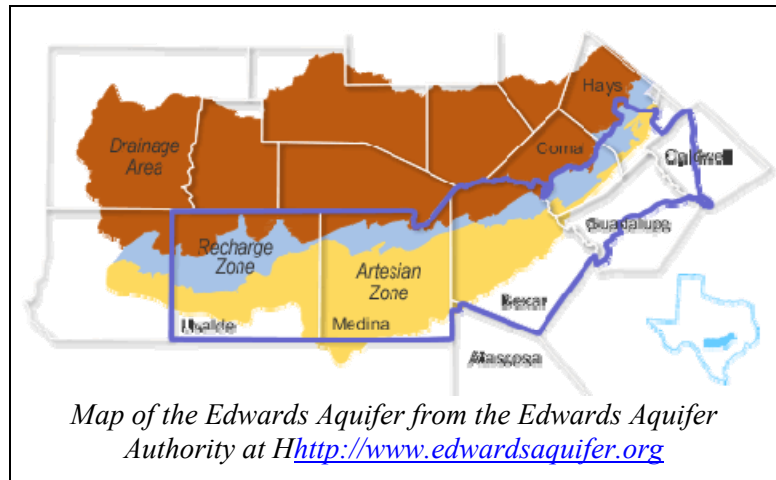
The PIN II project has made a significant impact on many growers in the High Plains and Wintergarden areas. More growers are now familiar with these new technologies to help them better manage irrigation water use on their farms depending on the available soil moisture and weather. The bottom line is that significant water savings are possible with these demonstrated precision irrigation practices and agricultural producers are adopting the practices shown to be both economical and effective.

We hope in the future that similar demonstrations will be funded to continue the learning process so growers can better understand how to precisely irrigate their crops without over-irrigating, yet maintaining economical yields. Further demonstrations would continue to help word spread to neighbors and others to enhance water savings throughout the region in the future.

CHAPTER 1: Wintergarden Agronomic Demonstrations and Implementation

BACKGROUND

On-farm research demonstrations were conducted and 18 growers were actively involved in evaluating the limited irrigation program that best fits their farm. Each field was monitored to record detailed data on the production, yield, growth, climate and irrigation practices utilized by the producer. In addition, computer models such as Crop Evapotranspiration and Crop Simulation Models (CropMan) and potential evapotranspiration (PET) were run to record growth and development and evaluate production practices.



At the research center, studies focused on stand establishment, yield, water-use efficiency and product quality responses to deficit irrigation rates and irrigation systems of agronomic and vegetable crops that have the potential to increase profitability. The production efficiency of subsurface drip irrigation systems (SDI), including the recently developed low-pressure system (LPS) as an alternative method, were compared. Varieties were also screened for high quality and improved adaptability for growth in water-restricted regions. Given the amount of rainfall received during the 2007 summer crop season very little irrigation was necessary.

Educational programs were conducted by AgriLife Research and Extension personnel to inform producers on the use of irrigation scheduling tools. In addition, AgriLife Research and Extension personnel visited individual farms to demonstrate use of electronic technology to obtain PET and crop water requirements from weather stations in the region.

All on-farm research demonstrations and field studies at the research center were established during the first Precision Irrigators Network (PIN) Project conducted from December 1, 2005 through September 1, 2006. Thus, data collection to support this project began immediately upon project inception.

On-farm demonstration establishment: Corn, Cotton, Peanut and Sorghum

Watermark sensors to monitor crop available soil moisture were installed in 21 fields from 18 growers in the Edwards and Carrizo aquifer region. The cooperating farms are shown below.

Table 1-1. Watermark sensors installed in 21 fields from 18 growers in 2007.

County	# Growers	Crops
Bexar	3	2 cotton, 1 corn
Frio	1	1 cotton, 1 peanut
Medina	4	3 cotton, 1 corn
Uvalde	10	2 cotton, 4 corn, 4 sorghum

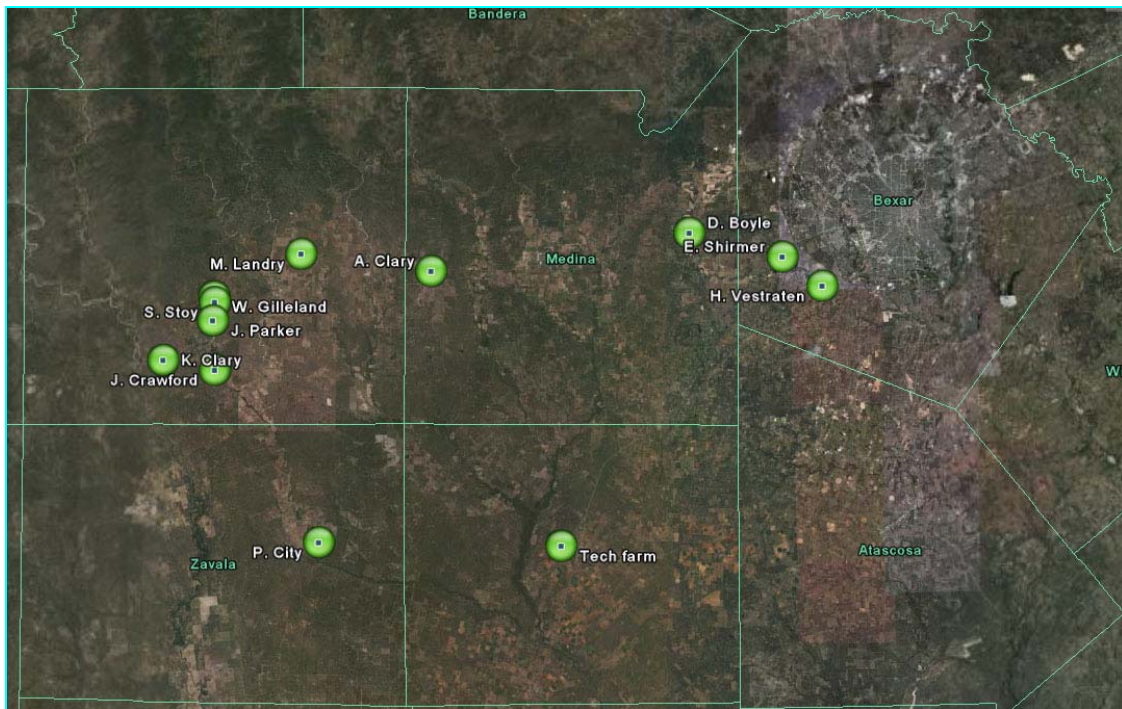


Figure 1-1. Areas that were studied in the 2007 season and potential growers that expressed interest at that time.

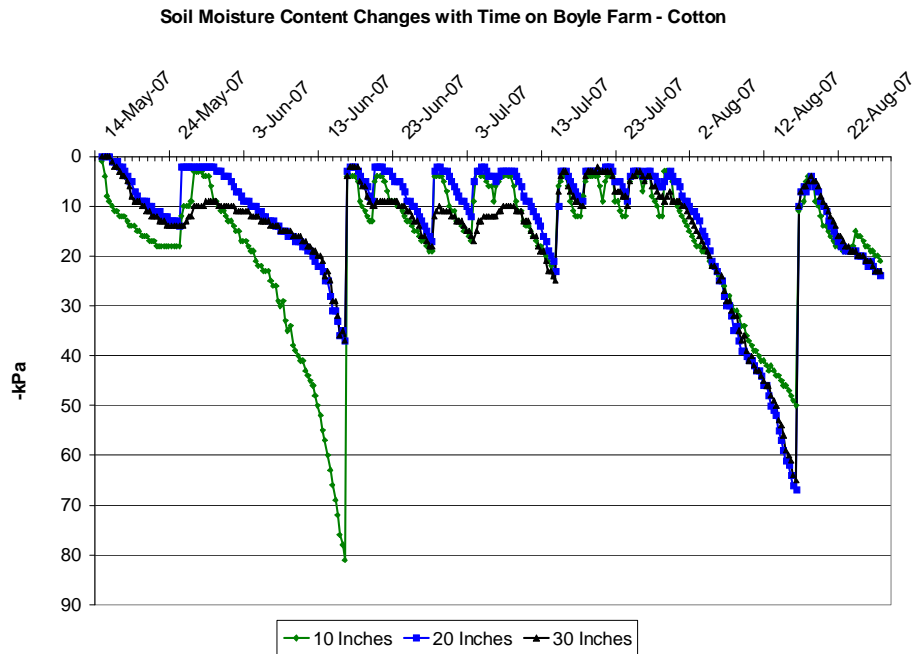


Figure 1-2A–B. Soil moisture data collection from one field with a manual data logger (left) and another field’s data collection with an electronic data logger (right).

These are simple, low-cost, on-farm soil moisture monitoring tools that can be easily purchased by the grower. Researchers instructed the growers to read the instrument on a daily basis and evaluate the soil moisture value. A soil moisture value between 0 and 50 represents wet soil and plentiful moisture conditions. Soil moisture values near 150 to 200 represents extremely dry soil moisture conditions. The scale for the soil moisture monitoring tools is in centibars, which is one of the standard units for soil moisture measurements. Therefore, Figures 1-5A-C use centibars as the unit of measurement.

Table 1-2. Grower harvest data for 2007.

County	Growers	Crop Monitored	NOTES
Bexar	A	Corn	110 bushels/acre
Bexar	B	Cotton	879 lbs/acre
Medina	C	Cotton	1,150 lbs/acre
Medina	D	Corn	150 bushels/acre
Medina	E	Cotton	912 lbs/acre
Medina	F	Cotton	1,008 lbs/acre
Uvalde	G	Cotton	1,248 lbs/acre
Uvalde	H	Sorghum	6,349 lbs/acre
Uvalde	I	Cotton	1,284 lbs/acre
Uvalde	J	Sorghum	5,350 lbs/acre
Uvalde	K	Corn	170 bushels/acre
Uvalde	L	Corn	160 bushels/acre
Uvalde	M	Corn	130 bushels/acre
Uvalde	N	Corn	150 bushels/acre
Uvalde	O	Sorghum	6,900 lbs/acre



Figures 1-3. Weekly soil moisture data collection from electronic data loggers on cotton.

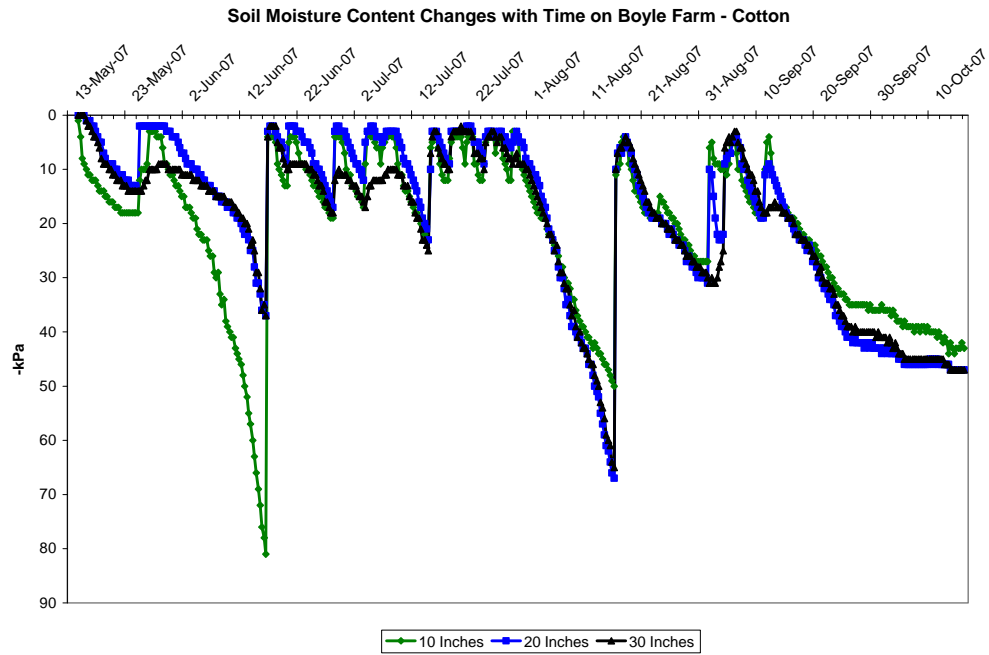
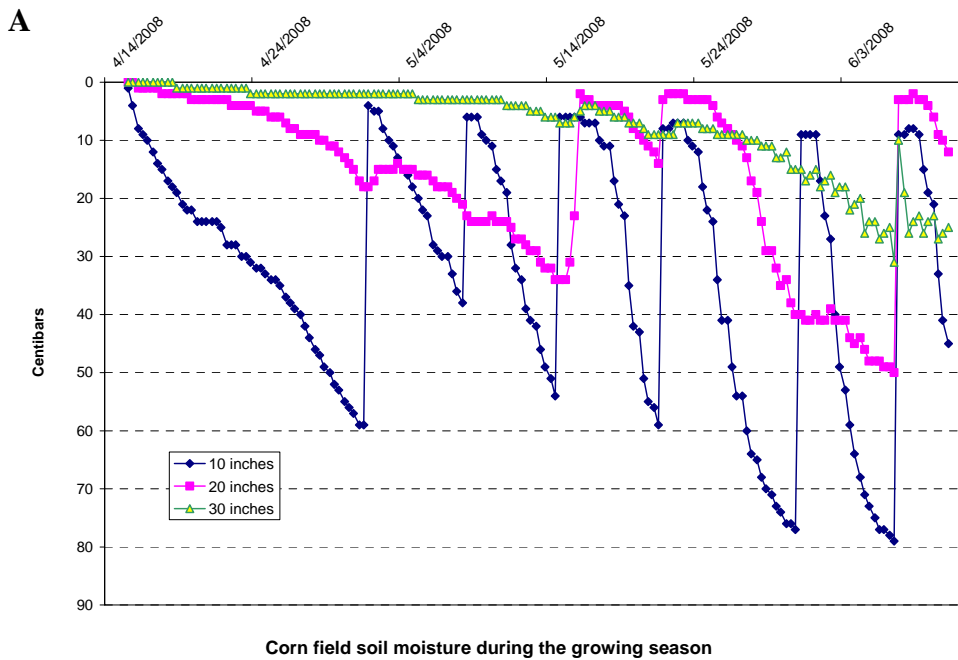


Figure 1-4. Non-limiting soil-water availability in cotton on grower C’s farm.

The following graphs in Figure 1-5 A–B show the soil moisture data collected from a corn and cotton field.



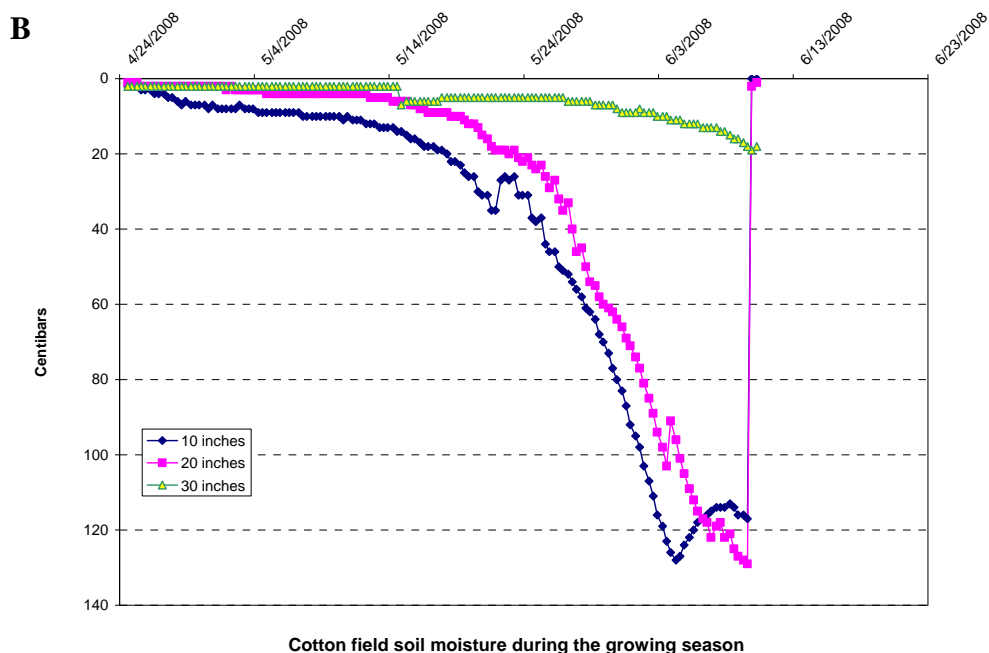


Figure 1-5 A–B. Soil moisture data collected during the growing season for a corn and cotton field.

Uvalde Research Center Demonstrations

Researchers established an onion crop in the lysimeter field on Nov. 13, 2007, to evaluate onion crop coefficients. Onion plants were grown at three irrigation rates (100%, 75% and 50% ETc) and two plant populations (397 and 484 x 1,000 seeds/ha). Bulbs were harvested May 28-29, 2008. Overall yields were excellent, particularly under 100% ETc. Onions were graded according to size and marketable yields determined.

A preliminary soil moisture sensor evaluation was also established to evaluate the performance of two commercial soil moisture sensors (capacitance or C-probes probes), which were compared with data obtained from neutron probe and real-time water loss by crop evapotranspiration inside lysimeters. This work was done in collaboration with Monsanto. We expect to further evaluate this technology with existing soil moisture technologies used in PIN II, with the objective to determine their efficacy and suitability for soil moisture monitoring and irrigation scheduling in vegetable and row crop production, and also to compare them with the existing technology and irrigation scheduling tools formerly used in PIN, such as ET and Kc's values.

METHODOLOGY

Most growers in the region used a “feel” method to implement irrigation scheduling. This method is based on growers’ experience and knowledge of their farm(s). Most often water was applied based on a “convenient schedule” more than on actual crop water needs using the entire allocation for one crop. Growers with large pivots in the region most often let their pivots run continuously unless a rainfall event occurred. This implementation, while practical, is no longer sustainable and growers are trying to implement ways to use their allocated 2 acre-feet more efficiently.

RESULTS

Crop yields were not compromised from the implementation of a precise schedule. Table 1-10 shows 2008 yield data similar to historic yields. These growers implemented an “informed” irrigation schedule leading to increased water use efficiency.

The goal for a few of the PIN growers was to be on target with ET-based irrigation. Fields were monitored for daily updates of crop water demand and related to soil water availability. Most growers were on target by applying only the irrigation water necessary to meet ETc. Most of these growers would have applied at least two more irrigations based on visual observation of soil surface condition and historic habit. These growers were instructed not to apply additional irrigation based on soil moisture and ET readings from their field. This resulted in 4 inches to 5 inches of water savings.

Table 1-3. 2008 crops, irrigation and yield.

Field ID	Crop	Planting date	Planted acres	Rainfall inches	Irrigation applied, inches	Total Water	Yield	Model ETc, inches	Water savings
Mark Lamon (Sabinal)	Corn	March 20	490	3.2	21	24.2	150 bushels /acre	25.2	0 (On Target)
Jerry Verstraeten (Castroville)	Corn	March 10	172	11.2	20	31.2	148 bushels /acre	30.8	0 (On Target)
Jerry Verstraeten (Castroville)	Cotton	April 5	90	11.2	15	26.2	1515 lbs	19.4	-5”
4M (Knippa)	Wheat	Nov 25	95	4.5	12	16.5	48 bushels /acre	13.7	-3”

The first two growers in Table 1-10 were in their second year of participating in the PIN project and were educated in following precise irrigation scheduling based on water balance. Therefore, the water applied met the exact crop water demand (i.e., they were “on target” and did not over-apply). In the second two fields, the growers followed their historic habit of irrigation management. By not following PIN recommendations, they ended up over-applying 5 and 3 inches of water, respectively.

The crop coefficients developed and validated during PIN I and PIN II include corn, cotton, onion, sorghum, spinach (PIN I only) and wheat. The agronomic Kc tables below demonstrate how researchers have improved the crop coefficients compared to the FAO. The table for onions can be found in Chapter 2.

Table 1-4. Cotton crop coefficients (Kc) determined at Uvalde, Texas (A) in comparison to those from FAO-56 (Allen et al., 1998) (B).

Growth Stage	DAP†	<u>Kc</u>
Seeding	7	0.40
1st square	8-45	0.45
1st bloom	46-65	0.80
Max bloom	66-86	1.08
1st open	87-110	1.23
25% open	111-125	1.25
50% open§	126-133	1.05
95% open	134-151	0.60
Pick	152-162	0.10

(B)		
<u>Kc ini</u>	0-30	0.35
<u>Kc mid</u>	80-135	1.15-1.20
<u>Kc end</u>	135-180	0.75-0.35

§ The cotton was chemically defoliated.

† DAP, days after planting.

Table 1-5. Wheat crop coefficients (Kc) determined at Uvalde, Texas (A) in comparison to those from FAO-56 (Allen et al., 1998) (B).

Growth Stage	DAP†	Kc
(A)		
Emergence	10	0.53
Early tiller 1	11-31	0.50
Early tiller 2	32-51	0.50
Mid tiller	52-68	0.70
Late tiller	69-97	0.70
Stem elongation	98-121	1.10
Heading	122-132	1.15
Flowering	133-140	1.10
Milk	141-151	1.00
Soft dough	152-166	0.85
Hard dough	167-183	0.40

(B)		
<u>Kc ini</u>	0-20	0.70
Kc mid	80-150	1.15
Kc end	150-180	0.25

Table 1-6. Corn crop coefficients (Kc) determined at Uvalde, Texas (A) in comparison to those from FAO-56 (Allen et al., 1998) (B).

Growth stage	DAP†	Kc
(A)		
Emergence	8	0.35
2-leaf	9-20	0.35
4-leaf	21-26	0.40
6-leaf	27-39	0.55
8-leaf	40-47	0.70
10-leaf	48-58	0.80
12-leaf	59-66	0.90
14-leaf	67-72	1.00
Tassel	73-75	1.05
Silk	76-83	1.10
Blister	84-87	1.15
Milk	88-93	1.20
Dough	94-98	1.20
Dent	99-105	1.15
1/2 mature	106-110	1.10
Black layer	111-137	0.90

(B)		
Kc <u>ini</u>	0-30	0.30
Kc mid	70-120	1.20
Kc end	120-170	0.35

Table 1-7. Sorghum crop coefficients (Kc) determined at Uvalde, Texas (A) in comparison to those from FAO-56 (Allen et al., 1998) (B).

Growth stage	DAP†	Kc
(A)		
Emergence	7	0.40
3-leaf	8-13	0.40
4-leaf	14-17	0.45
5-leaf	18-25	0.50
GDP‡	26-40	0.70
Flag leaf	41-50	0.70
Boot	60-65	0.75
Heading	67-73	0.80
Flowering	72-76	0.85
Soft dough	95-104	0.80
Hard dough	105-120	0.80
Black layer	121-129	0.75

(B)		
Kc <u>ini</u>	0-20	0.30
Kc mid	55-95	1.00-1.10
Kc end	95-130	0.55

CONCLUSION

On-farm demonstrations provided the sties for implementation of precision irrigation practices in partnership with agricultural producers. Watermark sensors were utilized. These are relatively inexpensive and readily available for producers to purchase and use to monitor available soil moisture. Scientific data collected by AgriLife researchers correlated well with the growers sensors.

Crop yields were not compromised by incorporation of precision irrigation practices. Several fields had 4 inches to 5 inches of water savings and at least two less irrigations using precision methods.

Demonstrations in farmers’ fields are crucial to grower acceptance and implementation of new technologies and futuristic practices. We expect adoption of these practices to spread in the future.

CHAPTER 2: Wintergarden Vegetable Demonstrations and Implementation

BACKGROUND

In addition to the traditional agronomic crops grown in the Wintergarden region, economically important vegetable crops were also evaluated in these studies including artichoke, watermelons, onions, cabbage and peppers. Data from each crop was collected and analyzed to calibrate the DSS while predicting possible water savings. Researchers calibrated the CroPMan model with available yield data for corn and scenario analyses with alternative water management practices were provided.

ARTICHOKE AND NITROGEN STUDIES METHODOLOGY

On-Farm Artichoke Irrigation and Nitrogen Studies

Field experiments were conducted at the Texas A&M AgriLife Research and Extension Center at Uvalde, Texas to determine the impact of irrigation regimes and nitrogen (N) rates on yield and quality of artichoke heads. The soil was an Uvalde clay loam (pH 7.9, organic matter 3.3%, with a textural composition of 22% sand, 40% silt and 38% clay). Two month old artichoke seedlings were transplanted on beds (80 in. between rows, 30 in. within row, giving a plant population of 2,617 plants·acre⁻¹) on Dec. 16, 2005. After the first season harvest ended (2005-2006), plants were cut back to the ground level on July 19, 2006 for 'Imperial Star' and July 25, 2006 for 'Green Globe Improved.' New off-shoots were kept for the second season (2006-2007) production (Figure 2-1).

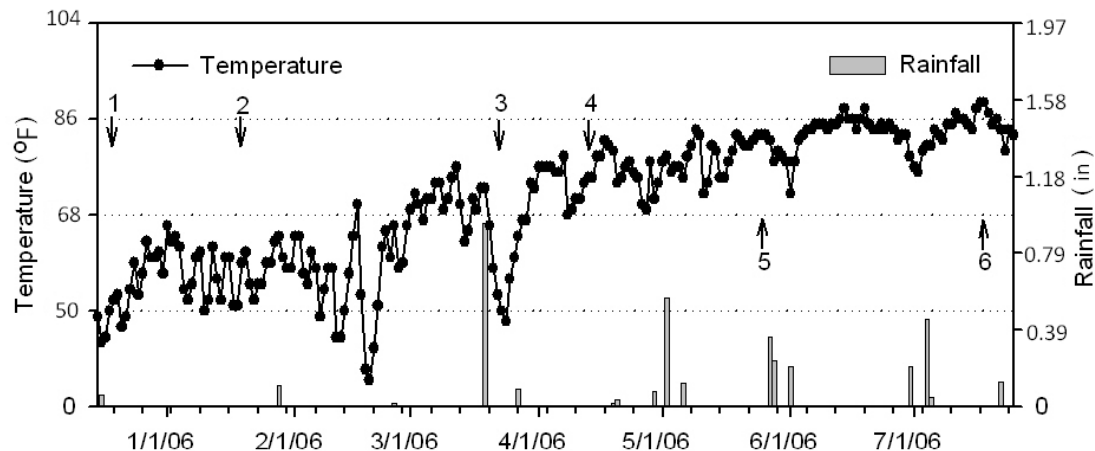
Main plots were allocated with three irrigation regimes: 50%, 75% and 100% crop evapotranspiration (ET_c) rates. The values obtained for ET_c were based on climatic parameters that were incorporated in the calculation of the reference evapotranspiration (ET_o), which was updated daily in the lysimeter facility located at the Uvalde Center. The ET_o values were adjusted by these phenological crop coefficients (K_c), which were referred to as FAO values (K_c ini = 0.5, K_c mid = 1.0, K_c end = 0.95) (FAO, 1998), based on crop canopy characteristics with slight modification. Irrigation water was supplied using SDI with drip tape placed at 12 in. below the soil surface, emitters spaced every 12 in. and a flow rate of 0.45 gal·min⁻¹·100 ft at 0.55 bar (Netafim LTD. Corporate Headquarters, Israel). Differential irrigation started after stand establishment on Jan. 31, 2006 (first season, 2005-2006) or after plants reached uniform growth on Oct. 17, 2006 (second season, 2006-2007). Total water inputs (irrigation + rainfall) at each irrigation rate during the experiment are described in Table 2-1. Subplots within main plots were allocated to four N fertilizer rates: 0, 53, 107 and 160 lb·acre⁻¹ applied as a granular ammonium nitrate (NH₄NO₃) by side dressing in two equal split doses, the first at stand establishment (Jan. 20, 2006 for the first and Oct. 9, 2006 for the second season) and the second at bud initiation (March 24, 2006 for the first and Feb. 1, 2007 for the second season). Figure 2-1 shows the artichoke production cycle. The units expressed in this figure are °F for temperature and inches (1 inch = 25.4 mm) for rainfall.

Based on the results of the first two years, a third year field experiment, shown in Figure 2-2 and Table 2-2, was conducted in the same location and conditions as in the biennial system, except for some modifications (e.g., foliar fertilizations and plasticulture) aimed at optimizing growth

and productivity. Two month-old artichoke seedlings were transplanted on beds (80 in. between rows, 36 in. within row, giving a plant population of 2,182 plants·acre⁻¹) and covered by black plastic mulch (1.5 mil thickness) on Oct. 24, 2007. Similar procedures were followed as in previous years.

First Season (2005-2006)

- 1) Transplanting (12/16/05)
- 2) Final stands (1/20/06)
Differential irrigation start
First Nitrogen application
- 3) Head initiation (3/24/06)
Second Nitrogen application
- 4) First harvest (4/12/06)
- 5) Last harvest (5/25/06)
- 6) Cut back (7/19/06)
End irrigation



Second Season (2006-2007)

- 7) Start irrigation (7/28/06)
- 8) Final stands (10/9/06)
Differential irrigation start
First Nitrogen application
- 9) Head initiation (2/1/07)
Second Nitrogen application
- 10) First harvest (3/2/07)
- 11) Last harvest (4/24/07)
- 12) Cut back (5/15/07)

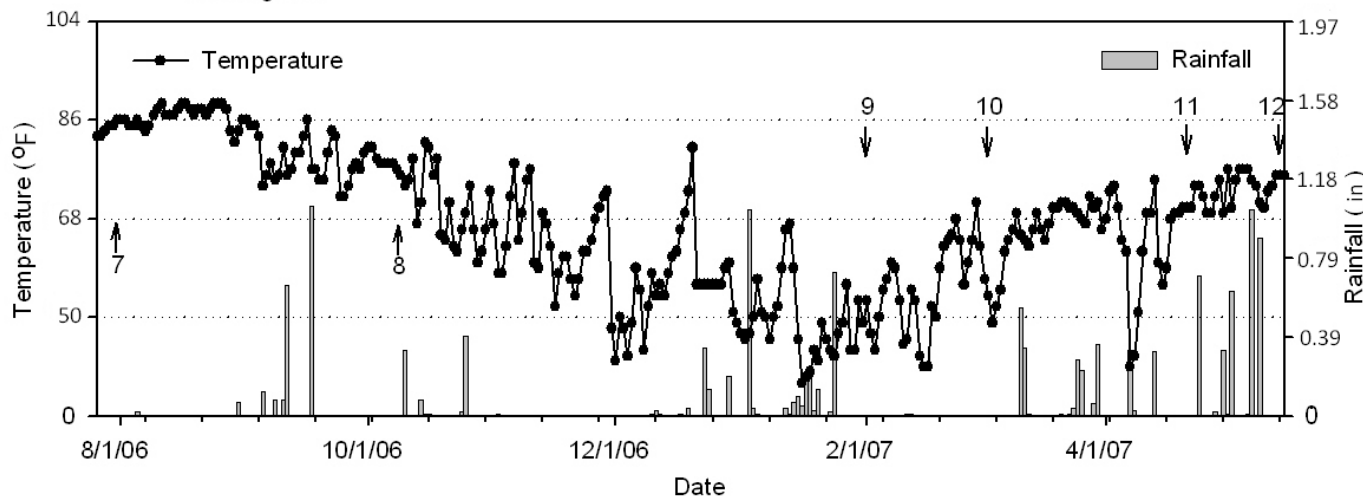


Figure 2-1. Time-course of average temperatures (solid lines), rainfall (bars) and specific agronomic practices (arrows) during the first and second season artichoke production cycle, 2005-2007, Uvalde, Texas.

Table 2-1. Frequency (No.) and amount (in) of irrigation applied or rainfall received during the artichoke production cycle, 2005-2007, Uvalde, Texas.

<i>2005-06</i>	Frequency and amount of irrigation or rainfall						Total applied			
	Dec.	Jan.	Feb.	Mar.	Apr.	May				
	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>			
<u>Irrigation</u>										
50% ETc	6- 5.36 ^x	6- 2.13	4- 1.06	5- 1.46	10- 3.07	13- 5.00	44- 18.1			
75% ETc	6- 5.36 ^x	6- 2.25	5- 1.62	6- 2.21	10- 4.69	13- 7.05	45- 23.2			
100% ETc	6- 5.36 ^x	6- 2.36	5- 2.09	6- 2.84	10- 6.34	13- 9.22	45- 28.2			
Rainfall	1- 0.06	1- 0.11	2- 0.03	3- 1.02	3- 0.14	4- 1.30	14- 2.68			
<i>2006-07</i>	Jun.- Aug.	Sep	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total applied
	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>
50% ETc	22- 8.04 ^y	10- 2.96	6- 1.97	6- 1.62	3- 0.83	0- 0	6- 1.77	5- 1.42	7- 2.13	65- 20.7
75% ETc	22- 8.04 ^y	10- 2.96	6- 2.32	6- 2.40	3- 1.26	0- 0	6- 2.68	5- 2.44	7- 3.19	65- 25.3
100% ETc	22- 8.04 ^y	10- 2.96	6- 2.68	6- 3.19	3- 1.65	0- 0	6- 3.55	5- 3.43	7- 4.29	65- 29.8
Rainfall	10- 1.54	5- 1.97	6- 0.87	1- 0.01	8- 0.79	14- 2.68	2- 0.02	11- 1.89	4- 1.38	61- 11.1

^xValues include pre-planting irrigation, 4 times with 4.41 in.

^yValues include pre-awaking irrigation, 7 times with 2.72 in.

Third Season (2007-2008)

- 1) Transplanting (10/24/07)
- 2) Final stands (11/28/07)
Differential irrigation start
First Nitrogen application
- 3) Head initiation (2/21/08)
Second Nitrogen application
- 4) First harvest (3/20/08)
- 5) Last harvest (4/28/08)
- 6) Cut back (5/9/08)
End irrigation

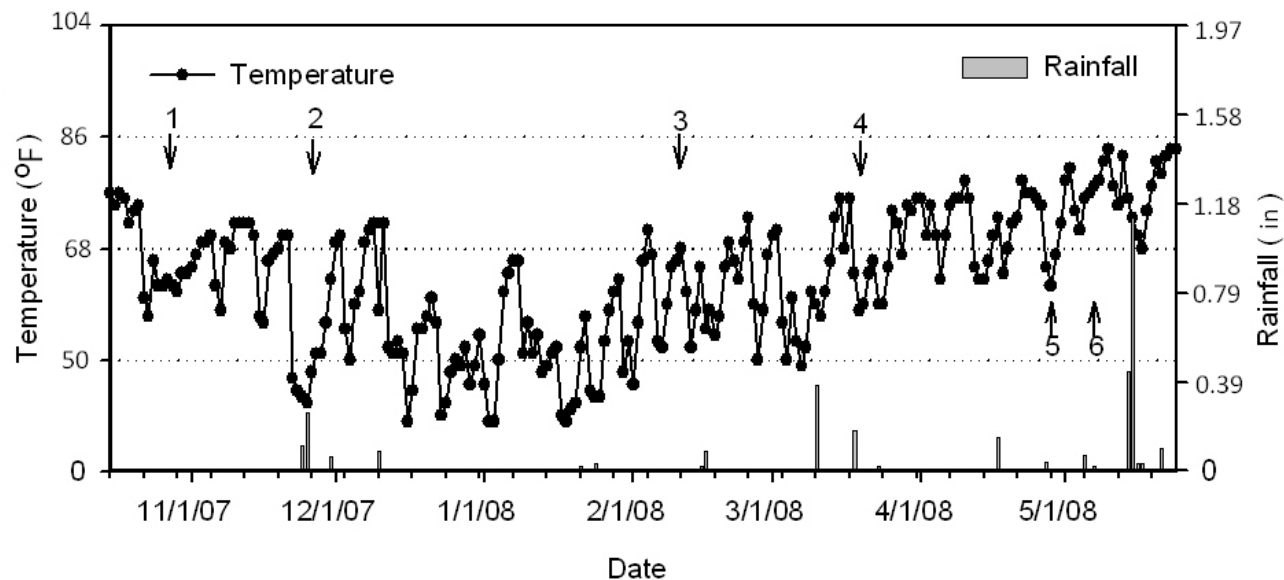


Figure 2-2. Time-course of temperature (solid lines), rainfall (bars) and specific agronomic practices (arrows) during the annual artichoke production cycle 2007-2008, Uvalde, Texas.

Table 2-2. Frequency (No.) and amount (in) of irrigation applied or rainfall received during the artichoke production cycle on black plastic mulch, 2007-08. Uvalde, Texas.

2007-08	Frequency and amount of irrigation or rainfall							
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total applied
	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>	<u>No.-in</u>
<u>Irrigation</u>								
50% ETc	6- 0.87 ^x	6- 0.71	3- 0.35	4- 0.47	7- 0.98	7- 1.54	7- 2.13	40- 7.05
75% ETc	6- 0.87 ^x	6- 0.71	4- 0.55	5- 0.71	9- 1.50	12- 2.29	14- 3.15	56- 9.77
100% ETc	6- 0.87 ^x	6- 0.71	4- 0.75	5- 0.95	8- 1.97	12- 3.07	14- 4.41	55- 12.5
Rainfall	0- 0	3- 0.43	1- 0.079	4- 0.079	2- 0.12	5- 0.59	2- 0.20	17- 1.50

^xValues include pre-planting irrigation, 2 times with 0.47 in.

Yield and yield components

Harvests occurred periodically between April 12 and May 25, 2006 for the first season (2005-2006); between March 2 and April 24, 2007 for the second season (2006-2007); and between March 20 and April 28, 2008 for the third season (2007-2008). Marketable yield ($\text{lb}\cdot\text{acre}^{-1}$), head weight (oz) and head number per plant ($\text{no}\cdot\text{plant}^{-1}$) were recorded (Tables 2-3 and 2-4). Water productivity (water use efficiency, WUE) expressed in pound (lb) of heads per water input ($\text{lb}\cdot\text{acre}^{-1}\cdot\text{in}$) was calculated.

Artichoke head size under differential irrigation and N rates was determined at various harvest times. Harvest periods were separated as early and late. Early harvests were done on April 13, 20 and 26 and May 3, 2006 for the first season; March 2, 12, 19, 23 and 28, 2007 for the second season; and March 20, 24 and 28 and April 1, 4 and 7, 2008 for the third season. Late harvests were done on May 8, 12, 18 and 25 for the first season; April 3, 10, 16 and 24, 2007 for the second season; and April 11, 14, 18, 21, 25 and 28, 2008 for the third season. Head size was classified into marketable heads based on four sizes; <2.8 in., 2.8-3.5 in., 3.5-4.3 in. or >4.3 in. and unmarketable—those with tip burn and open bracts.

Soil Nitrogen content (first and second season)

Soil residual N was measured after the harvesting season to investigate soil N availability and to estimate plant N acquisition during a crop cycle. Soil sampling (0-6 in. depth) was completed on July 27, 2006 for the first season and on June 25, 2007 for the second season. Nitrate-nitrogen ($\text{NO}_3\text{-N}$, ppm) was extracted from soils using a 1N KCl solution. Nitrate was determined by reduction of nitrate ($\text{NO}_3\text{-N}$) to nitrite using a cadmium column followed by spectrophotometric measurement. Ammonium-nitrogen ($\text{NH}_4\text{-N}$) was extracted from soils using a 1N KCl solution. Ammonium-N was determined spectrophotometrically at 4200Å wavelength. Soil N analysis was conducted at the Texas A&M Soil, Water and Forage Testing Laboratory in College Station, Texas.

Statistical analysis

The experiments were conducted using a split plot design with four replications (13 plants per each individual plot sized 6.5 ft × 32.5 ft). Irrigation was assigned to the main plot and N levels to the subplots. Due to lack of vernalization, the late cultivar Green Globe Improved did not produce heads and therefore no marketable yield was obtained. Data (soil analysis, yield, yield components, head size and chemical constituents) were all analyzed by ANOVA using SPSS (version 14.0 for Windows; SPSS Inc., Chicago, IL). Differences among treatments were performed using the least significant difference procedure (LSD) at $p = 0.05$.

Artichoke transplant stress study

The objective of this complementary study was to evaluate the efficacy of abscisic acid (ABA) as an antitranspirant to enhance stress (drought) tolerance of artichoke transplants. It has been demonstrated that artichoke seedlings are known to be sensitive to high temperature and water deficit stress. We compared foliar application of ABA at concentrations up to 2,000 ppm and the three film-forming materials used previously in pepper and tomato (Antistress or AS, Transfilm or TF and Vapor Guard or VG) and evaluated the level of drought tolerance that 'Green Globe' artichoke seedlings could sustain when exposed to withholding water for a short period (4 days). This experiment was conducted under greenhouse controlled conditions.

ARTICHOKE RESULTS

Artichoke: Climate and water conditions

In general, winter (November to February) temperatures during 2005-2006, 2006-2007 and 2007-2008 were similar, with average daily temperatures in the range of 56.1°F to 57.7°F (computed from Figures 2-1 and 2-2). The main difference among seasons was that in 2005-2006, the average temperature in January was significantly higher (57.7°F) than the other two seasons (49.1°F to 53.2°F) (computed from Figures 2-1 and 2-2). Rainfall trends of the first and third seasons were considered dry, while the second season was wet. In fact, total rainfall during the crop cycle was 2.7 in., 11 in. and 1.5 in. for 2005-2006, 2006-2007 and 2007-2008, respectively (Tables 2-1 and 2-2). The larger amount of rainfall recorded in 2006-2007 was due to a longer crop cycle as well as higher precipitation recorded in January, March and April 2006 as compared with the other two seasons. Total irrigation applied during the crop cycles for the 100% ETc was 28.2 in., 29.8 in., and 12.5 in. for 2005-2006, 2006-2007 and 2007-2008, respectively (Tables 2-1 and 2-2). Frequent irrigations occurred during harvest seasons in 2005-2006 and 2007-2008, but not in 2006-2007 due to the large number of precipitation events. Overall, plastic mulch application saved approximately 52% to 58% of irrigation amounts in the third season (2007-2008) compared with 2005-2006 and 2006-2007, respectively (computed from Tables 2-1 and 2-2).

Artichoke: Yield and yield components

In the 2005-2007 seasons, marketable yields were significantly increased by the 100% ETc treatment (11,746 and 14,017 lb·acre⁻¹), whereas a 35% and 20% reduction in yield occurred under deficit irrigation (50% ETc) in the first and second season, respectively (Table 2-3). Nitrogen fertilizer did not significantly affect yield in both seasons, as seen in Table 2-3. The highest yields were achieved with the combination of 100% ETc and 53 lb·acre⁻¹ N (12,413 lb·acre⁻¹, data not shown) in the first season and 100% ETc and 107 lb·acre⁻¹ N (15,717 lb·acre⁻¹, data not shown) in the second season. Higher irrigation rates significantly increased head number in both seasons and weight in the first season.

Table 2-3. Marketable yield, number of heads and WUE of artichoke cv. Imperial Star in response to irrigation and N rates, 2005–2007.

Treatment	2005-06				2006-07			
	Yield (lb·acre ⁻¹)	Head (no·plant ⁻¹)	Wt. (oz)	WUE (lb·acre ⁻¹ ·in)	Yield (lb·acre ⁻¹)	Head (no·plant ⁻¹)	Wt. (oz)	WUE (lb·acre ⁻¹ ·in)
<u>Irrigation (I)</u>								
50% ETc	7566 c	8.3 c	6.02 b	418	11227 b	10.2 b	8.34	355
75% ETc	10333 b	11.1 b	6.59 a	446	12780 b	11.6 b	8.46	351
100% ETc	11746 a	12.3 a	6.62 a	416	14017 a	12.9 a	8.67	342
<u>Nitrogen (N)</u>								
0 lb·acre ⁻¹	10095	10.8	6.37	431	11313	10.6	8.02	311
53 lb·acre ⁻¹	9879	10.5	6.51	417	12194	10.9	8.69	388
107 lb·acre ⁻¹	9969	10.6	6.40	422	14040	12.8	8.59	364
180 lb·acre ⁻¹	9582	10.3	6.36	408	13152	12.0	8.66	311
<u>Interaction</u>								
I×N	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

Means within columns followed by different letters are significantly different. (LSD, p = 0.05).

N.S: Not significant.

Water use efficiency (WUE) was not affected by either irrigation or N rates. The higher values of WUE in the first season compared to the second season were because of less water inputs due to a shorter crop cycle in the first season (6 months in the first and 9 months in the second season).

Table 2-4 shows that in the third season, marketable yield was significantly increased by the 100% ETc (15,181 lb·acre⁻¹), whereas a 30% yield reduction occurred under deficit irrigation (50% ETc) in 2007-2008. Similarly, both head number and weight were significantly increased with higher irrigation rates as shown in the first season. However, yields were not affected by N rates. The highest yield was achieved with the combination of the 100% ETc and 53 lb·acre⁻¹ N (16,074 lb·acre⁻¹, data not shown). WUE was affected by irrigation rates, being significantly higher at 50% and 75% ETc than at 100% ETc, while N rate did not affect WUE (Table 2-4).

Table 2-4. Marketable yield, head number and weight, and WUE of artichoke cv. Imperial Star in response to irrigation (I) and N rates, 2007-08.

	2007-08			
	Yield (lb·acre ⁻¹)	Head		WUE (lb·acre ⁻¹ ·in ⁻¹)
		(no·plant ⁻¹)	Wt. (oz)	
<u>Irrigation (I)</u>				
50% ETc	10445	8.9 b	9.88 c	1266 a
75% ETc	14024	11.7 a	10.61 b	1244 a
100% ETc	15147	12.3 a	11.00 a	1083 b
<u>Nitrogen (N)</u>				
8.9 lb·acre ⁻¹	12732	10.7	10.32	1145
53 lb·acre ⁻¹	13481	11.1	10.64	1201
107 lb·acre ⁻¹	12798	10.7	10.35	1154
160 lb·acre ⁻¹	13809	11.3	10.68	1240
<u>Interaction</u>				
I × N	N.S	N.S	N.S	N.S

Means within columns followed by different letters are significantly different. (LSD, p = 0.05).
N.S: Not significant.

Marketable artichoke heads were classified into size as small (<2.8 in.), medium (2.8 in. - 3.5 in.), large (3.5 in. - 4.3 in.) and jumbo (>4.3 in.) and the unmarketable or cull heads were those with tip burn and open bracts. In the first season, the distribution of head sizes was not affected by both irrigation and N rates at early harvest, while a higher proportion of medium heads was obtained by 75% ETc compared with 50% ETc at late harvest. The proportion of open bracts on unmarketable heads was significantly lower at 75% ETc compared with 100% ETc at late harvest, as seen in Figure 2-3. Tip burn was significantly increased by the combination of 50% ETc and higher N rates (107 and 160 lb·acre⁻¹ N) at late harvest. In the second season, the variability of head size was smaller than the first season and the majority of heads were of medium size ranging from 67% to 74% of total heads. Overall, irrigation and N rates did not affect the proportion for marketable heads, but a higher proportion of tip burn was obtained from 50% and 75% ETc at late season harvest. In the second season, the proportion for marketable heads was more clearly affected by irrigation rates. In the early harvest, a larger proportion of jumbo heads (27%) was obtained from 100% ETc, which resulted in a smaller proportion of large heads (73%) compared with 50% ETc (85%). A similar trend of head distribution was measured in the late season, which had a higher proportion of large heads (38%), and corresponding smaller proportion of medium heads (48%) for 100% ETc compared with deficit irrigation (57%). These comparisons can be found in Figure 2-4. Overall, N did not significantly affect head proportion for either marketable or unmarketable heads.

2005-06

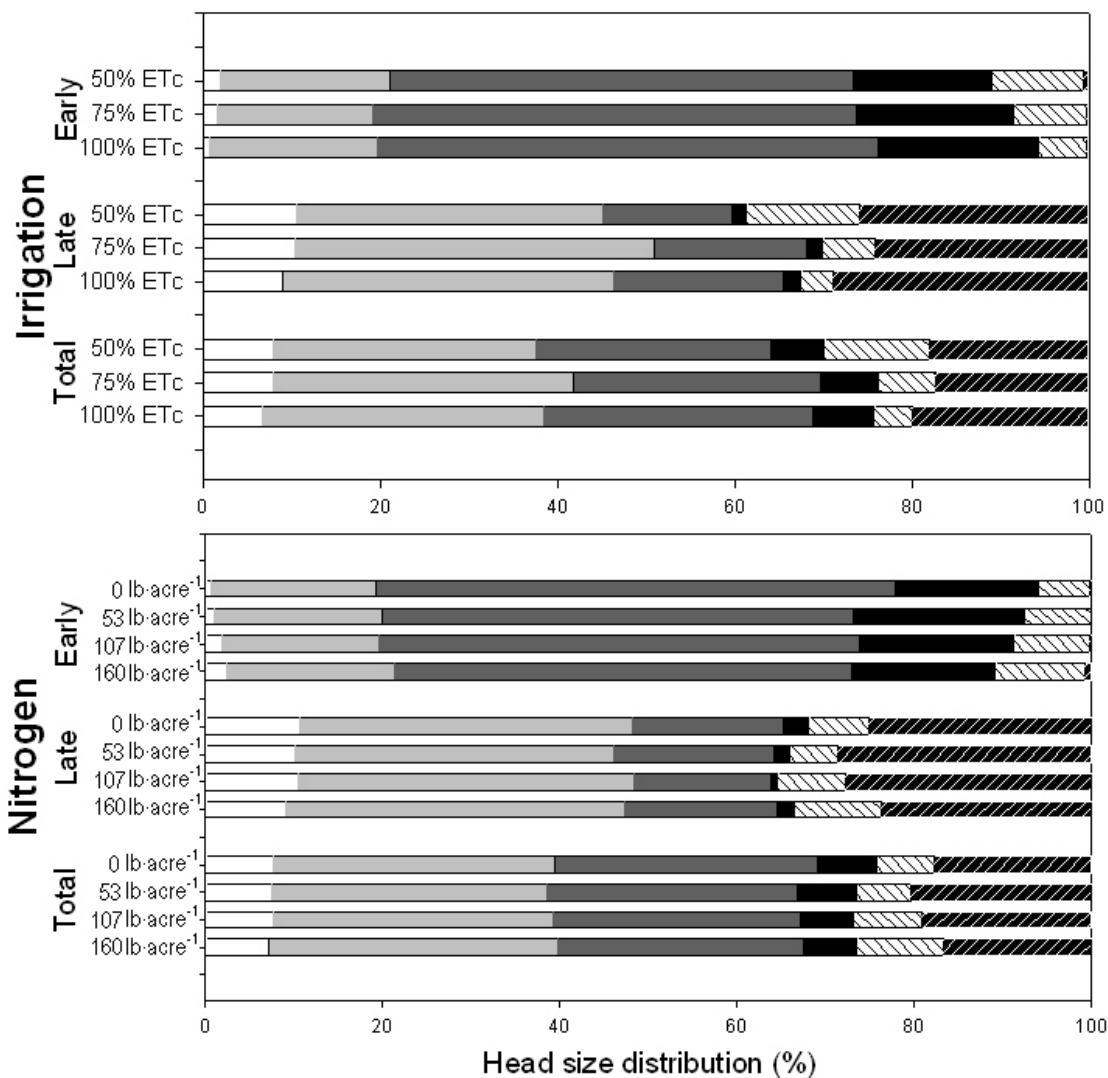


Figure 2-3. Head size distribution of artichoke cultivar Imperial Star in response to irrigation (top) and nitrogen (bottom) rates in the first season (left) and the second season (right).

2006-07

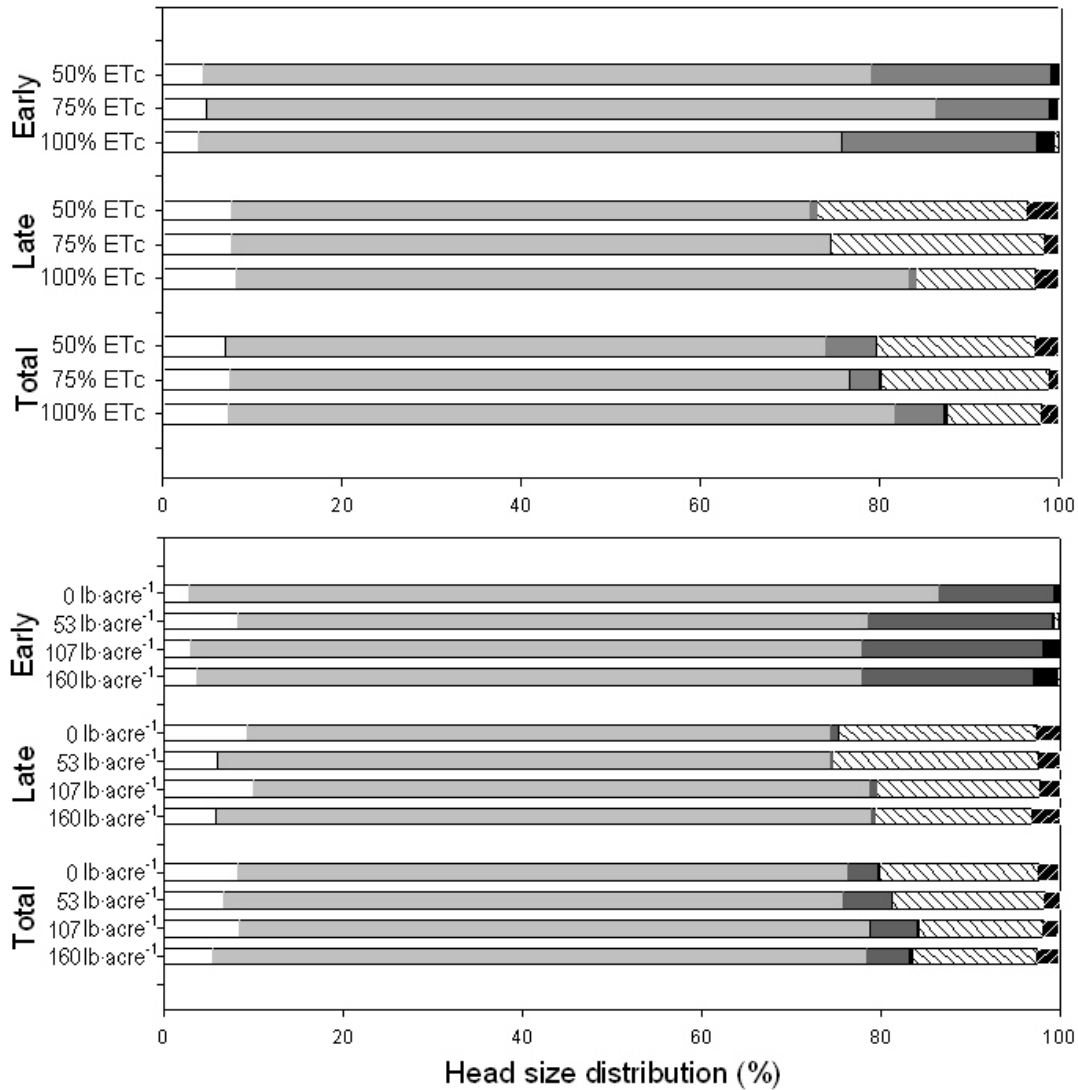


Figure 2-4. Head size distribution of artichoke cultivar Imperial Star in response to irrigation (top) and nitrogen (bottom) rates in the first season (left) and the second season (right).

2007-08

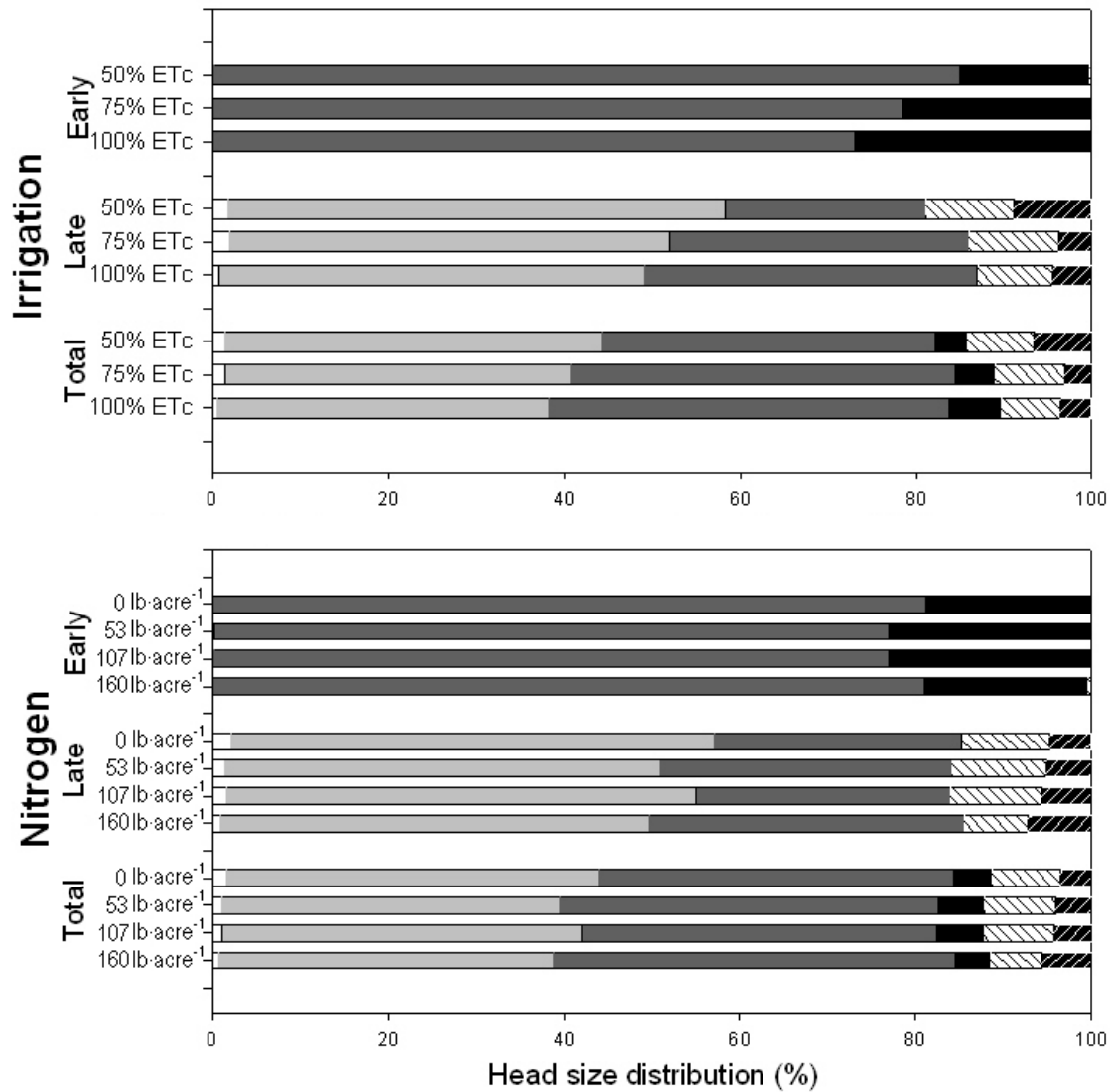


Figure 2-5. Head size distribution of artichoke cultivar Imperial Star in response to irrigation (top) and N (bottom) rates in season, 2007-2008.

Artichoke: Soil Nitrogen contents

Soil N content was evaluated in 2006 and 2007 after harvest (end of a crop cycle). Pre-plant soil NH₄-N and NO₃-N were 3.7 and 77.4 ppm, respectively. Irrigation did not significantly affect soil NH₄-N and NO₃-N when measured after the first season harvest, while both NH₄-N and NO₃-N were significantly affected by N fertilizer rates with the highest at 160 lb-acre⁻¹ N (Table 2-5). The significant irrigation × N interaction for NO₃-N in first season indicated that the combination of 160 lb-acre⁻¹ N and higher irrigation rates (75% and 100% ETc) showed that a

high concentration of NO₃-N was present in the soil (0-6 in. depth) compared with other N rates in 75% and 100% ETc or any other N rates in 50% ETc (Figure 2-6). In the second season, there were not significant differences among treatments, but there was an increasing trend for NH₄-N and NO₃-N content in response to N rates (Table 2-5).

Table 2-5. Soil nitrogen content after harvest for artichoke cultivar Imperial Star in response to irrigation and N rates, 2005-2007.

	2005-06		2006-07	
	NH ₄ -N (ppm)	NO ₃ -N (ppm)	NH ₄ -N (ppm)	NO ₃ -N (ppm)
<u>Irrigation (I)</u>				
50% ETc	3.5	171.1	5.6	34.7
75% ETc	9.3	335.4	9.2	35.2
100% ETc	7.3	304.4	6.0	40.7
<u>Nitrogen (N)</u>				
0 lb·acre ⁻¹	2.6 b	68.9 c	4.8	36.7
53 lb·acre ⁻¹	3.4 b	182.3 bc	6.3	37.7
107 lb·acre ⁻¹	4.4 b	280.1 bc	6.9	38.6
160 lb·acre ⁻¹	16.4 a	549.9 a	9.8	34.6
<u>Interaction</u>				
I × N	N.S	*	N.S	N.S

Soil samples (0-6 in depth) were collected on July 27, 2006 for the first season (2005-2006) and June 25, 2007 for the second season (2006-2007).

Pre-plant soil NH₄-N and NO₃-N were 3.7 ppm and 77.4 ppm, respectively (2005).

Means within columns followed by different letters are significantly different (LSD, p = 0.05).

N.S: Not significant.

*p < 0.05

2005-06

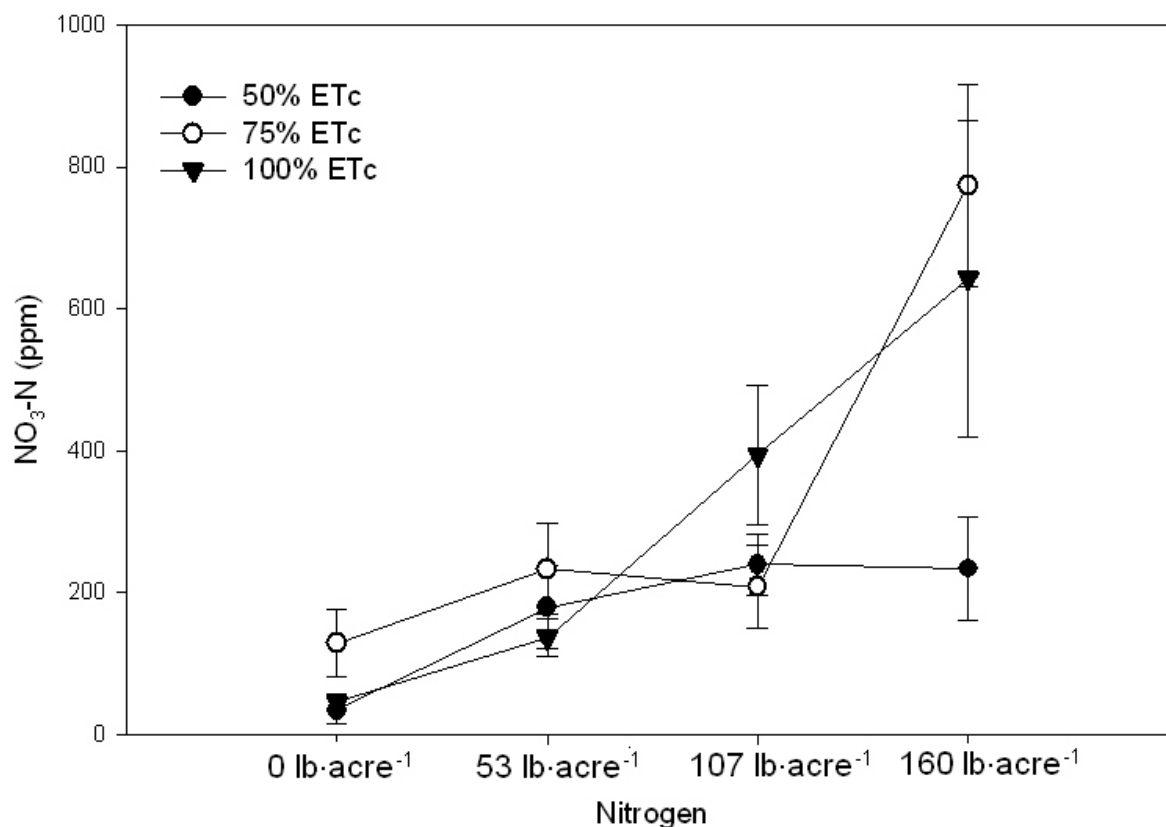


Figure 2-6. Soil NO₃-N content in response to irrigation (ETc) and N rates in the first season, 2005-2006. Vertical bars indicate mean ± SE (n = 4).

Artichoke transplant stress tolerance

Our results after exposing artichoke transplants for a 4-day period of withholding irrigation showed that ABA at 1,000 ppm had a stronger impact on imparting drought stress tolerance than 500 ppm ABA (Figure 2-7). This effect was probably due to induced stomatal closure, leading to transient decline of photosynthetic rates and an increased seedling water status as compared to film-forming materials (data not shown). In addition, seedlings treated with ABA (1,000 ppm) had higher survival rates and grew more vigorously than untreated controls or seedlings treated with film-forming material treatments (Figure 2-8).

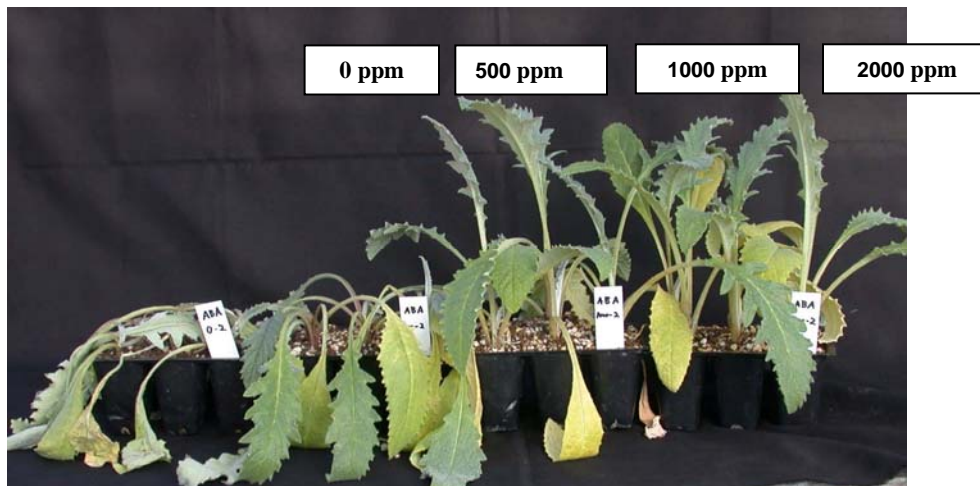


Figure 2-7. Artichoke transplants 4 days after withholding water. Photosynthetic rates at day 3 were 1.1, 5.8, 10.0 and 7.3 $\mu\text{mol m}^{-2} \text{s}^{-1}$ for 0, 500, 1,000 and 2,000 ppm of ABA foliar spray, respectively.

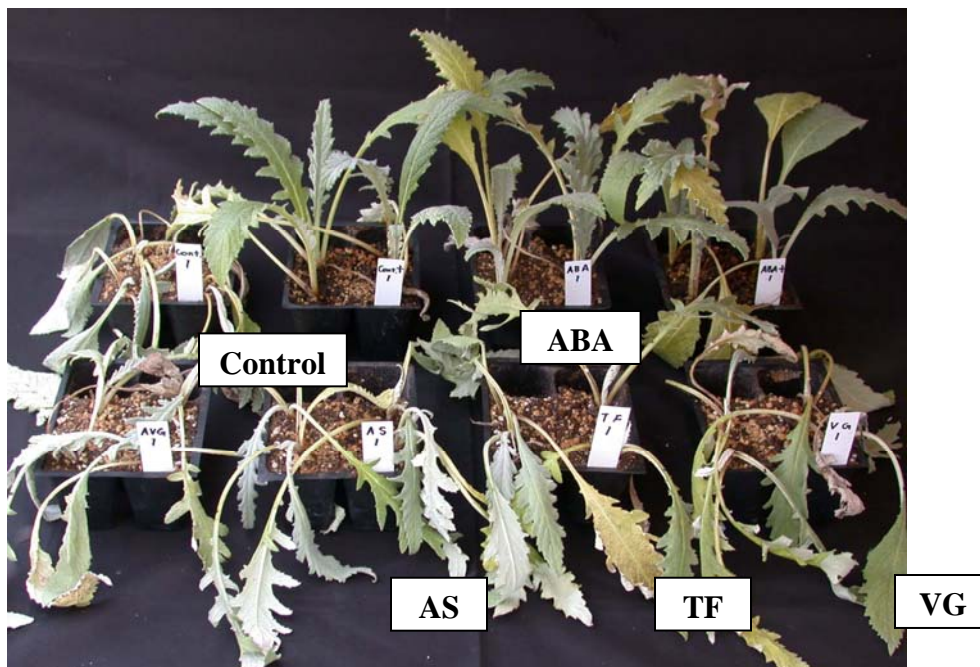


Figure 2-8. Artichoke transplants 4 days after withholding water. Photosynthetic rate at day 3 were 1.6, 5.4, 1.4, 1.5, and 1.3 $\mu\text{mol m}^{-2} \text{s}^{-1}$ for the water (control), abscisic acid (ABA), Antistress (AS), Transfilm (TF), and Vapor Gard (VG) foliar spray, respectively.

ARTICHOKE CONCLUSION

In conclusion, our results indicate that irrigation was more effective than N rates to optimize artichoke yield. Yield reduction was associated primarily with a decrease in head number and weight. Considering the three seasons of the study, a threshold level of ≥ 28 in. of total water inputs and $107 \text{ lb}\cdot\text{acre}^{-1}$ of N appears sufficiently enough to obtain high marketable yields for artichoke under our environmental conditions. It is important to emphasize that growers need to check soil-available N before planting, since the N responses are highly related to soil available N prior to planting. This study clearly shows that there are significant irrigation, season and irrigation \times season effects on artichoke quality. Evidently, it is possible to enhance phenolic contents in artichoke heads by deficit irrigation, but at the cost of significant yield loss as average 29% or 9% by 50% or 75% ETC, respectively. Based on our results, to achieve optimum yield and obtain valuable quality of artichoke heads, we recommend the annual production system with transplants established in October, with a water input of ≥ 28 in. in the southwest Texas region.

The additional experiment on ABA applied to artichoke transplants indicates that ABA is a useful tool to improve the overall plant water status and impart drought stress tolerance. This is important to producers that decide to plant artichoke transplants during late summer or early fall in order to obtain early spring harvests.

ONION STUDIES METHODOLOGY

Onion: Irrigation and Nitrogen rate (Exp. 1)

Studies were conducted on the short day onion cultivar TG 1015, in Uvalde. Plots were established on November 2, 2006 in the LPS and November 6, 2006 in the SDI system. Four lines of onions per 40 in bed were planted at approximately 4.0 in between plants using a precision vacuum planter. Standard weed, disease and pest control were applied to the crop combined with manual weeding and mechanical row cultivation.

Treatments

A total of 9 treatments (3 nitrogen and 3 irrigation rates) were investigated. We used two sources of N, urea ammonium nitrate (UAN) and the slow release fertilizer Nitamin 30 L which was either split four times (Nitamin1 or N1) or three times (Nitamin 2 or N2). The amount of N applied and application dates for both locations are shown in Table 2-6. The total amount of macronutrients applied was 120N-43P-76K lb·acre⁻¹. Irrigation rate treatments were 50%, 75% and 100% ETc. Irrigation was applied based on water requirements and rainfall data in order to compensate crop evapotranspiration (ETc) (Table 2-7). To calculate ETc researchers used specific crop coefficients (Kc) for the Uvalde area, as seen in Table 2-8.

Table 2-6. Dates and amount of N applied during the onion growing season in the LPS and SDI.

Irrigation system	Application date	Growth stage	Application rate (lb N·acre ⁻¹)		
			UAN	Nitamin1	Nitamin2
LPS	11/17/06	Emergence	30	30	30
	1/11/07	3-4 leaves	30	30	45
	2/20/07	Beginning of bulbing	30	30	0
	3/23/07	Bulb development	30	30	45
		Total	120	120	120
SDI	12/2/06	Emergence	30	30	30
	1/13/07	3-4 leaves	30	30	45
	2/21/07	Beginning of bulbing	30	30	0
	3/22/07	Bulb development	30	30	45
		Total	120	120	120

Table 2-7. Rainfall and irrigation during the onion growing season in Uvalde.

Irrigation system	Irrigation rate (% ETc)	Rainfall (in)	Irrigation (in) ^z			Rainfall and irrigation (in)
			Initial	Differential	Total	
LPS	100	12.7	5.9 (12)	8.8 (15)	14.7 (27)	27.4
	75	12.7	5.9 (12)	6.7 (15)	12.5 (27)	25.2
	50	12.7	5.9 (12)	4.5 (15)	10.4 (27)	23.1
SDI	100	12.7	8.9 (9)	8.8 (13)	17.7 (22)	30.4
	75	12.7	8.9 (9)	6.7 (13)	15.6 (22)	28.4
	50	12.7	8.9 (9)	4.7 (13)	13.6 (22)	26.3

^zValues between parenthesis are the number of irrigation events.

Table 2-8. Crop coefficients used at different growth stages of onion cv. TG 1015.

Growth stage	Crop coefficient (Kc)
Emergence	0.50
2 leaves	0.60
3-4 leaves	0.70
Beginning of bulbing	0.80
Bulb development	0.85
Bulb fully developed	0.90
Dry leaf stage	0.70

Harvest and quality

Harvest began when 80% of the tops had fallen over on May 31, 2007 in the LPS and June 5, 2007 in the SDI. The foliage was clipped after dislodging the bulbs from the soil and sacked in 50 lb bags that were left in the field for one day for drying prior to grading. Bulb size categories based on diameters were: <1.8 in. (small); 1.8-3.0 in. (medium); 3.0-3.7 in. (large); 3.7-4.0 in. (colossal) and > 4.0 in. (super colossal). A sub-sample of 10 large size onions for each treatment-replication was collected at harvest for soluble solid content (SSC, % brix by refractometry), pyruvic acid content for pungency and the flavonoid quercetin.

Parameters

The parameters measured were SPAD (chlorophyll content), total available soil N, nitrate-N and ammonium-N, yield, bulb size, soluble solid content, pungency and the phytochemical quercetin. Data was analyzed by ANOVA using SPSS and SAS.

Onion: Irrigation and Planting density Population (Exp. 2)

An experiment was established in 2007-2008 under the LPS system under the same conditions as the irrigation and nitrogen rate experiment described above. The objective was to evaluate the effects of three irrigation rates (100%, 75% and 50% ETc) and two planting densities (161 and 196 x 1000 seeds·acre⁻¹). Bulbs were harvested May 28-29, 2008. Parameters measured were marketable yields, number of bulbs·acre⁻¹, bulb size and bulb size distribution.

Onion: Nitrogen Sources under SDI (Exp. 3)

Treatments

Another experiment was established in 2007-2008 under the SDI system under the same conditions as Exp.1, except that the emphasis was on blends of slow release nitrogen sources. A total of nine treatments (4 nitrogen sources with 2 nitrogen rates, and one unfertilized control) were used. N sources were urea ammonium nitrate (UAN) as a standard, slow release fertilizer Nitamin 30 L, and two blends Nfusion 30% (UAN 32/Nfusion at 70/30 ratio) and Nfusion 50% (UAN 32/Nfusion at 50/50 ratio). Table 2-9 shows the amounts of N applied which were 100 and 150 lb·acre⁻¹, split in three applications: 20% at emergence, 40% at 2 leaf stage, and 40% at 7-9 leaf stage. Irrigation was applied based on water requirements and rainfall data in order to compensate ETc.

Harvest and quality

Harvest was done when >80% of the tops had fallen over on June 3, 2008. The foliage was clipped after dislodging the bulbs from the soil and sacked in 50 lb bags that were left in the field for one day. After onions were dried in storage, bulb size categories based on diameters were

measured: <1.8 in (small); 1.8-3.0 in (medium); 3.0-3.7 in (large); 3.7-4.0 in (colossal) and > 4.0 in (super colossal). The parameters measured or calculated in this study were bulb fresh weight, leaf fresh weight, bulb/shoot ratio, marketable and total yield, and bulb size distribution.

Table 2-9. Dates and growth stages of onion cv. TG 1015 at planting, fertilization and harvest.

Date	Growth stage	Culture
11/13/07	Seeds	Planting
11/30/07	Emergence	1st N application (20%)
2/21/08	2 leaves	2nd N application (40%)
3/27/08	7-9 leaves (beginning of bulbing)	3rd N application (40%)
6/3/08	Dry leaf stage	Harvest

Statistical analysis (Onion experiments)

The experiments were conducted using a split plot design (Exps. 1 and 2) and randomized complete block design (Exp. 3) with four replications. Individual plot size consisted of 2 rows of 40 in. bed and 10 ft long. Irrigation was assigned to main plots in Exps. 1 and 2, and Nitrogen rates and planting density to subplots, respectively. For each experiment data growth and yield data were all analyzed by ANOVA using SAS Differences among treatments were performed using the least significant difference procedure (LSD) at p = 0.05.

ONION RESULTS

Onion Irrigation and Nitrogen Rates (Exp. 1)

Chlorophyll

In the LPS, there were not significant differences in chlorophyll content (expressed as SPAD values) across N source and irrigation rate treatments, except at the April 13 sampling, where N2 had significantly higher values than UAN (Table 2-10). SPAD values were similar across all treatments under the SDI (not shown).

Table 2-10. Impact of N source and deficit irrigation on shoot lodging and SPAD values of onion cv. TG 1015 in the LPS.

Treatment	SPAD value		
	Feb 14	Apr 13	May 15
<i>N source</i>			
UAN	56.08	59.10	43.54
Nitamin1	55.21	59.39	44.32
Nitamin2	53.31	61.52	44.09
LSD _{0.05}	NS	1.75	NS
<i>Irrigation rate</i>			
100% ETc	54.13	59.48	43.26
75% ETc	54.94	59.42	44.67
50% ETc	55.54	61.10	44.02
LSD _{0.05}	NS	NS	NS

Total available soil N, nitrate-N and ammonium-N

Tables 2-11 and 2-12 show soil nitrate-N, ammonium-N and total soil N across five sampling times for the LPS and SDI. In the LPS, soil nitrate, ammonium and total N were significantly higher for N1 and N2 as compared to UAN at Feb. 14 and March 22 (Table 2-11). This period coincides with the fast leaf development and initiation to mid-bulb growth. Soil N (ammonium and nitrate) was not significantly affected by irrigation rate; however there was a consistent trend of decreasing values with deficit irrigation (50% ETc) for four of the five sampling times (Table 2-11).

In the SDI, nitrate, ammonium and total soil N were similar across N sources, except for a decrease on both nitrate and total soil N for N1 and N2 as compared to UAN when measured Jan. 10 (Table 2-12). Total soil N, was significantly lower at 50% ETc compared to 100% ETc on Jan. 10 and May 30 (Table 2-12). Comparing both irrigation systems, it is interesting to note the higher levels of N under the SDI were more than 3-fold as compared to the levels on the LPS when measured on Jan. 10, March 22 and May 30, 2007.

Table 2-11. Impact of N source and deficit irrigation on available soil N content during the growth of onion cv. TG 1015 in the LPS.

Treatment	Available soil N (ppm)														
	Nov 2			Jan 10			Feb 14			Mar 22			May 30		
	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total
<i>N source</i>															
UAN	72.2	8.8	81.0	44.6	7.3	51.8	6.3	9.4	15.6	16.8	8.4	25.2	11.4	10.4	21.8
Nitamin1	67.5	9.6	77.1	31.0	8.5	39.5	24.0	12.1	36.1	24.1	8.7	32.8	8.7	12.0	20.7
Nitamin2	69.1	9.1	78.2	38.3	8.0	46.4	25.3	14.2	39.5	35.1	10.6	45.7	11.1	11.8	22.9
LSD _{0.05}	NS	NS	NS	NS	NS	NS	13.0	2.7	13.5	3.2	1.5	3.5	NS	NS	NS
<i>Irrigation rate</i>															
100% ETc	73.2	9.5	82.7	45.8	7.8	53.6	17.6	12.2	29.8	29.8	10.1	39.9	10.3	12.8	23.1
75% ETc	66.5	9.2	75.6	35.7	7.8	43.6	21.6	11.5	33.1	26.5	8.7	35.2	11.6	11.3	23.0
50% ETc	69.1	8.8	77.9	32.3	8.2	40.4	16.4	11.9	28.2	19.8	8.8	28.5	9.3	10.1	19.4
LSD _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2-12. Impact of N source and deficit irrigation on available soil N content during the growth of onion cv. TG 1015 in the SDI.

Treatment	Available soil N (ppm)														
	Nov 2			Jan 10			Feb 14			Mar 22			May 30		
	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total	NO ₃ ⁻	NH ₄ ⁺	Total
<i>N source</i>															
UAN	122.3	6.7	129.0	306.3	4.3	310.6	30.9	8.3	39.2	98.9	7.9	106.8	73.7	7.8	81.5
Nitamin1	115.3	6.5	121.7	236.1	5.7	241.7	29.3	7.1	36.4	91.1	7.4	98.4	73.4	7.0	80.3
Nitamin2	124.4	6.8	131.2	225.5	5.8	231.3	30.3	6.7	37.0	96.3	7.7	104.0	62.8	7.3	70.1
LSD _{0.05}	NS	NS	NS	*	1.2	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Irrigation rate</i>															
100% ETc	115.9	6.5	122.4	358.0	5.4	363.3	34.3	7.9	42.2	96.4	7.2	103.6	85.5	7.1	92.7
75% ETc	119.5	6.9	126.4	238.7	5.4	244.1	30.9	7.2	38.1	95.1	8.8	103.9	78.1	7.6	85.7
50% ETc	126.5	6.5	133.1	171.2	5.1	176.3	25.3	7.0	32.3	94.8	7.0	101.7	46.2	7.3	53.5
LSD _{0.05}	NS	NS	NS	*	NS	*	NS	NS	NS	NS	1.4	NS	33.5	NS	34.2

Marketable Yield and Quality

Table 2-13 shows marketable yield, soluble solids content (SSC) and pungency (pyruvic acid) for onions under the LPS system. Overall, marketable yield, SSC and pyruvic acid were not affected by N source and irrigation treatments. A slightly higher yield (numerically but not statistically at $P \leq 0.05$) was found with N2 (Table 2-13). Deficit irrigation treatments did not show any trends. The lack of significant differences is not surprising since we had an unusually wet season, and therefore the excess of water provided in the 100% ETc plots was not reflected in improved yields.

Table 2-13. Impact of N source and irrigation rate on marketable yield, size, soluble solids content and pyruvic acid for onion in the LPS in Uvalde, Texas.

Treatment	Marketable yield (lb·acre ⁻¹)	SSC (°Brix)	Pyruvic acid (μmol·ml ⁻¹)
<i>N source</i>			
UAN	56336	5.90	4.12
Nitamin 1	58016	5.77	4.34
Nitamin 2	59808	5.62	3.97
<i>Irrigation rate</i>			
100% ETc	57120	5.78	4.09
75% ETc	59136	5.79	4.20
50% ETc	58352	5.73	4.18

Similarly, in the SDI system, marketable yield, SSC and pyruvic acid were not affected by N source and irrigation rate (Table 2-14), except that bulbs from the UAN treatment had higher °Brix than those of the Nitamin treatments. In terms of bulb size, Nitamin treatments significantly increased the percentages of high value bulb sizes (large and colossal) compared to UAN (Table 2-15).

Table 2-14. Impact of N source and irrigation rate on marketable yield, soluble solids content and pyruvic acid for onion in the SDI in Uvalde, Texas.

Treatment	Marketable yield (lb·acre ⁻¹)	SSC (°Brix)	Pyruvic acid (μmol·ml ⁻¹)
<i>N source</i>			
UAN	56896	5.75	4.06
Nitamin 1	62944	5.45	3.63
Nitamin 2	59472	5.52	4.06
LSD (0.05)	ns	0.21	ns
<i>Irrigation rate</i>			
100% ETc	59136	5.58	3.90
75% ETc	59248	5.58	4.05
50% ETc	60816	5.56	3.80
LSD (0.05)	ns	ns	ns

Table 2-15. Impact of N source and deficit irrigation on bulb size distribution of cv. TG 1015 in the SDI.

Treatment	Size distribution ^z (% marketable yield, wt/wt)			
	Small	Medium	Large	Colossal
<i>N source</i>				
UAN	1.56	46.17	45.67	6.59
Nitamin 1	1.04	40.38	47.90	10.68
Nitamin 2	1.60	35.12	53.00	10.28
<i>Irrigation rate</i>				
100% ETc	1.90	41.60	48.25	8.26
75% ETc	1.37	38.23	50.10	10.31
50% ETc	0.94	41.85	48.23	8.98
<i>Contrasts</i>				
UAN vs. Nitamin	NS	**	*	*
UAN vs. Nitamin 1	NS	*	NS	NS
UAN vs. Nitamin 2	*	**	**	NS
Nitamin 1 vs. Nitamin 2	**	NS	*	NS
100% ETc vs. 75% ETc	*	NS	NS	NS
100% ETc vs. 50% ETc	**	NS	NS	NS
75% ETc vs. 50% ETc	NS	NS	NS	NS

^zSmall = < 1.8 in; medium = 1.8-3.0 in; large = 3.0-3.7 in; colossal = > 3.7 in
 NS,*,** Not significant or significant at $p = 0.1$ or 0.05 , respectively.

Onion Irrigation and Planting Density (Exp. 2)

Overall, total marketable yields increased with increasing total water inputs. Yields were significantly higher for 100% ETc and significantly decreased with deficit irrigation. Similarly bulb size was highest with 100% ETc and decreased with deficit irrigation. Yields also increased with the higher planting density, but the average bulb size decreased. There were no planting density and irrigation interactions. (Table 2-16)

Table 2-16. Impact of planting density and deficit irrigation on marketable yield and average bulb size of onion cv. TG 1015 in Uvalde, TX during 2007-2008.^z

Planting density (seeds·acre ⁻¹)	Irrigation rate (% ETc)	Marketable yield			Bulb size (oz·bulb ⁻¹)
		(bulbs·acre ⁻¹)	(lb·acre ⁻¹)	(%, wt/wt)	
160,998	100	97,003 c	83405 ab	99.7	11.1 a
	75	101,583 bc	79541 ab	98.7	10.0 ab
	50	96,348 c	61534 c	99.2	8.1 bc
196,216	100	121,703 ab	92539 a	99.4	9.7 ab
	75	124,484 a	82587 ab	99.5	8.5 bc
	50	111,725 ab	66022 c	99.4	7.5 c
ANOVA		----- <i>p</i> -value -----			
Planting density (PD)		0.015	0.061	0.471	0.027
Irrigation rate (IR)		0.160	0.000	0.621	0.000
Interaction (PD × IR)		0.544	0.359	0.452	0.494

^zMeans in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test. Seeding and harvest were performed on November 12, 2007 and May 27, 2008, respectively.

Regarding onion size distribution, there were significant irrigation and planting density interactions. Overall, largest size onions (Colossal + Super Colossal) resulted with the combination of 100% ETc and lower planting density, with about 25% of the total bulbs produced (Table 2-17). Conversely, a higher percentage of medium to large size resulted from 50% ETc at both planting densities.

Table 2-17. Impact of planting density and deficit irrigation on bulb size distribution of onion cv. TG 1015 in Uvalde, Texas during 2007-2008.^z

Planting density (seeds·acre ⁻¹)	Irrigation rate (% ETc)	Bulb size distribution ^y (% marketable yield, wt/wt)					
		Small	Medium	Large	Jumbo	Colossal	SC
160,998	100	1.2 abc	17.1 d	32.4 b	23.6 a	16.4 a	9.2 a
	75	0.7 c	25.0 d	38.9 ab	21.0 ab	9.7 ab	4.9 ab
	50	2.3 a	37.4 b	44.4 a	13.1 bc	2.8 b	0.0 b
196,216	100	1.0 bc	26.3 cd	42.8 a	21.0 ab	7.3 ab	1.6 b
	75	1.8 ab	34.6 bc	43.4 a	14.9 abc	5.0 b	0.4 b
	50	2.3 a	47.5 a	37.4 ab	8.7 c	3.1 b	1.0 b
ANOVA		----- <i>p</i> -value -----					
Planting density (PD)		0.407	0.009	0.435	0.129	0.024	0.033
Irrigation rate (IR)		0.001	0.000	0.183	0.001	0.004	0.024
Interaction (PD × IR)		0.043	0.982	0.003	0.738	0.117	0.046

^zMeans in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test. Seeding and harvest were performed on November 12, 2007 and May 27, 2008, respectively.

^yOnion bulbs were categorized as small (< 2.3 in), medium (2.3-3.0 in), large (3.0-3.8 in), jumbo (3.8-4.1 in), colossal (4.1-4.5 in), and super colossal (SC, > 4.5 in) based on bulb diameter.

Onion nitrogen sources under SDI (Exp. 3)

5B4B3B2B1B0B Marketable and total yields were significantly different ($P < 0.05$) across treatments (Table 2-18). Among all N sources, Nfusion 50% at either rate or Nitamin at 150 lb·acre⁻¹ were the best treatments as compared to control, but there were not differences among all N sources (Table 2-18). The quality of onions was excellent with over 98% of marketable bulbs and generally less than 1% of splits.

Table 2-18. Effects of slow N-release sources at low and high application rates on yield components of onion cv. TG 1015 in Uvalde, Texas, 2007-2008.^z

N source ^y	N rate (lb·acre ⁻¹)	Marketable yield			Bulb size (oz·bulb ⁻¹)
		(bulbs·acre ⁻¹)	(lb·acre ⁻¹)	(%, wt/wt)	
Control	0	94,058	80346 b	99.7	11.0
UAN	100	102,401	89775 ab	99.9	11.2
	150	100,111	88423 ab	98.7	11.4
Nitamin	100	101,092	88334 ab	98.8	11.1
	150	105,836	95279 a	98.4	11.5
Nfusion 30%	100	102,074	86419 ab	99.2	10.8
	150	98,475	88192 ab	99.7	11.4
Nfusion 50%	100	93,404	91519 ab	99.8	12.5
	150	96,839	94683 a	99.8	12.5
ANOVA (<i>p</i> -value)		0.640	0.035	0.852	0.262

^zMeans in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test. Seeding and harvest were performed on November 13, 2007 and June 3, 2008, respectively.

Table 2-19. Effects of slow N-release sources at low and high application rates on bulb size distribution of onion cv. TG 1015 in Uvalde, Texas during 2007-2008.^z

N source ^y	N rate (lb·acre ⁻¹)	Bulb size distribution ^x (% marketable yield, wt/wt)					
		Small	Medium	Large	Jumbo	Colossal	SC
Control	0	0.1	20.9	30.0 ab	24.9	17.4	6.7
UAN	100	0.6	15.2	29.5 ab	23.6	17.7	13.4
	150	0.5	16.2	30.2 ab	19.1	21.7	12.3
Nitamin	100	0.6	18.8	37.9 a	21.7	16.3	4.8
	150	0.3	18.7	34.6 ab	27.1	15.5	3.9
Nfusion 30%	100	0.7	20.9	33.3 ab	21.7	14.8	8.6
	150	0.6	19.3	32.1 ab	23.7	14.7	9.6
Nfusion 50%	100	0.9	15.7	31.7 ab	22.4	16.1	13.2
	150	0.6	15.1	25.2 b	27.4	22.2	9.5
ANOVA (<i>p</i> -value)		0.439	0.102	0.071	0.189	0.286	0.181

^zMeans in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test. Seeding and harvest were performed on November 12, 2007 and May 27, 2008, respectively.

^yUAN = urea ammonium nitrate; Nitamin = Nitamin 30L; Nfusion 30% = blend of Nfusion and UAN at 30:70; Nfusion 50% = blend of Nfusion and UAN at 50:50.

^xOnion bulbs were categorized as small (< 2.3 in), medium (2.3-3.0 in), large (3.0-3.8 in), jumbo (3.8-4.1 in), colossal (4.1-4.5 in), and super colossal (SC, > 4.5 in) based on bulb diameter.

ONION CONCLUSIONS

Onion irrigation, nitrogen rates and plant populations

Based on the results from both N studies, the slow release Nitamin 30L showed some positive trends when applied through the LPS and SDI systems as compared to UAN. Marketable yields were 6% and 3% numerically but not statistically higher for Nitamin 2 (3 split applications) and Nitamin 1 (four equal split applications), respectively, than UAN in the LPS. Similarly, marketable yields were 4.5% and 10% numerically but not statistically higher for Nitamin 2 and Nitamin 1 respectively, than UAN in the SDI.

In the LPS system, the levels of soil nitrate-N, ammonium-N and total N were higher for Nitamin 2 and Nitamin 1 during the period of fast plant development and nutrient demand. The lack of significant differences at the $P \leq 0.05$ level for most parameters measured in response to irrigation rates were most likely due to the environmental variation associated with unusual rainfall events. During this 'wet' 2006-07 growing season, rainfall accumulated to 12.8 in. in Uvalde.

The results from the onion irrigation and plant populations indicate that to obtain highest yields, it is necessary to use 100% ETc with optimum stage-specific Kc. Optimum irrigation at the lower plant populations produced the highest percentages of bulb sizes, which translates to higher income and profitability to producers since the price per 50 lb bags progressively increased with size in combination with highest plant populations.

PEPPER, WATERMELON AND CABBAGE METHODOLOGIES

Pepper and watermelon N experiment

Three groups of pepper (jalapeno, chile, paprika) were evaluated for marketable yields in response to four N rates (0, 60, 120 and 180 lb·acre⁻¹) at Uvalde under a subsurface drip system. Similarly, four watermelon cultivars were evaluated under drip irrigation with plastic mulch, with three N rates (0, 80 and 160 lb/ac) and two irrigation rates (100% ETc and 50% ETc). The experiments were conducted using a split plot design with N as the main plots and cultivars as subplots, and four replications.

Monitor soil moisture cabbage fields

Soil moistures at 6, 12 and 24 in. depths during the growing season of cabbage were monitored under center pivot irrigation, LEPA and furrow irrigation. Changes in irrigation and rainfall were related to the particular field and irrigation system used by the grower.

PEPPER, WATERMELON AND CABBAGE RESULTS

Watermelon – Irrigation and Nitrogen

Overall, deficit irrigation (17 in. received) reduced watermelon marketable yields across all cultivars with an average decline of 28% (Table 2-20). The response was mostly due to a decrease in fruit size and fruit number. Similarly, watermelon yields were highest with increasing N levels up to 160 lb/acre. Comparing cultivars, both seeded types (2x or diploids) had significantly higher yields than SS 7187 (seedless, 3x) but not than Amarillo. As expected the difference was mostly due to the increase in fruit size for the diploid type melons.

Table 2-20. Effects of cultivar, irrigation rate, and N rate on marketable yield and fruit size of watermelon in Uvalde, TX, 2006.^z

Treatment	Marketable yield		Size (lb·fruit ⁻¹)	% marketable
	(fruit·plant ⁻¹)	(lb·acre ⁻¹)		
Cultivar / ploidy				
SF 800 2 ×	1.19 bc	67784 a	20.4 a	94.3 a
Stargazer 2 ×	1.30 ab	67246 a	18.9 b	94.7 a
SS 7187 3 ×	1.04 c	36123 b	12.5 d	70.3 c
Amarillo 3 ×	1.42 a	59942 a	15.3 c	85.2 b
Irrigation				
100% ETc	1.35 a	65022 a	17.4 a	88.2 a
50% ETc	1.13 b	50526 b	16.1 b	84.0 b
N rate (lb·acre ⁻¹)				
0	1.12 b	52577 b	16.7	85.9
80	1.24 ab	57816 ab	16.7	86.4
160	1.35 a	62929 a	16.8	86.0

^zMeans in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the LSD test.

Pepper Nitrogen rate

Three groups of pepper (jalapeno, chile, paprika) were evaluated with four N rates (0, 60, 120, and 180 lb·acre⁻¹). Yield and quality responses differed among the different pepper types. In Jalapenos, best responses were obtained with increasing N rates up to 180 lb/acre, however no statistically differences were detected between the low (60 lb/ac) and high rates (180 lb/ac) (Table 2-21). These N rates did not affect yield components. Comparing cultivars, both Ixtapa and J222 were superior in total marketable yields, with less cull than the experimental SJ71. Overall, blossom end rot, was relatively low and not affected by N rates in this type of pepper.

In Green Chiles, the responses were quite similar to jalapenos, with a numerical but not statistical difference among the N rates (best 60 to 120 lb/ac). Best responses were also obtained with increasing N rates up to 120 lb/acre, however no statistically differences were detected among the N rates (Table 2-22). In terms of yield components, there was a trend of increasing culls (sunscald and BER) with increasing in N rates. Both cultivars, Sonora and C130 had higher marketable yields than NM6-4. Similar trends were measured for the two paprika cultivars (Tables 2-23), except that were less responsive to N than the other two pepper types. The peppers were very susceptible to sunscald, and expressed a high level of BER.

Table 2-21. Effects of N application rate on marketable fruit yield in three cultivars of jalapeno pepper at Uvalde in summer 2006.^z

Treatment	Marketable yield		Yield component (% total yield, wt/wt)			
	(fruit·plant ⁻¹)	(lb·acre ⁻¹)	Marketable	Sunscald	BER	Culls ^y
Cultivar						
IXTAPA	60.2 a	40149 a	92.3 b	1.75 a	1.75	1.75 b
J222	66.2 a	42425 a	95.1 a	2.75 b	2.75	2.75 b
SJ71	41.8 b	24614 b	91.3 b	6.74 b	6.74	6.74 a
N rate (lb·acre ⁻¹)						
0	45.6 c	27683 b	92.5	4.87	4.87	4.87
60	54.1 b	34628 a	92.0	3.42	3.42	3.42
120	62.6 a	39921 a	93.2	3.69	3.69	3.69
180	62.1 ab	40686 a	93.9	3.00	3.00	3.00

^zData were pooled by main effects due to absence of interactions. Means in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test.

^ySeriously deformed or extremely small fruits were categorized as culls.

BER = blossom end rot.

Table 2-22. Effects of N application rate on marketable fruit yield in three cultivars of green chile pepper at Uvalde in summer 2006.^z

Treatment	Marketable yield		Yield component (% total yield, wt/wt)			
	(fruit-plant ⁻¹)	(lb·acre ⁻¹)	Marketable	Sunscald	BER	Culls ^y
Cultivar						
Sonora	31.1	29761 a	82.2	8.5 b	6.68	2.68 b
C130	33.5	29639 ab	77.6	10.2 at	8.67	3.59 b
NM6-4	38.0	25158 b	71.7	12.3 a	8.30	7.74 a
N rate (lb·acre ⁻¹)						
0	32.6	25373	81.4 a	7.1 d	5.84	5.62
60	36.2	30603	77.7 b	9.2 c	8.28	4.83
120	36.6	29779	76.0 bc	11.7 b	8.18	4.10
180	31.5	26989	73.4 c	13.3 a	9.23	4.13

^zData were pooled by main effects due to absence of interactions. Means in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test.

^ySeriously deformed or extremely small fruits were categorized as culls.

BER = blossom end rot.

Table 2-23. Effects of N application rate on marketable fruit yield in three cultivars of paprika pepper at Uvalde in summer 2006.^z

Treatment	Marketable yield		Yield component (% total yield, wt/wt)			
	(fruit-plant ⁻¹)	(lb·acre ⁻¹)	Marketable	Sunscald	BER	Culls ^w
Cultivar						
B58	25.2	15532	60.6	17.8 a	16.1	5.5 b
PA137	24.0	12435	63.2	9.4 b	13.3	14.2 a
N rate (lb·acre ⁻¹)						
0	20.6	10889	63.0	12.5	13.6	10.8
60	24.7	14495	64.1	12.8	14.5	8.6
120	27.6	15567	60.4	13.5	15.6	10.4
180	25.6	14981	60.0	15.3	15.1	9.6

^zData were pooled by main effects due to absence of interactions. Means in a column followed by the same letter are not significantly different at $\alpha = 0.05$, according to the Tukey's HSD test.

^wSeriously deformed or extremely small fruits were categorized as culls.

BER = blossom end rot.

Soil Moisture Monitoring in Cabbage Fields

Soil moisture was monitoring in commercial fields to determine volumetric water changes at 6, 12 and 24 in. soil depths. Changes in soil moisture were associated with the particular irrigation system and frequency of irrigation used by the grower. For example, in Batesville (Figure 2-9) irrigation under center pivot was kept between 25% and 40% when measured between 6 and 12 in. Since soil moisture at 24 in. remained relatively flat, which indicates that there was not over- or under-irrigation. Conversely, a cabbage field in Knippa under the LEPA system, showed that soil moisture progressively declined as the crop matured, in part due to the lower frequency of irrigation, even though the field has 3 events of 2 in. of rainfall (Figure 2-10). The next graph

(Figure 2-11), shows soil moisture changes of a cabbage crop grown under furrow irrigation. This is a typical curve for furrow irrigation with higher peaks at each irrigation and with less frequency of irrigation (four times). Overall soil moisture profile was kept between 25% and 45% volumetric water content, with a relatively constant value at the end of the dry down period at 24 inches (30%). It appears that the majority of root activity also occurred between 6 and 12 inches depth. In Uvalde irrigation under center pivot was kept between 20% and 40% when measured between 6 and 12 in. (Figure 2-12). Soil moisture at 24 in. remained relatively constant (25%) and flat during the cropping season, which indicates that there was not over-irrigation.

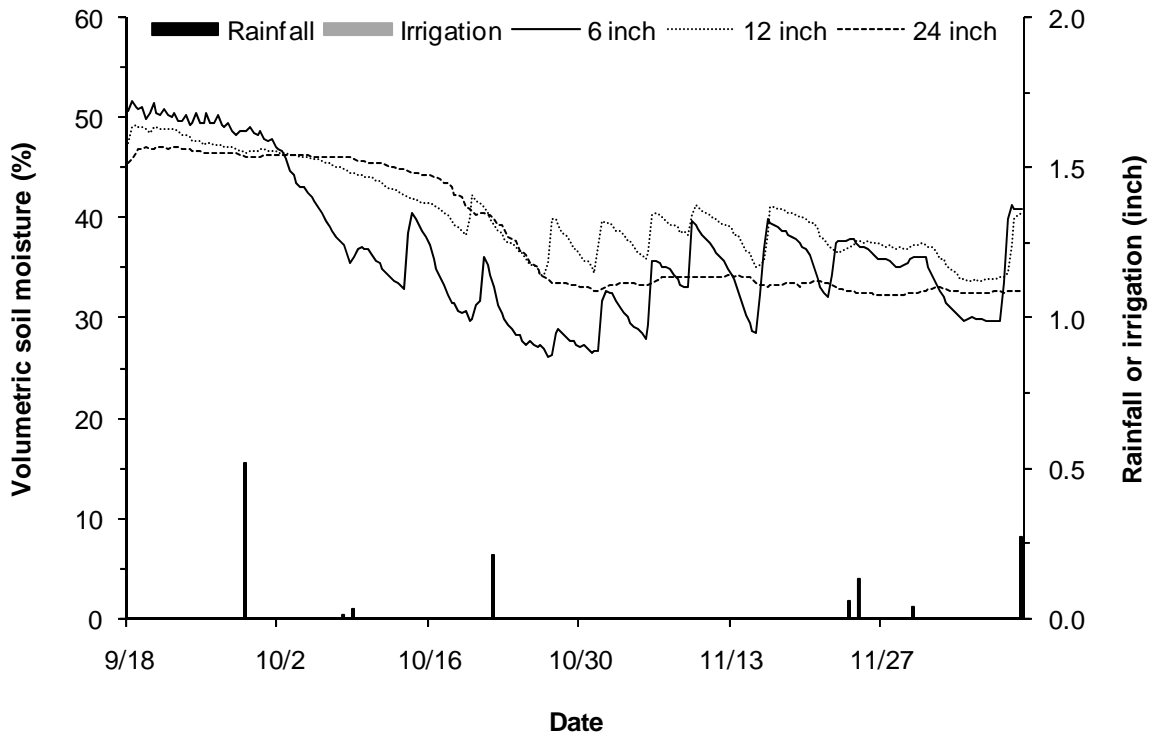


Figure 2-9. Soil moisture changes during the growing season of cabbage under the center pivot irrigation system and their responses to rainfall and irrigation in Batesville, TX 2007.

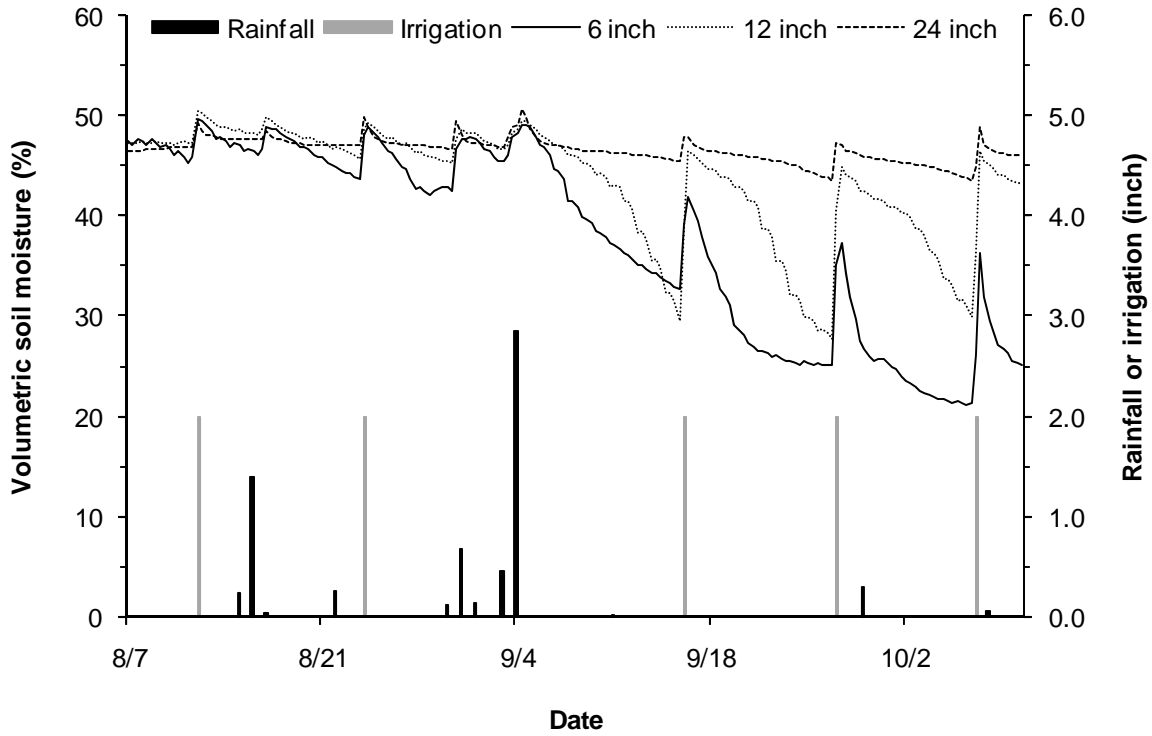


Figure 2-10. Soil moisture changes during the growing season of cabbage under the LEPA irrigation system and their responses to rainfall and irrigation in Knippa, TX 2007.

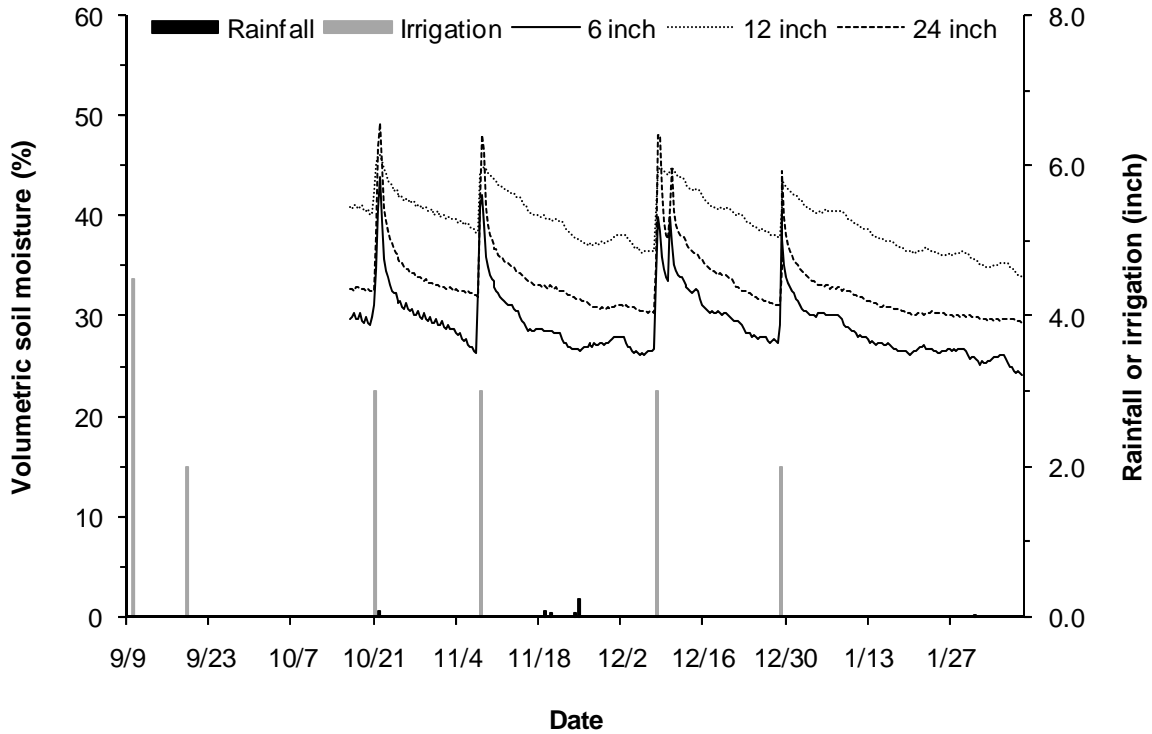


Figure 2-11. Soil moisture changes during the growing season of cabbage under the furrow irrigation and their responses to rainfall and irrigation at the Frio farm, TX in 2007-2008.

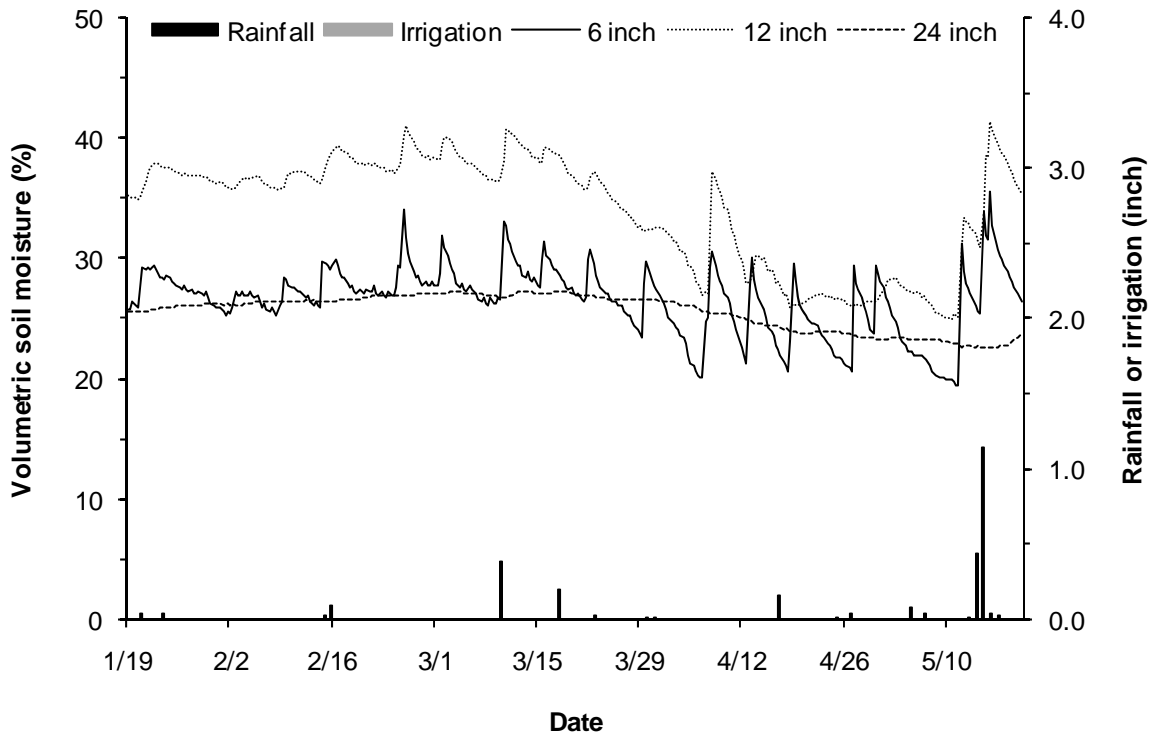


Figure 2-12. Soil moisture changes during the growing season of cabbage under the center pivot irrigation and their responses to rainfall and irrigation at the Crawford farm in Uvalde, TX in 2007-2008.

PEPPER AND WATERMELON CONCLUSIONS

From the three groups of pepper evaluated in one season (jalapeno, chile, and paprika) we conclude that optimum yields were measured with 120 lb·acre⁻¹. It is important to note that residual soil N can be a significant source of N, and hence the lack of significant differences among rates for certain peppers may be masked by the residual soil N. Physiological disorders, such as blossom end rot was cultivar dependant, being lowest in jalapenos. In watermelon, as expected deficit irrigation reduced total yields compared to well-irrigated treatments. However, the response also differed with cultivars, being higher for seeded or diploid types as compared to seedless or triploid ones.

CHAPTER 3: High Plains Demonstrations and Implementation

BACKGROUND

The Texas High Plains region demonstrations focused on on-farm evaluations and system irrigation data acquisition for decision support system (DSS) model input. Each targeted field was monitored to record detailed data on the production, yield, growth, climate and irrigation practices utilized by the producer. In addition, computer models such as CroPMan and NPET will be run to record growth and development and evaluate production practices. Crops assessed included corn, grain sorghum and cotton.

Educational programs were conducted in conjunction with Texas AgriLife Extension Service personnel to inform producers on the use of irrigation scheduling tools and demonstrated use of electronic access to daily ET data and crop water requirements from weather stations within the Texas High Plains region. An ET irrigation scheduling user's guide was developed and prepared for growers to inform them on wise and efficient use of ET-based irrigation scheduling, even in limited water capacity or allocation scenarios.



North Plains Research Field Corn Field Day
Event and Tour

METHODOLOGY

One of the most appropriate DSS tools in intensively irrigated regions of Texas is that of irrigation scheduling. The “best” system infrastructure support to ensure accurate irrigation scheduling data is typically derived and underpinned on a regional basis with the use of an agricultural representative ET network that is comprised of well-maintained and operated meteorological stations. The North Plains Evapotranspiration (NPET) network (Marek et al., 1995 & 1996) is such a system, which is an integrated part of the Texas High Plains ET (TXHPET) network (<http://txhighplainset.tamu.edu/>) (Marek et al., 2005), and continues to maintain its primary focus as an ET-based irrigation scheduling tool for intensively irrigated producers in the northern Texas High Plains region. The network maintains its focus on accurate computations and estimates of crop water use for irrigated producers based on the latest science and computational methodologies derived from research and field measurements. This accuracy is eminent due to irrigated agriculture continuing to be the predominant water resource user within the Texas High Plains.

Crop ET (ET_c) values used in the NPET network are derived from measured, but limited, research data gathered since 1997 from the large weighing, monolithic lysimeters located at the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS) facility at Bushland, Texas. Given the diversity and number of cereal grain crops grown within the Texas Panhandle region, assessment of the base crop coefficients data sets has taken decades to acquire ample data for representative, average crop development models, with each crop requiring multiple years of production data. The data acquisition task, while seemingly lengthy, is not nearly complete for all crops with multiple planting dates, and more research remains to be conducted particularly as improved varieties of cereal grain and oilseed crops are being preliminarily grown as alternative fuels in response to the most recent national energy crisis. Computation of daily ET_c from network acquired data is determined by computing the daily reference ET (ET_{os} – Allen et al., 2005) from local meteorological data and multiplying that daily reference value by the respective, applicable crop coefficient (K_c), determined from lysimeter data through correlations per the various growth stage of each crop.

Meteorological parameters and crop growth behavior data continue to be needed within the Texas High Plains region outside the lysimeter vicinity to determine if applicability (over or under application of irrigation water) is being correctly estimated and irrigation adequately applied as predicted with the network-based estimates. Additionally, more year plant development differences, if any, that exist between the multiple planting dates for the corn crop need evaluation in addition to that recorded from the previous PIN I study (TWRI, 2006). Several crops were evaluated in the past PIN I study assessment, but this effort focused on corn which has been recently grown to the maximum degree again due to the increase in corn prices caused by the national energy crisis and resulting ethanol demand. This assessment, as conducted with the prior study, was to be evaluated by monitoring predicted versus field monitored crop growth stages as determined by the growing degree units (heat units) of the NPET “average-based” models. If there was a difference, quantification of the amount of the deviation was to be computed in terms of potential water savings by adjusting the network-based models as done in the previous study. It should again be noted that should an impact adjustment be required to the NPET corn model as a result of these assessments, changes would be based on multiple year’s research data and considering applicable producers data sets.

Should the difference turn out to be significantly large, a potential impact assessment as to how the difference would impact the next 50-year regional water plan irrigation demand estimates and an assessment using the adjusted ET_c values may be warranted in a subsequent and later project analysis. Segregation of differing corn models per regional area, such as North-South or East-West, in the Texas High Plains may be another challenge as complete research data sets do not exist and may never be adequately complete, unless a broad-based and targeted initiative to obtain such data is pursued and supported. Given the recent number of modifications to varieties by biotechnology in recent years, classification of varieties would be needed. The impact assessment analysis, if applicable, should be evaluated using Region A’s Texas A&M–Amarillo model since it is the current irrigation demand methodology used with the region’s water plan. Region A is defined as the Texas’ northernmost 21 counties (Figure 3-1). The region is known for intensively irrigated agriculture and uses nearly 90% of its water resources for irrigated production.

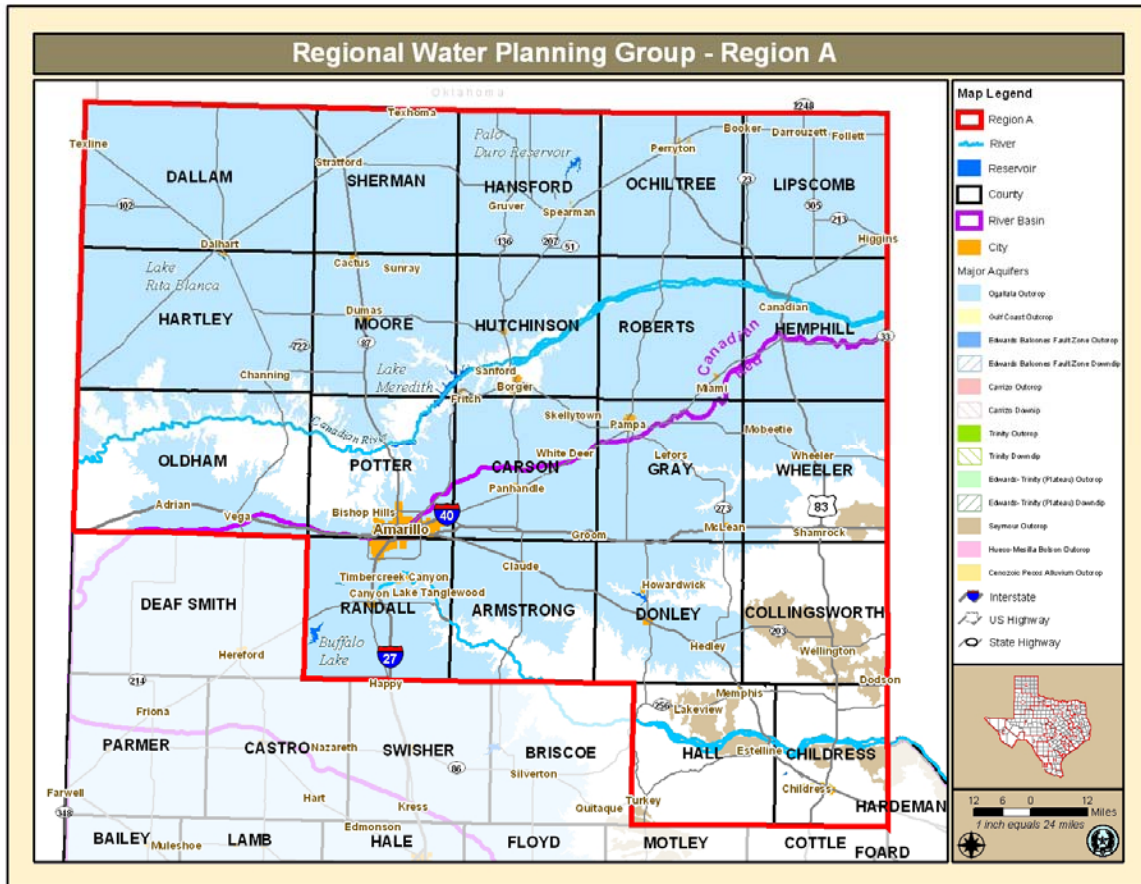


Figure 3-1. Region A as defined by the 75th Texas Legislature (TWDB, 2009)
http://www.twdb.state.tx.us/mapping/maps/pdf/rwpg/letter_size/Region%20A%208x11.pdf

The research part of this study task in 2007 and 2008 entailed only the crop of long-season corn. Location of the research plots was at Texas AgriLife Research’s North Plains Research Field (NPRF) north of Dumas, Texas whereby irrigation control could be maintained, and plots could be timely irrigated according to the NPET network computed irrigation requirements for Etter, Texas (an ET-based NPET station is located adjacent to the study plots). Crop stage development was assessed on a twice per week basis by field personnel. Each planting date of the corn had three replications and was established in a randomized block design for the four differing planting dates coinciding with the corn planting dates used in the NPET network. Irrigation water applied was monitored by totalizing meters on research plots and supplied from groundwater of the Ogallala aquifer. Rainfall at the Etter ET network station is recorded by a tipping bucket precipitation gage with 0.01 inch increment per tip.

Soil moisture conditions for 2007 and 2008 were initialized within the NPRF research plots at field capacity prior to planting. This action was initiated to establish a base level of soil profile moisture whereby a research-based checkbook type irrigation scheduler program was to be utilized. Plot size for each treatment was established at 30 feet wide by 200 feet long and segregated by 5 foot borders from adjacent plots. All crop plantings occurred on 30 inch beds. Soil moisture conditions were evaluated through gravimetric means. Yields were determined by hand harvesting a portion of each plot and adjusted to standard USDA corn moisture levels.

Using a long-season variety of corn in 2007, the research-based planting dates of April 16, May 1, and May 15 were implemented. The first planting date in 2007 was not accomplished due to early season rainfall. In 2008, the corn planting dates occurred on April 2, April 15, May 1, and May 14. These planting dates approximately coincided to those of the NPET network model with slight deviations due to weekend occurrences. Crop growth stage development (Figure 3-2) was monitored and adjusted according to the actual planting date by adding or reducing the respective number of



Figure 3-2. Differing growth stage view of the North Plains ET network based corn planting date plots at the North Plains Research Field near Etter, Texas.

cumulative growing degree units as compared to the closest planting date of the NPET network crop model. The crop variety of corn used in 2007 was Pioneer 33B49 and in 2008 it was Pioneer 33D47 RR2. The variety used in 2007 was no longer available in 2008, so a similar (length of maturity) variety with similar genetics was used as a replacement.

Irrigation scheduling was implemented throughout the growing season. Soil moisture depletion was targeted to an allowable maximum depletion of 60% for the corn before irrigation was conducted to replenish the soil profile and prevent undue stress. Maintenance of the desired level of irrigation along with the allowable soil depletion level was maintained throughout the season. In 2007, research-based irrigation applications tracked well with the NPET scheduling triggers. However, due to staff medical issues, an overall above irrigation resulted in 2008 in the early part of the season and, as expected, yields were subsequently reduced. The production level, while still considered excellent for the region, was suppressed by the early over-applications and leaching of nutrients from the soil profile.

The NPET network estimates crop ET by utilizing a set of growing degree day (GDD) based trigger tables to determine the stage of crop development along with a set of associated crop coefficient for various cereal grain crops. The NPET growth stage triggers and ancillary crop coefficients for long season corn are presented in Table 3-1.

Table 3-1. Current NPET growing degree day triggers for all four planting dates of stage development for long season corn.

Cumulative GDD	Corn stage	Crop Coefficient, K_c
200	seeded	0.25
350	emerged	0.35
515	4-leaf	0.45
675	4-leaf	0.7
850	6-leaf	0.85
975	8-leaf	1
1135	10-leaf	1.15
1295	12-leaf	1.2
1500	14-leaf	1.25
1575	tassel	1.25
1820	silk	1.3
2050	blister	1.3
2275	milk	1.3
2500	dough	1.2
2750	dent	1
3000	1/2 mat.	0.9
3400	blk lyr	0.7
3800	harvest	0

The GDD triggers in Table 3-1 along with the K_c 's are currently consistent for the NPET models for all corn planting dates, which is known to not exactly represent multiple-planting date crop development. However, research data prior to this and the prior PIN I study is not adequately available to adjust the values to a precision level as of yet, and one of the applications of this study is to provide potential insight into the planting date adjustments, as necessary. NPET network GDD heat unit calculations are derived from the literature and utilize maximum (T_{max}) and minimum (T_{min}) air temperatures to reflect conditions that a particular plant continues with normal growth functions. Daily temperatures above ($MaxT_{air}$) or below ($MinT_{air}$) these temperatures are considered not to contribute to plant growth and are computationally reset to T_{max} or T_{min} designated values. GDD accumulations are generally highly correlated to crop stage development. Thus GDD-based models can be relatively simple to use and calculate water consumption during any season using accurate K_c 's developed through scientific research and preferably using accurate lysimeter measurements.

The computation of daily GDD's is governed by the following conditions:

If $MaxT_{air} < T_{max}$ then $T_{max} = MaxT_{air}$,
 If $MaxT_{air} > T_{max}$ then $T_{max} = T_{max}$,
 If $MinT_{air} > T_{min}$ then $T_{min} = MinT_{air}$, and
 If $MinT_{air} < T_{min}$ then $T_{min} = T_{min}$

An additional constraint is:

If $MaxT_{air}$ and $MinT_{air} < T_{min}$ then T_{max} and $T_{min} = T_{min}$,
 where $GDD = ((T_{max} + T_{min}) / 2) - T_{min} = 0$.

The above set of equations is generally accepted in the scientific community and is the NPET method of calculation of GDD for all crops, including corn. Table 3-2 below depicts the generally accepted lower and upper bound growth temperatures of the NPET network for corn.

Table 3-2. Air temperature limits used in NPET GDD computations.

Crop	Tmax	Tmin	Tbase
Corn	86 °F	50 °F	50 °F

An example of GDD calculations for corn with a daily maximum temperature of 100°F and a daily minimum temperature of 56°F is illustrated below. The respective computations are:

Since $100^{\circ}\text{F} > 86^{\circ}\text{F}$, $T_{\text{max}} = 86^{\circ}\text{F}$, and
 since 56°F is not $< 50^{\circ}\text{F}$, $T_{\text{min}} = 56^{\circ}\text{F}$.

Thus, the daily corn heat units are: $((86 + 56) / 2 - 50) = 21$ GDD.

A comparison of the NPET model triggering values, based on average, mid-range crop development values, were compared to the monitored development stages of the corn plots at the NPRF. Differences were observed and computed in terms of GDD's to reach a particular growth stage. Subsequently, the K_c 's were adjusted in a stage adjusted model ("stage adjusted," SA, model or SAM). A stage adjusted model is defined herein as computed by summing the exact observed number of days per particular growth stage times the respective crop coefficient multiplied by the daily reference ET value. This "adjusted" computation is "exact" as to the crops development as opposed to the GDD triggered (NPET modeled) method of changing the crop coefficient when a particular development is achieved by accumulating a number of crop GDD's.

Using the crop coefficients of Table 3-1 to compute a stage adjusted growth development ET value. The ET values were compared to the estimated NPET ET model values and the difference in water use between the predicted and observed calculated. This shifted or stage adjusted model ET, if less than the predicted NPET value, would represent a potential reduction in irrigation quantity (demand) required to meet full crop ET. If the stage adjusted value was larger than the NPET model value, the NPET ET values predicted are "shorting" the corn to meet full ET_c based on the observed study data. In essence, the SAM represents the "exact" growth model witnessed in the field and represents the "actual" related ET_{co} for corn for that growing year and conditions. (Note that the SAM ET data can only be derived in a near real-time to post-season aspect empirically and for the exact growing conditions as monitored, which is why predictive models are usually used for regional estimation applications).

Crop development observations were conducted on grower's fields within the NPRF vicinity. Area growers' fields were monitored and the study data compared with producers' water-use and corn growth stage data. The total amount of irrigation applied in producer's fields and as compared to the NPET was obtained through totaling the number of irrigation events throughout the growing season. Each irrigation event per producer was recorded throughout the growing season by crop personnel cooperating with the NPRF. Each event measurement was determined

either through a metered or revolution monitored process yielding a depth of irrigation applied per event. Since center pivot systems today have flow and pressure monitoring capability, depth application is selectable and maintainable with these units. For units without flow monitoring capability, the producers' respective system design nozzling sheets assisted in determining application depth per rotational setting and by monitoring system pressure(s). Field verification of the respective applications throughout the season was obtained through soil sampling. The anticipated target was that a net reduction in irrigation water applied could be demonstrated or achieved without adversely affecting production as compared to 100% ET_{co} (reference crop ET notation using a grass cover crop) estimated by NPET.

RESULTS

The summer 2007 growing season at the NPRF seemingly appeared to be a desirable production year for corn considering the number of rainfall events (and high price of pumping energy). This perception was supported by the lack of consistent above 100°F days as experienced in years past. Several small rain events less than 0.5 inches occurred but were not “counted” as contributing to soil moisture profile storage but were rather reflected in the research-based irrigation scheduling program by reduction of the ET demand on the following day (technically by reducing the vapor pressure deficit of the previous days meteorological data). The 2007 NPRF distribution of precipitation recorded for the summer growing season is presented in Figure 3-3. A total effective amount of 7.32 inches of rainfall contributed to the NPRF plot corn production. This rainfall amount however only represented 21.4% of the seasonal crop ET need.

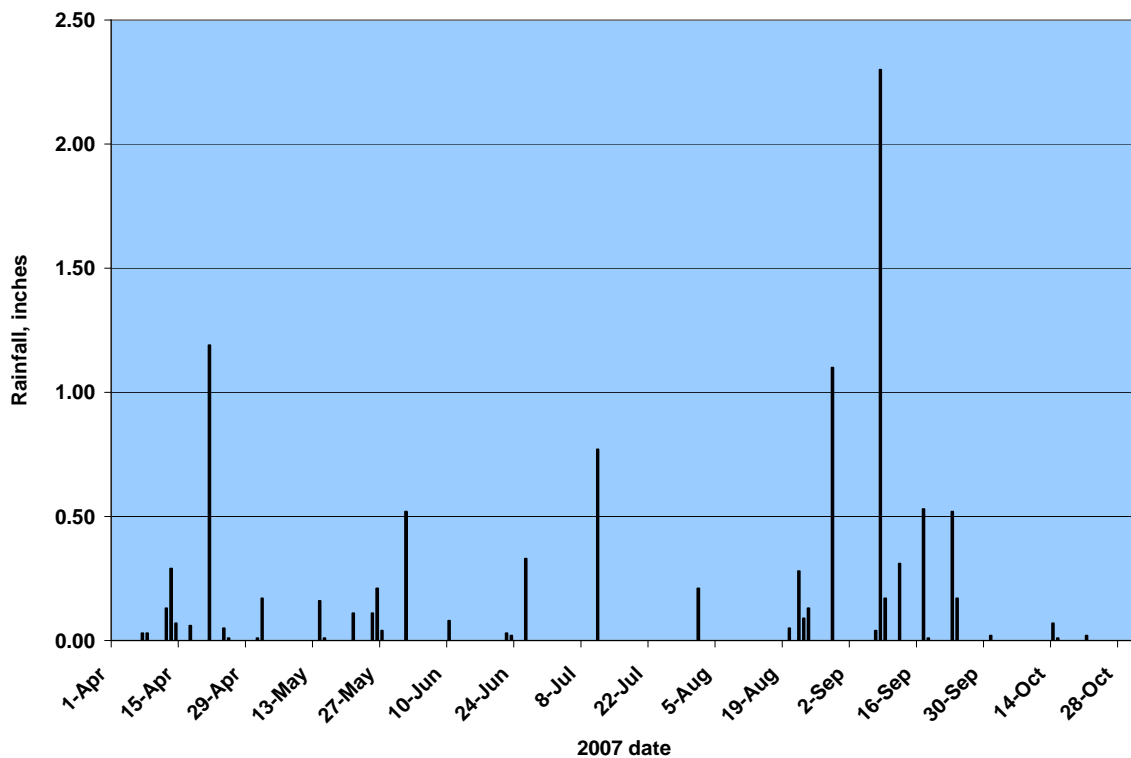


Figure 3-3. 2007 summer crops rainfall at the North Plains Research Field.

Viewing Figure 3-4 below, in 2008, a similar apparent “good rainfall” year for corn production was experienced during the early portion of the growing season, even though a number of 100°F days were incurred during this season. The large, late rainfall events in October did not significantly contribute to corn development or yield production. A total effective amount of 6.1 inches of rainfall was attributed to the research corn production plots. This rainfall amount only represented 16% of the seasonal crop ET need.

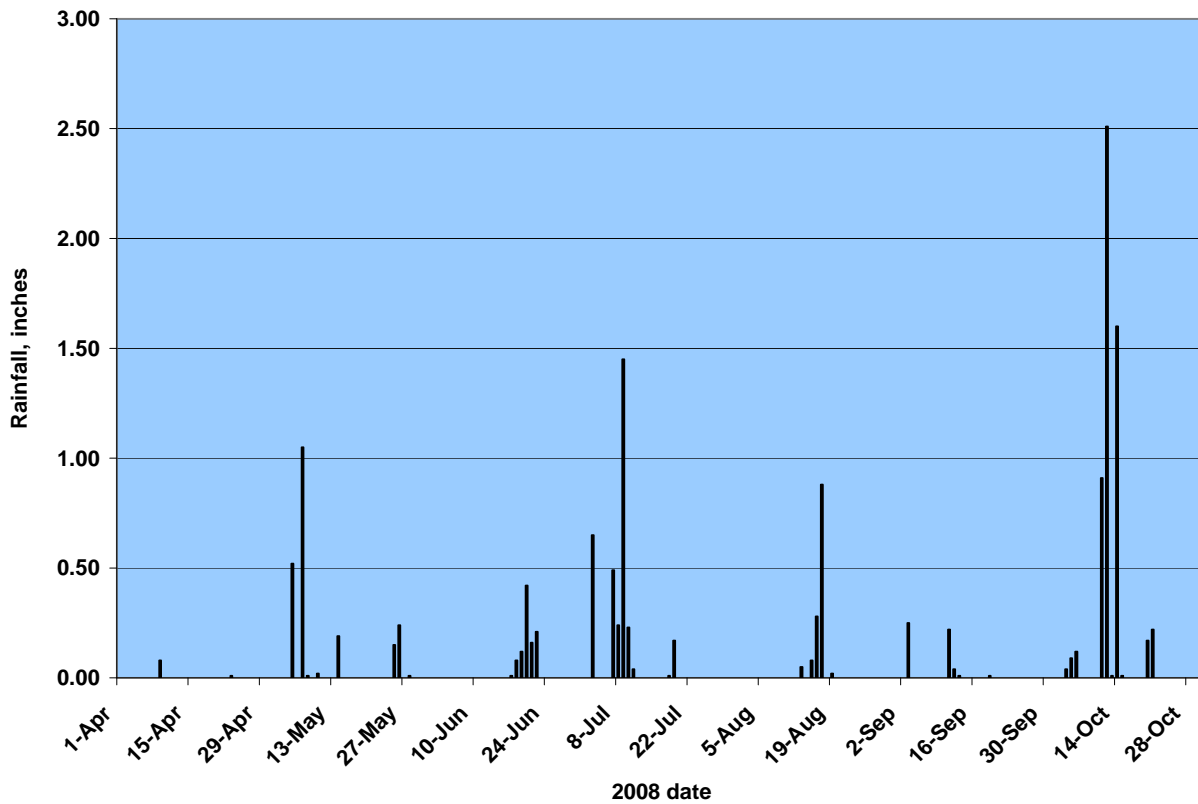


Figure 3-4. 2008 summer crops rainfall at the North Plains Research Field.

The daily 2007 and 2008 ET_{os} (reference ET notation for meteorological stations with a grass cover crop) data is presented in Figures 3-5 and 3-6. Although the 2007 and 2008 seasons seemingly appeared to be less than “normal” ET_{os} demand years from the daily ET_{os} values, partly due to rainfall influencing the overall seasonal meteorological conditions, the cumulative crop ET’s were actually above average in terms of demand (see tables later and appendix data).

Only selected comparisons will be illustrated and summarily discussed within the results section regarding planting date comparisons of NPRF research plot data. The discussion will generally be limited to planting date (PD) 2 of the 2008 season but applies to the other planting dates as well. Additional data for the PDs of 2007 and for the other PDs of 2008 are included in the Appendix A. It should be noted that PD2 is not exclusively representative of the mean planting dates within the NPRF (Dumas, Texas) area and all planting dates need to be considered and evaluated, particularly to determine any valid water savings inference for the area or region.

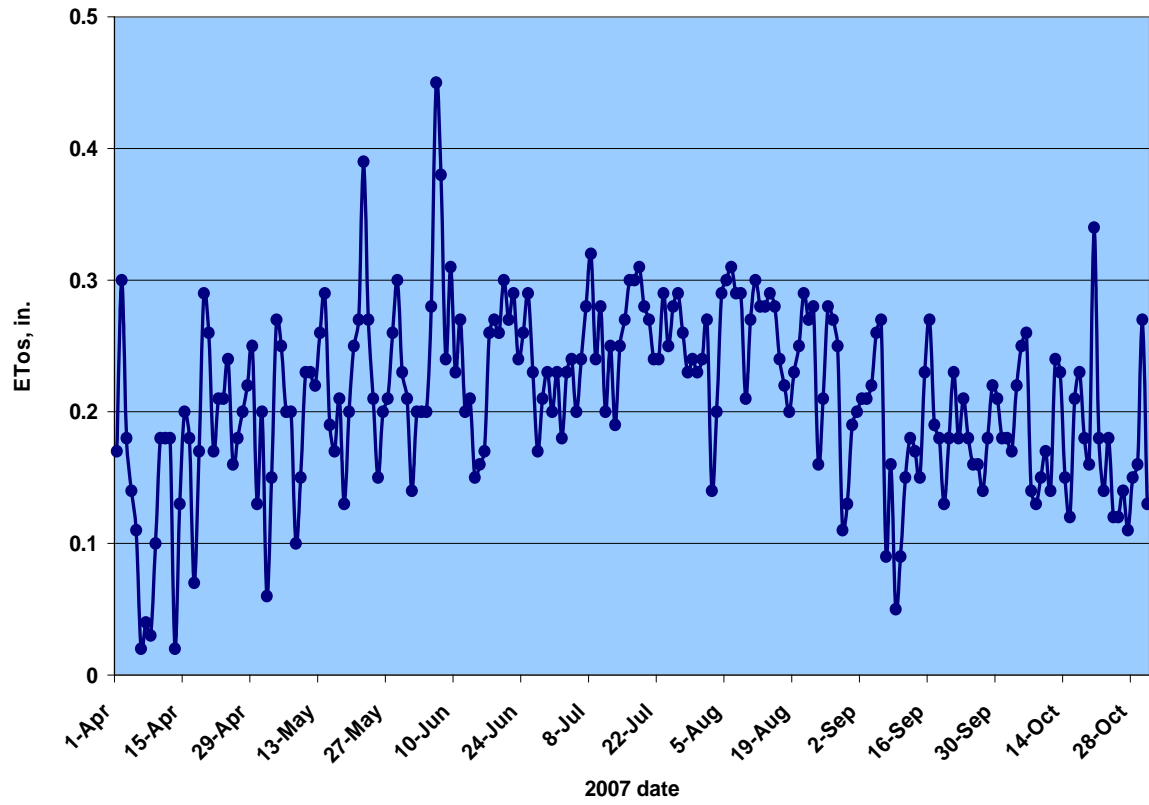


Figure 3-5. 2007 summer crops ET_{os} computed at the North Plains Research Field.

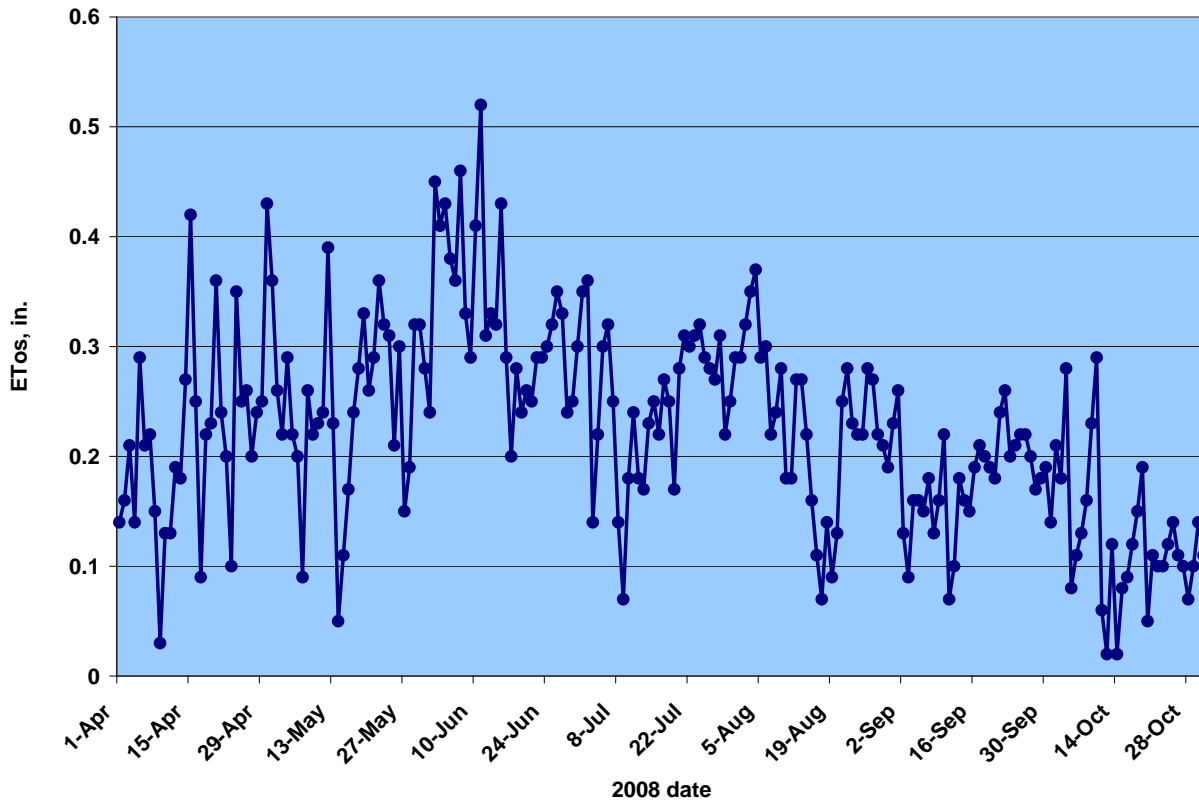


Figure 3-6. 2008 summer crops ET_{os} computed at the North Plains Research Field.

One of the most common methods of verification of the applicability and representation of a predictive model is that of comparing the predicted to the actual or monitored occurrence of events. With regards to the NPET corn model, a comparison of the monitored development as compared to the predicted based on the GDD triggers is evaluated. The process of adjusting the NPET model in this analysis against the monitored crop development technique again is referred to as “stage adjusted” (SA) and results in a stage adjusted model (SAM) ET computation. It is referred to as stage adjusted technique because the process involves adjusting the K_c to the observed date of growth stage development as compared to the stage triggering value using the NPET average based, GDD development table.

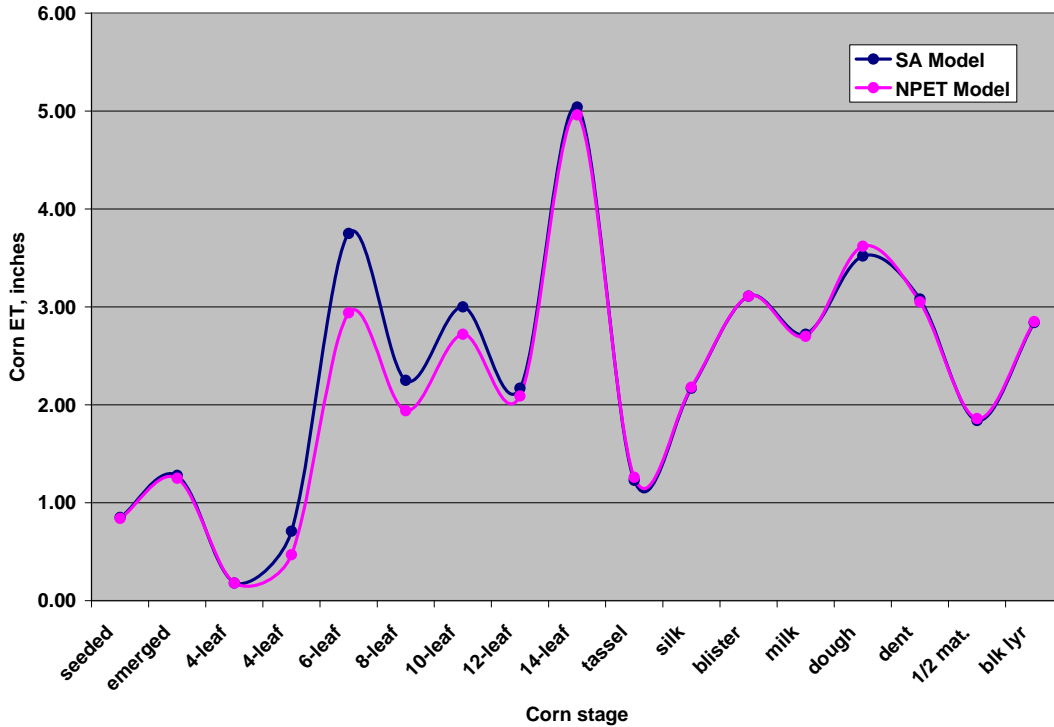


Figure 3-7. NPET model and stage adjusted ET values per corn stage for planting date 2 in 2008.

The stage adjusted ET_{co} values and difference as compared to the NPET ET_{co} model for the 2008 PD2 of corn is shown in Figure 3-7 and shows excellent agreement. Early in the growth stages, the NPET model under-predicted corn ET_{co} values. (Other year and planting date comparisons are included in the Appendix A). While year 2008 comparisons agreed well for all planting dates, 2007 was a differing year and comparison agreement was not as good as in 2008.

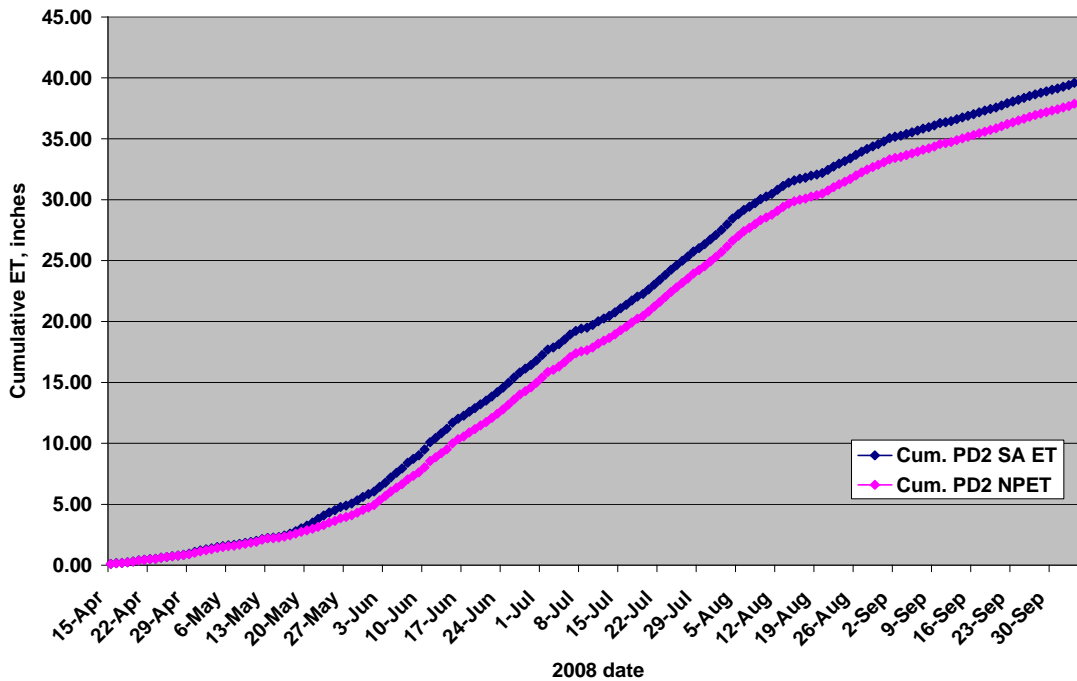


Figure 3-8. 2008 comparison of cumulative corn ET of the NPET model and observed, stage adjusted ET from NPRF study for NPET network planting date 2.

The cumulative effect of the NPET ET_{co} model deviations as compared to the SA model early in the season is apparent in Figure 3-8 and is relatively minor; however, the difference is never compensated for throughout the rest of the observed corn season. Nonetheless, there is again excellent agreement between the predicted versus plot observed cumulative ET values.

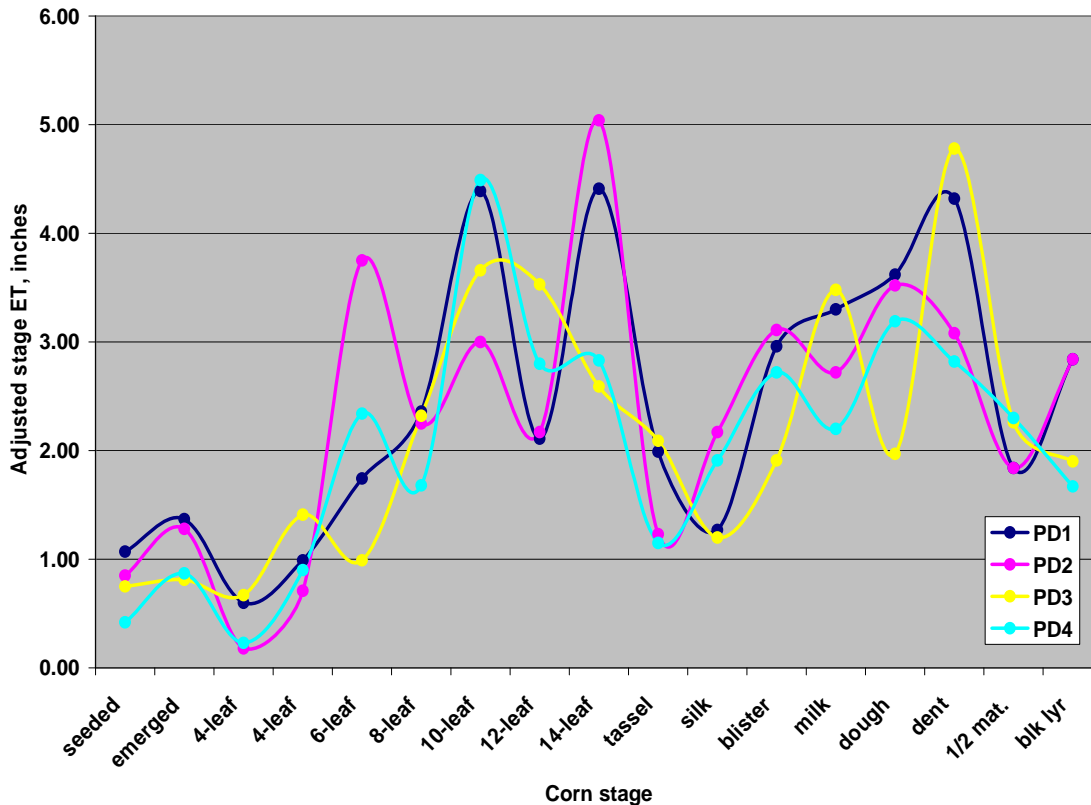


Figure 3-9. Comparison of the stage adjusted corn ET requirements per stage per planting date for 2008 season.

The stage adjusted model ET_{co} comparison of all the planting dates in 2008 as computed from the monitored (observed) data is presented in Figure 3-9. As expected, some deviations were expected with the respective development stages, but overall “behavior” of the respective four planting date ET’s appears to be poor and varied more wildly than anticipated or desired. What was expected was that a family of curves would result with some degree of generalized separation being between the respective planting date lines (as from the seeded to 4 leaf stage). Due to growth stages of the observed corn being realized at a quicker pace than other PD’s in the SA model, some crossing was expected (e.g., emerged and 4 leaf stages) as an adjustment of the stage associated K_c and value was made, but more consistency among the PD lines was anticipated. Additionally, when applying the associated K_c sooner than in the NPET ET_{co} model, the computation should result in a lesser ET_{co} for that stage. This is generally the result of days of duration per stage being less as the corn develops sooner than predicted and greater if the corn develops later than predicted. While the PD comparisons in Figure 3-8 appear confusing, the lack of congruency between the respective lines could partly be attributed to the application of Table 3-1 uniformly for all PDs, as mentioned earlier. It would appear logical that corn planted at a later date would “expedite” some stages generally with a lower number of GDD’s when planted later than the optimal time of a typical growing season. In fact, it has been observed in past research that extreme late planted corn (beyond the nominal period of the growing season) “races” through development stages (sacrificing height and yield) to produce some reproductive

degree of yield. The other potential confounding factor to this plot is possibly the event(s) of rainfall alteration at the respective growth stage to the ET_{co} of the different planting dates.

Table 3-3. Summary of observed versus stage adjusted corn ET for NPRF research plots.

Year and PD	NPET model ET, inches	Stage adjusted ET , inches	Difference, Inches*
2007- 2	34.18	41.15	-6.97
2007- 3	32.05	40.36	-8.31
2007- 4	29.52	36.24	-6.72
2008-1	39.31	41.18	-1.87
2008-2	38.02	39.74	-1.72
2008-3	35.07	36.32	-1.25
2008-4	32.59	34.52	-1.93
Average	34.39	38.50	-4.11

*Difference is computed with reference to the NPET ET_{co} values.

Subsequent tabular and graphical planting date comparisons of the GDD's, daily ET and cumulative ET values for corn are provided in the Appendix A. The average difference between the NPET model and the SAM ET values generally were about 2 to 3 inches with the corn planting dates. The data of these comparisons indicate that not enough total water was applied for full corn ET using the SA model computations. The level of water estimated by the SA model appears high given the production level of both the research field plots and that of the area producers using only a percentage of the NPET model ET_{co} . It is apparent that the deficiency in calculating a (sound and theoretically based) SAM ET value, is that the current assumed uniform GDD versus stage growth (Table 3-1) does adequately represent the four planting dates in the NPRF region and more lysimeter or equivalent ET_{co} data is needed. The difference could also potentially be due to improved and altered genetics being used today as compared to the variety of the original ET_{co} network values years ago. Proposed biotechnology and genetic alterations in the near future will only increase support for revised K_c values.

Table 3-4. Corn production levels and ET_{co} of planting dates at the NPRF in 2007 and 2008.

Year and PD	Planting Date	Production Level* bu/ac	Stage adjusted ET, in.	ET difference, from year PD4, in.
2007-2	16-Apr	226	41.2	5.0
2007-3	1-May	224	40.4	4.2
2007-4	15-May	206	36.2	--
2008-1	2-Apr	247.67	41.2	6.7
2008-2	15-Apr	266.37	39.7	5.2
2008-3	1-May	242.66	36.3	1.8
2008-4	14-May	267.95	34.5	--

From a comparison of the respective NPET planting dates in 2007 (Table 3-4), it would appear that water savings could be attained by implementing a delayed or latter corn planting date. This was also witnessed in the earlier 2006 PIN I study at the NPRF. Typically, the highest yield production has been experienced with an earlier planting date and progressively decreases through the 4th planting. This did not happen in 2008 as August had an abnormally “shaded” month for photosynthesis development. It should be mentioned that in northern Texas High Plains practice, producer plantings take several weeks (with harvest requiring additional time) due to the large acreages involved, and few producers meet full corn ET requirements throughout the season. Furthermore, the post-season, weather-related risks of high winds, fall rains, hail and snow events present harvest and operational concerns for producers when considering major production shifts through altered corn planting dates. Additionally, non-contracted corn production sales price trend decreases as harvest season progresses, so a latter harvest period would impact profitability as well. Lastly, a later or delayed corn planting trend can have rotational consequence to the follow-up wheat cropping practice following corn. Nonetheless, a reduced ET_{co} could be considered for producers using a later planting date.

Grower comparisons

Several local producers’ crops were monitored and compared to the development data of the NPRF study. In all, 11 in 2007 and 10 in 2008 producers’ fields were monitored, as compared to the targeted number of 4 to 6. The producer field summary is presented in Tables 3-5 and 3-6. Producer stage adjusted comparison results as compared to NPET model values indicated that there was less than 1.2% difference in 2008 for corn. In 2007, there was less than a 7% difference. It appears that the selected producers’ fields matched the NPET values more closely than the NPRF research plots and could be attributed to a lower and different irrigation event pattern as well as maturity differences due to differing varieties among the various producers and fields.

Table 3-5. 2007 NPRF area producer crop summary.

Field ID	Crop	Planting date	Planted Area, acres	Irrigation applied, inches	NPET model ET, inches	Water savings, *, ac-in	Water savings, *, %
A	Corn	20-Apr	120	27.3	38.0	409	9.0
B	Corn	29-Apr	120	22.1	39.0	1,288	27.5
C	Corn	5-May	120	25.6	40.1	1,004	20.9
D	Corn	7-May	480	21.6	39.5	5,650	29.8
E	Corn	17-May	380	19.2	39.3	5,339	35.7
F	Corn	23-May	380	14.3	38.2	6,749	46.5
G	GS	14-May	240	18.0	33.4	2,220	27.7
H	GS	24-May	65	18.4	21.7	-140	-9.9
I	GS	10-Jun	120	19.4	26.8	218	6.8
J	Cotton	10-May	110	9.1	25.3	1,114	40.0
K	Cotton	13-May	120	8.8	26.4	1,369	43.3
Total			2,255			25,220	

* Savings are based in reference to seasonal NPET network crop ET (ET_{co}) demands.

Table 3-6. 2008 NPRF area producer crop summary.

Field ID	Crop	Planting date	Planted Area, acres	Irrigation applied, inches	NPET model ET, inches	Water savings, *, ac-in	Water savings, *, %
A	Corn	15-Apr	120	27.7	37.2	403	9.0
B	Corn	16-Apr	240	24.1	37.0	1,625	18.3
C	Corn	17-May	240	20.9	36.6	2,292	26.1
D	Corn	19-Apr	120	26.5	36.6	479	10.9
E	Corn	23-Apr	480	24.0	35.2	2,448	14.5
F	Corn	28-Apr	120	24.3	35.7	636	14.8
G	Corn	1-May	120	23.1	36.0	811	18.8
H	GS	20-May	120	19.1	26.4	334	10.5
I	GS	30-May	120	21.4	24.1	-224	-7.8
J	Cotton	15-May	120	11.2	25.1	1,128	37.4
Total			1,800			9,932	

* Savings are based in reference to seasonal NPET network crop ET (ET_c) demands.

Technology Transfer

This study effort was mentioned at the Wheat Ag Day (Marek, et al., 2007- see Figure 3-10) conducted at the NPRF and discussed with area producers at the NPRF Ag Day on August 7, 2008. The 2008 Ag Day (Figure 3-11) was attended by several of the area's large production growers, area water district directors (who are also producers) and by area state representatives. Other farmers from south of Amarillo attended the function as well. A total of 81 persons attended the event, with 25 being large irrigated producers. A representative of TWDB (Cameron Turner) was present and was acknowledged during the luncheon for the TWDB's support of the study. Field signage was also displayed at the research plot site with credit of sponsorship by the TWDB. Local radio, newspaper and TV stations covered the Ag Day event with excellent media coverage for a period of 2 weeks past the event.



Figure 3-10. Thomas Marek at 2007 NPRF Ag. Day discussing new district pumping regulation along with district personnel.



Figure 3-11. 2008 NPRF Corn Field Day.

As outlined in the Task 2 scope of work, a user's manual explaining the use of ET for producers was drafted for use with the NPET network (plus South Plains ET and TXHPET) and is also included in the Appendix B. It is entitled "*Understanding ET and Its Use in Irrigation Scheduling*" and explains the basis of ET and its application in irrigation scheduling. This information is to become part of the ongoing TXHPET user manual series. The TXHPET user manual series refers to a series of manuals and how-to videos and audio clips that has began and are being developed to assist irrigated producers and agricultural users to navigate and utilize TXHPET, NPET and SPET web site information and other agricultural materials in the most simplified and useful manner for their respective regional uses. The TXHPET development team is currently under TWDB grant award for further development of several of these informational tools. An electronic draft of the "*Understanding ET and Its Use in Irrigation Scheduling*" manual is currently available at <http://amarillo2.tamu.edu/ET101/>.

CONCLUSION

It should be recalled that the NPET models are based on "average" GDD trigger data derived from several years of observations from lysimeter research data. Evaluating the data pattern regarding predicted and observed cumulative ET based on the multiple year's staged adjusted years data, changes to the network triggers are not immediately warranted from this data alone for the NPET corn models. The data gathered from this study appears to indicate that the assumption of the uniform GDD versus corn growth development for all PDs needs more

lysimeter research and propagation of the multiple PD development tables for a long season corn variety. Note however that this study data and results do not diminish the value of the use NPET models as they still provide the best available and representative basis of irrigation scheduling and a benchmark from which to calculate ET_{co} use against. While the models may have site-specific errors in any given year, the network models provide a valuable resource for regional and groundwater district based water planning efforts.

From the producer data gathered, it is apparent that area producers have and are continuing to be ET-conscious as well as water conservation-conscious as they are using less than full ET_{co} requirements, thereby conserving groundwater resources for future generations as well as for other uses. This is being accomplished while still apparently remaining profitable in their operations.

CHAPTER 4: Decision Support Systems Validation and Calibration

BACKGROUND

Data from the Wintergarden and High Plains was supplied seasonally to personnel at the Texas AgriLife Blackland Research and Extension Center at Temple in charge of DSS validation and calibration. This input was incorporated into the CroPMan model for future DSS use. Using the crop production and management information obtained in the on-farm evaluations, this task determined the effectiveness of CroPMan and Crop ET for optimizing the timing and quantity of in-season irrigation. In addition, analytical capabilities of CroPMan were assessed to pre-test alternative management scenarios that fit the individual grower's situation and identify practices and/or farming systems to optimize production.

Wintergarden corn, cotton and spinach data were submitted by Giovanni Piccinni, Daniel Leskovar, Jonghan Ko and Beth Zaiglin at the Texas AgriLife Research and Extension Center at Uvalde. High Plains data was submitted by Thomas Marek at Texas AgriLife Research and Extension Center at Amarillo.

For the Wintergarden, information from 22 growers was compiled for the 2006 crop year including current-year cropping operations, yield, soil type, irrigation type, fuel type used, pumping depth and precipitation. Soil type and weather data for each field along with the cropping budgets were used to create simulation runs. Crop growth parameters were calibrated using cropping practice data supplied by Giovanni Piccinni and Daniel Leskovar. Crop parameters were adjusted accordingly in order to make simulation yields come closer in value to actual yields. Alternative irrigation management scenarios were constructed, and an economic analysis was made for each scenario to determine profitability of each scenario. Several analyses of case studies were prepared for the PIN I Workshop in which individual fields were analyzed for potential irrigation water savings and profitability in 2006. Presentations were given to producers with specific examples from demonstration farms. Crop simulation results for crops included location, soil type, crop, planting and harvest date, nitrogen applied, phosphorus applied and irrigation required. Simulated versus measured yields were compared and example water mark sensor readings were presented. This "Growers' Portfolio" was given out in 2006 for the summer crops during PIN I, right before PIN II began.

Data from 15 to 20 producers in the Wintergarden region was collected for the 2007 crop year including irrigation dates and amounts, previous cropping system, tillage dates, planting date, plant population and row spacing, fertilization dates and amounts, precipitation dates and amounts, and yield. Data was for cotton, sorghum and corn depending on each producer's cropping system.

The Wintergarden growing season of 2006 was very dry, so there was not a noticeable and widespread problem of over irrigating. In one of the case studies, however, irrigation on corn could have been reduced by one-eighth or 3 inches and profits would have been increased slightly over those estimated for the actual irrigation application rate. For all other cases, irrigating at a higher rate on both corn and cotton would have increased profitability. These results were presented to the producers at a PIN meeting in October.

In 2007, on the other hand, a tremendous amount of rainfall was received and in many cases little, if any, irrigation was needed to maintain the crop's water needs. In this case we would expect that the simulation results may show a potential for saving irrigation water, and if so, the resulting impact on profitability of the water conservation strategies. In the first case study, yields were simulated based on various irrigation levels. Based on the amount of irrigation that the producer applied, he yielded approximately 150 bu/acre (base). By applying five more inches of water he could have increased his corn yield by 7 bu/acre. See Figure 4-1.

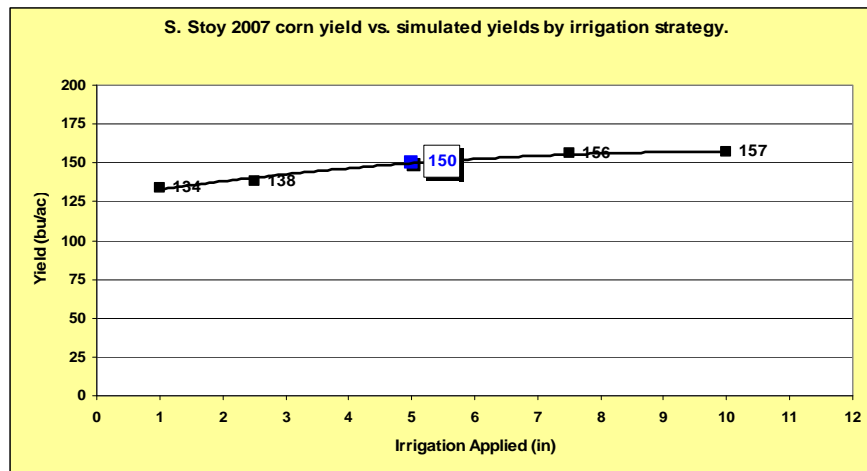


Figure 4-1. Corn yield as a function of irrigation applied, case study #1.

Taking into account all the expenses associated with irrigating the corn, the producer could have actually maximized his profit with only two and a half more inches of water (Figure 4-2). With this additional water, he could have increased his profit by approximately \$5/acre. This is a fairly insignificant amount, and in this case the producer did an excellent job of managing his irrigation.

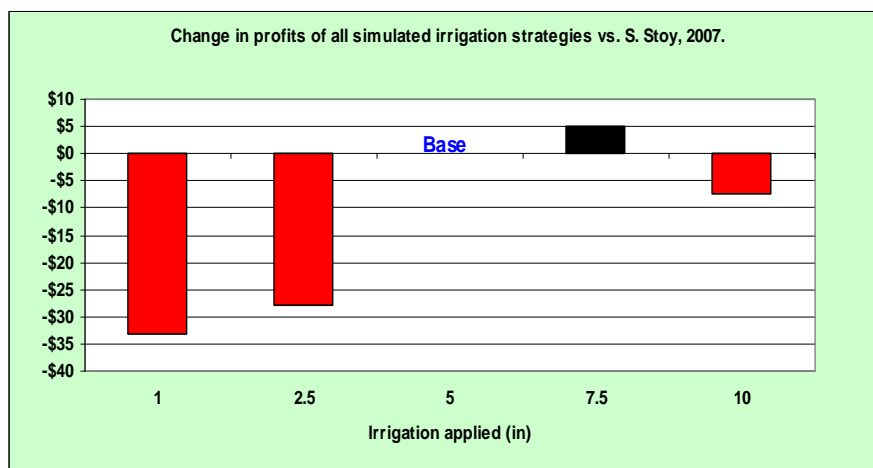


Figure 4-2. Change in profits for all simulated irrigation strategies, case study #1.

The second case study was much like the first. The producer applied 6 inches of irrigation to his corn crop and yielded 160 bu/acre (base). He could have maximized his yield by applying ten inches increasing his yield by 8 bu/acre (Figure 4-3).

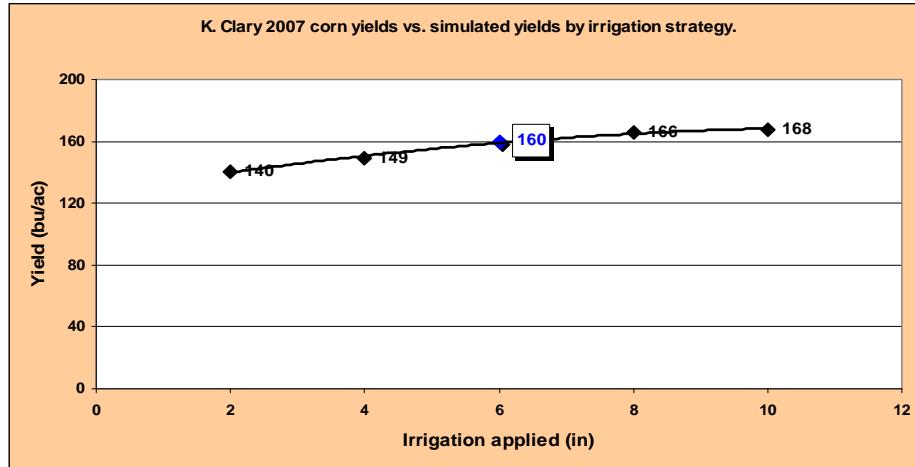


Figure 4-3. Corn yield as a function of irrigation applied, case study #2.

Again, the expenses associated with irrigating the corn were analyzed; in this case it was determined that the producer could have maximized his profit with only two additional inches of water (Figure 4-4). With this additional water, he could have increased his profit by approximately \$6/acre. It appears that the producer did an excellent job of managing his irrigation during the 2007 growing season.

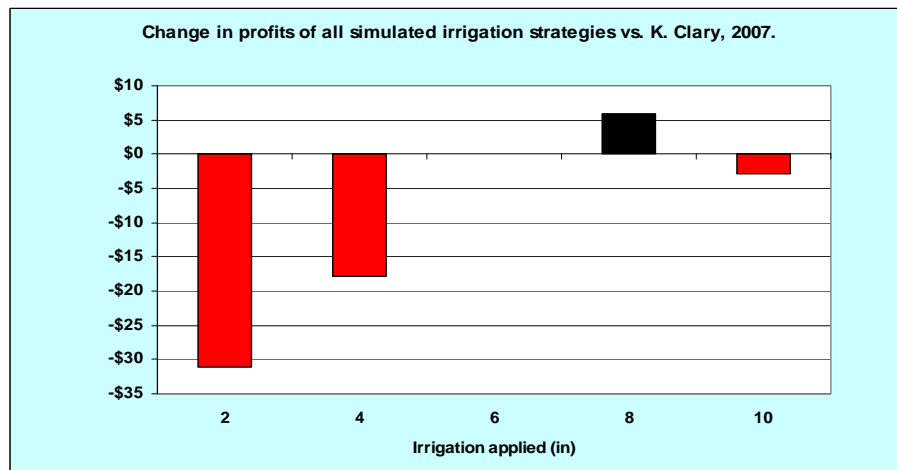


Figure 4-4. Change in profits for all simulated irrigation strategies, case study #2.

Similar data was collected from the Thomas Marek in the High Plains region and used for model calibration and validation. Cropping practice and yield data from the High Plains was received

for use in validating CroPMan using crop yields of corn and wheat produced from 2003-2007. Alternative irrigation and fertilization management scenarios were analyzed and reported. This data was used to construct simulation runs in CroPMan/WinEPIC for calibration of the model for the High Plains. Throughout the two-year span of the project 21 grower fields were involved in the High Plains demonstration.

Model Updates

Project activities consisted of updating the WinEPIC model for future uses. This process required changing over to a new EPIC executable and adding it into the CroPMan/WinEPIC interfaces available at <http://cropman.brc.tamus.edu>.

A new and improved version of the EPIC model was released by Jimmy Williams, the primary developer of EPIC. Williams is not directly involved with the PIN 2 project, but modelers worked closely with him in developing and improving the EPIC model. EPIC is the model engine for CroPMan as well as WinEPIC, another interface developed mainly for use by researchers and scientists with a greater knowledge of plant physiology and the influence of the environment on plant growth. Version changes included adding new parameters for:

- Lower limit of the Natural Resources Conservation Service (NRCS) curve number
- Change in the power of day length as it influences leaf area development
- Upper limit for nitrogen fixation
- Upper limit of daily crop nitrogen uptake

Activities focused on calibrating the new and improved version of EPIC to predict the experimental and producer yields of grain sorghum, corn and cotton. The calibration was based on specific yield data for a select set of years. Figure 4-5 is one example of that calibration and the resulting validation.

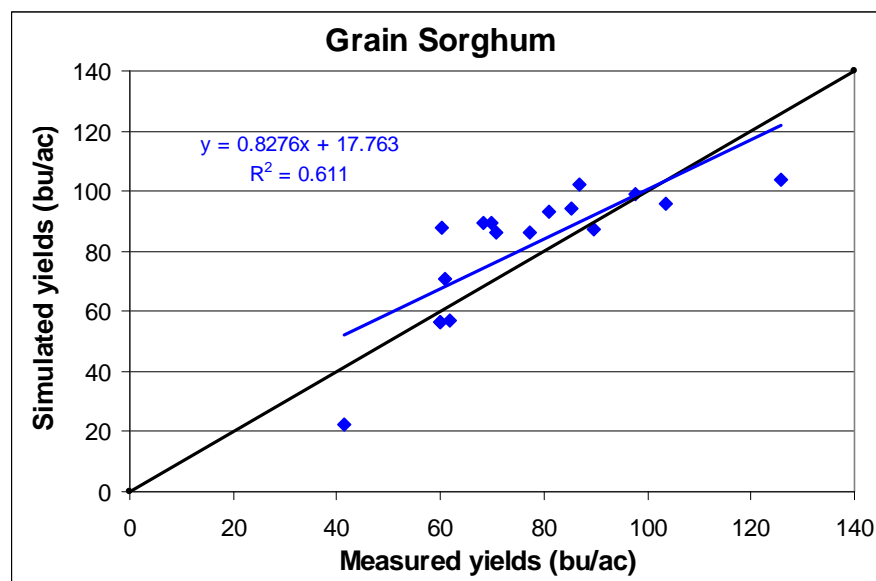


Figure 4-5. EPIC calibration and resulting validation for grain sorghum in Texas Wintergarden region.

Equations and parameters were also added in preparation for adding RUSLE2, which is a modified version of the RUSLE model. Both of these methods are empirical methods used to estimate soil erosion by water. This new version was incorporated into the CroPMan interface and enabled modelers to gain more accuracy in simulating the cropping systems of interest. This was also used to analyze 2007 crop yields and simulate alternative irrigation management strategies.

Using the updated version of CroPMan, 2007 crop yields were analyzed and alternative irrigation management strategies were simulated. Results were presented at Uvalde Texas Agricultural Irrigation Association (TAIA) meeting in February 2008. Producers were also presented with:

- An irrigation strategy decision-aid tool known as Irrig-Aid, which is an Excel worksheet designed to provide irrigated producers with a convenient web-based tool to assess crop yield and profit impacts of allocating water between alternative crops.
- Another potential web-based in-season irrigation management tool known as the Soil Water Management Tool which uses the EPIC crop simulation model as an engine. This tool has already been developed for the Lower Rio Grande Valley area of Texas.

RESULTS

High Plains Region

Cropping practice and yield data were received from Thomas Marek at Texas AgriLife Research and Extension Center at Amarillo for corn produced in the Texas High Plains in 2008. Cropping practice data included fertilizer amounts and dates applied, planting date, row spacing, plant population, irrigation amounts and dates applied, harvest date, and moisture content of yield at harvest. This data was used to construct simulation runs in CroPMan/WinEPIC in order to determine if alternate irrigation strategies were possible.

Through the simulation of the data provided for 2008 High Plains corn, the model indicated the corn crop experienced several days of aeration stress due to the amount of irrigation applied and the physical properties of the soil (low saturated conductivity and poor infiltration), which inhibited the crop from reaching its full potential. Through “what-if” simulations, it was determined yield could be maintained with less irrigation by applying less often. Table 4-1 illustrates this point.

Table 4-1. Simulated yields at varying irrigation levels for four sites in Texas High Plains.

Site 1			Site 2		
Simulated Yield ‡, bu/ac	Irrigation applied, inches/ac	Aeration Stress, days	Simulated Yield ‡, bu/ac	Irrigation applied, inches/ac	Aeration Stress, days
219	38.38*	6.8	214	38.96*	9.1
223	30	0	219	30	0
213	25	0	214	25	0
193	22	0	193	22	0
Site 3			Site 4		
Simulated Yield ‡, bu/ac	Irrigation applied, inches/ac	Aeration Stress, days	Simulated Yield ‡, bu/ac	Irrigation applied, inches/ac	Aeration Stress, days
217	40.68*	7.1	217	38.04*	6.5
213	27	0	211	27	0.1
211	25	0	206	25	0
194	22	0	184	22	0
‡ yields are reported as dry weights, 0% moisture					
* actual irrigation amount applied during growing season					

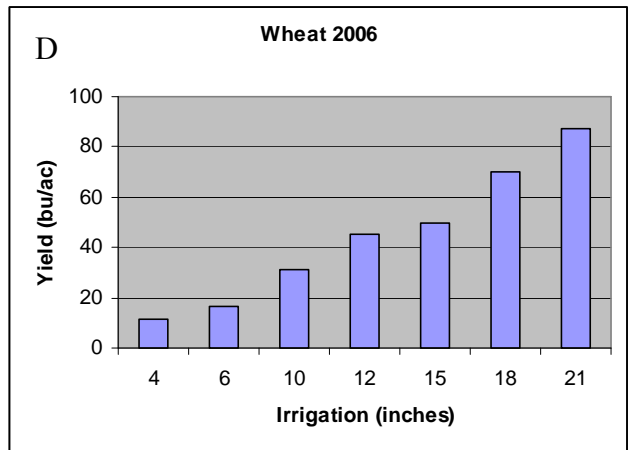
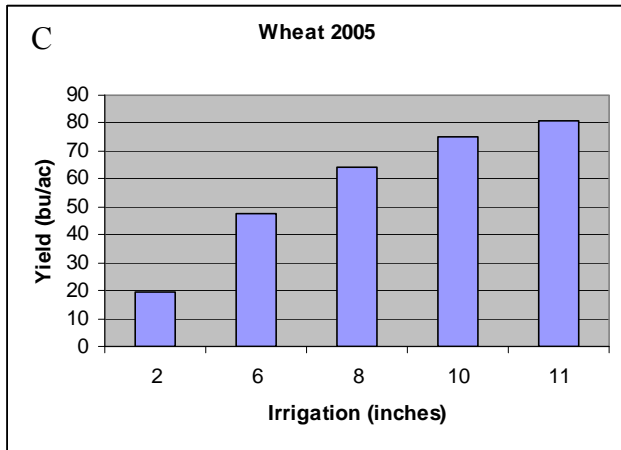
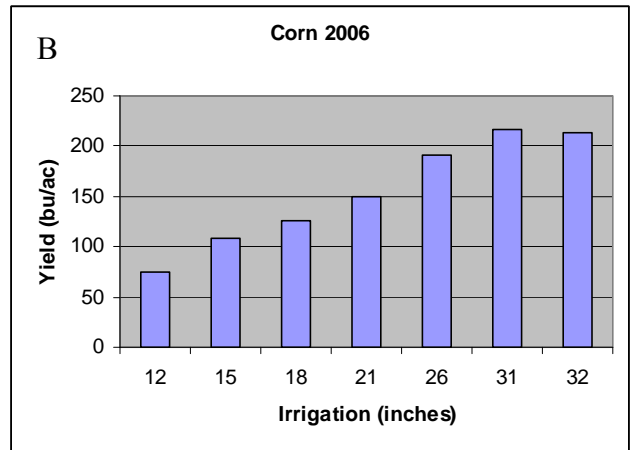
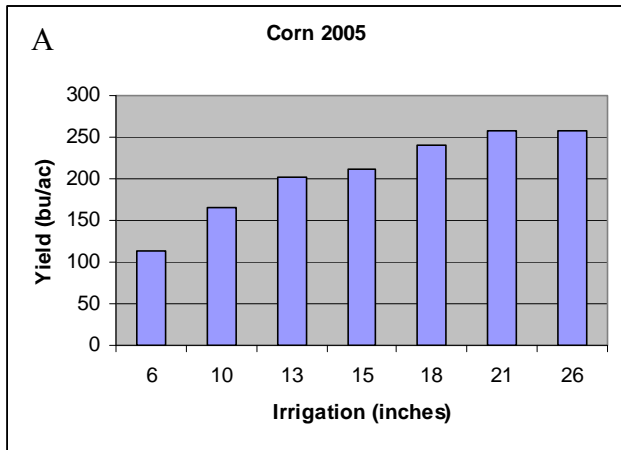
According to Table 4-1, Site 1 and 2 yields could have been maintained by applying only 30 inches of irrigation per acre. This would have been a savings of over 8 inches per acre per site. Site 3 and 4 simulations indicated the crop yield could have been maintained with 27 inches of irrigation. This amounts to a savings of more than 11 inches per acre per site.

Table 4-2 shows measured and simulated yields for corn and wheat. In all cases except two (2007 wheat and 2004 corn), simulated yields compared very closely to measured yields indicating the model's ability to simulate crop yields under varying scenarios.

Table 4-2. Comparison of measured and simulated yields for corn and wheat in the Texas High Plains.

Crop	Year	Measured dry yield (bu/ac)	Simulated dry yield (bu/ac)
Wheat	2003	43.1	41.2
	2004	37.6	42.3
	2005	26.8	28.5
	2006	15.8	17.1
	2007	28.4	42.2
Corn	2004	131.8	191.6
	2005	136.6	130.8
	2006	208.0	212.5
	2007	191.3	197.0

After model calibration, alternative irrigation and fertilization management was analyzed to determine the amount of irrigation and fertilization required. Two scenarios were chosen from both wheat and corn to illustrate this optimization. Figures 4-6A–D illustrate the potential yield at varying irrigation levels given a rate of nitrogen fertilization ample to prevent any nitrogen stress. Daily weather data from nearby weather stations were used in the simulations. Irrigation levels were chosen based on auto irrigation and fertilization simulations for each of the crop-year combinations.



Figures 4-6A–D. Simulated yield at varying irrigation levels based on non-limiting nitrogen fertilization for 2005 and 2006 corn and wheat in the Texas High Plains.

Based on this data, in 2005 and 2006 corn had a potential of yielding 250 and 200 bushels per acre, respectively. In 2005, 21 inches of irrigation were needed to attain this yield, while in 2006, 31 inches were needed to reach the potential yield. Additionally, in 2005 and 2006, wheat reached a potential of approximately 80 to 90 bushels per acre. However, in 2006 an additional 10 inches of irrigation was required to reach this yield level.

Figures 4-7A–D illustrate the variation in yield due to irrigation with fertilization being applied according to actual cropping practices. In all cases the highest irrigation level is the amount of irrigation actually applied by the producer. According to the data, reducing irrigation on the corn would have resulted in significant yield decreases. On the other hand, decreasing irrigation on wheat did not result in as dramatic a yield decrease, and therefore, could indicate an opportunity for water savings of at least a couple of inches per year while maintaining comparable yields.

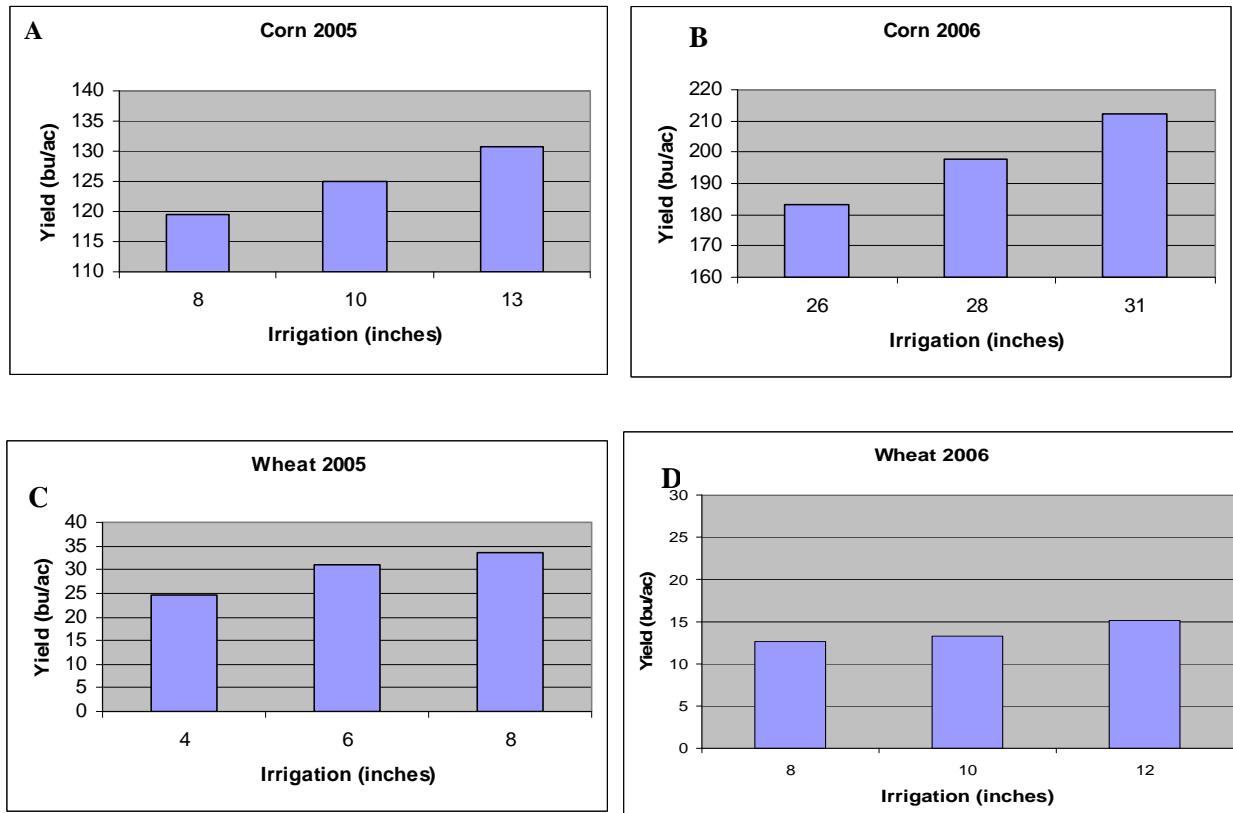


Figure 4-7A–D. Simulated yield at varying irrigation levels based on actual fertilization practices for 2005 and 2006 corn and wheat.

Wintergarden Region

Cropping practice and yield data were received from Beth Zaiglin at Texas AgriLife Research and Extension Center at Uvalde for corn and cotton produced in the Texas Wintergarden in 2008. Cropping practice data included fertilizer amounts and dates applied, planting date, row spacing, plant population, total irrigation amounts applied during the season and harvest date. This data was used to construct simulation runs in CropMan/WinEPIC in order to determine if alternate irrigation strategies were possible. Since actual irrigation dates and amounts were not available, irrigation was applied uniformly throughout the growing season until the specified amount applied was accounted for. This method will introduce some error into the simulation but was the only solution for this case. It should be noted that in some instances yields differed slightly when irrigation was set in the model to apply on specific dates and when it was applied automatically by the model. The model can be set to automatically apply irrigation based on an irrigation trigger as well as a minimum and maximum single application amount. The model will apply irrigation each time this trigger is reached and will apply at set intervals until a total specified amount of irrigation has been applied. This may mean that the specified amount of irrigation is applied before the crop has fully matured. In these cases yield will be affected. Table 4-3 below shows the reported data as well as simulation results.

Table 4-3. Comparison of measured and simulated yields based on reported cropping practices.

Producer	Crop	Reported Irrigation Applied, inches	Reported Nitrogen Applied, lbs/ac	Measured Yield*	Simulated Yield	Simulated Stress Days	
						Water	Nitrogen
Lamon	Corn	22.00	140	132 bu/ac	137 bu/ac	22	0
Verstraeten	Cotton	15.00	140	1515 lbs/ac	1665 lbs/ac	60	0
Verstraeten	Corn	20.00	70	130 bu/ac	124 bu/ac	18	17

* Yields reported as dry weight, 0% moisture

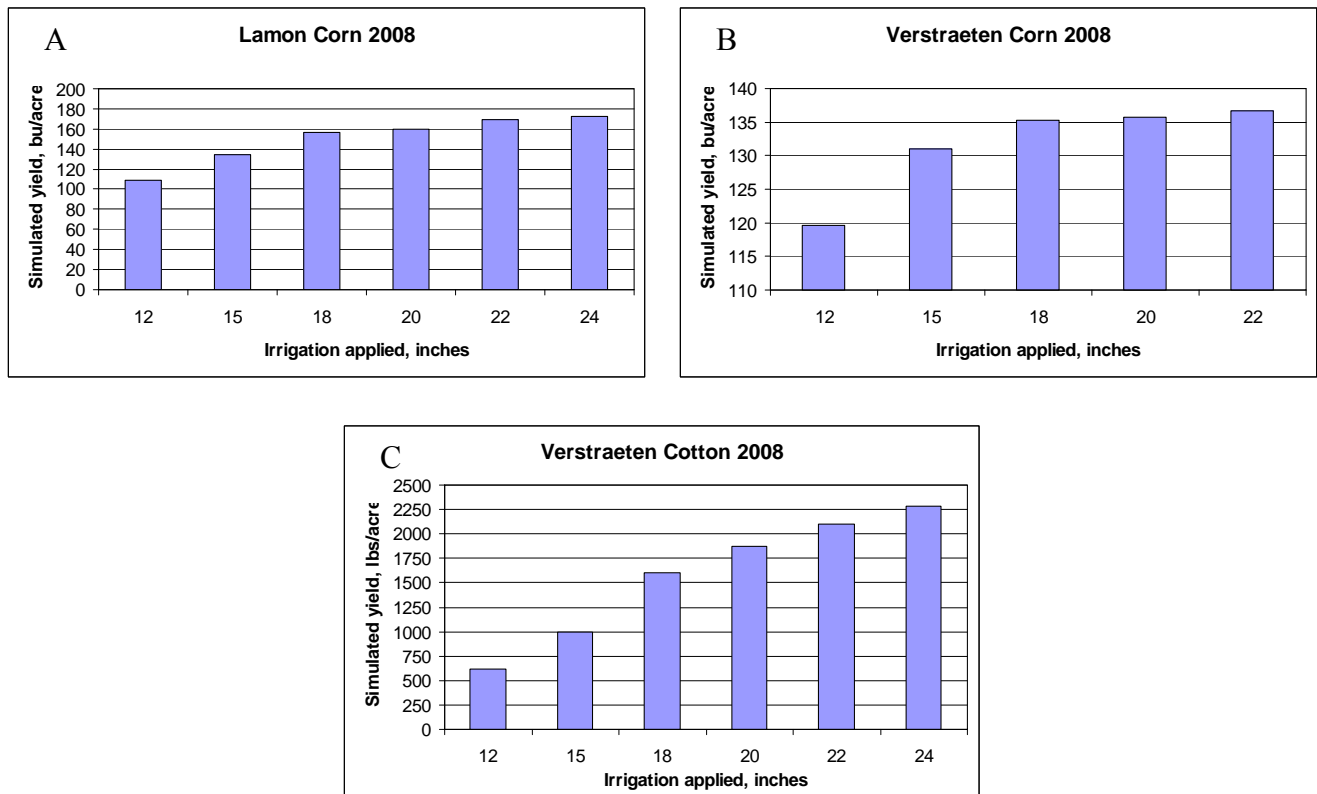
Simulation results for all three farms were very favorable. Simulated yields were within 10% of the actual reported yield. The number of water stress days simulated by the model indicated that the crops may have benefitted from additional irrigations.

Table 4-4. Simulated potential yields.

Producer	Crop	Irrigation Applied, inches	Nitrogen Applied, lbs/ac	Simulated Yield	Simulated Stress Days	
					Water	Nitrogen
Lamon	Corn	24	140	173 bu/ac	6.484	1.556
Verstraeten	Cotton	24	140	2288 lbs/ac	22.735	0
Verstraeten	Corn	22	70	136 bu/ac	5.559	27.207
Verstraeten	Corn	22	140	180 bu/ac	6.373	4.042

* Yields reported as dry weight, 0% moisture

Table 4-4 illustrates the potential yield for the three farms. In all cases irrigation was applied automatically by the model based on set irrigation triggers. The model was set up to irrigate when the crop reached a stress level of 10% and could apply between 0.5 and 2 inches per application. According to the simulations, Lamon could have increased his corn yield by over 40 bu/ac by applying an additional 2 inches (24 inches total) of irrigation and 140 lbs/ac nitrogen (reported application amount). Verstraeten could have increased his cotton yield by more than 600 lbs/ac with an additional 9 inches of irrigation per acre. According to the model, Verstraeten's corn yield could have only been increased by a few bushels per acre with the addition of 2 inches more of irrigation (22 inches total) water based on 70 lbs nitrogen per acre reported application, however, he could have increased his yield over 50 bu/ac by applying 22 inches per acre of water and an additional 70 lbs nitrogen per acre (140 lbs N/ac total).



Figures 4-8A–C. Simulated yield of corn and cotton grown in the Wintergarden region of Texas using the automatic irrigation feature of the model.

Figures 4-8A–C depict the yield distribution of the three sites using automatic irrigation. Figure 4-8A indicates that with 15 inches of irrigation the measured corn yield, based on reported cropping practices, could have been maintained. This could have resulted in a water savings of 7 inches per acre. Figure 4-8B indicates that 15 inches of irrigation could have been applied to the corn crop to reach a comparable yield to the yield reported by Verstraeten. This would have equaled a water savings of 5 inches per acre. Figure 4-8C indicates Verstraeten could have saved 2 inches of water per acre and still obtained approximately the same cotton yield. These results indicate that with slightly different irrigation timing, water could have been saved which could have been used for another crop or sold to surrounding water districts.

Figure 4-9 below shows the 2006 results for grain sorghum. The validation resulted in a slope of 0.82 and an r-square value of 0.53. A slope of 1.00 indicates that the model is predicting measured yields exactly.

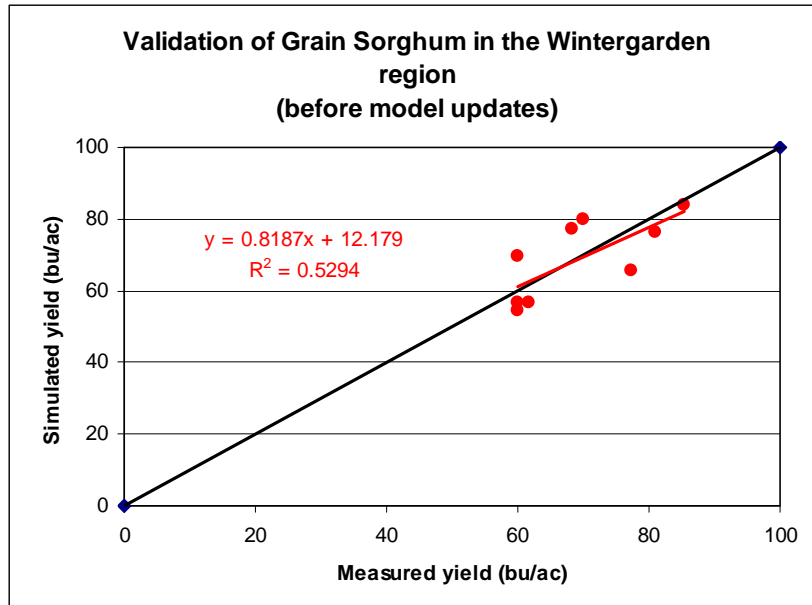


Figure 4-9. 2006 model calibration results for grain sorghum in the Wintergarden region.

Conclusion

Valuable information was gathered from the producers involved in the PIN II project. The PIN II project provided a strong foundation for attaining field data from producers and applying it in DSS tools such as CroPMan. Through the use of CroPMan, current as well as alternative cropping scenarios were assessed and presented to the producers to illustrate to them possible changes to their future cropping practices. It provided potential water savings as well as potential profit increases without the loss in time and money that would have been spent if the same scenarios were carried out in the field. New practices were mainly confined to varying irrigation amounts. The potential water savings and potential profit increases can be illustrated in Figures 4-3 and 4-4. These graphs show that if the producer increased his irrigation by 2 inches he would have gained over \$5 per acre. This is not a water savings but it is profit maximization.

Producers were also provided with an additional decision aid known as Irrig-Aid which is a tool developed from numerous CroPMan simulations and production functions. IRRIG-AID is a downloadable spreadsheet-based decision tool designed to assess the risk of various crop, soil, and irrigation practices, as well as quantify economic trade-offs in allocating soil and water resources to various cropping alternatives. It is available for downloading at <http://cropman.brc.tamus.edu/decision-aids.aspx>. This tool provides producers with a decision support tool which is useful for planning irrigation strategies between crops. It enables producers to determine the most profitable irrigation distribution among several crops being grown. The tool also provides a profit analysis report that can be used in applying for operation loans needed by the producers.

DSS tools such as CroPMan and Irrig-Aid provide valuable information to producers, which enable them to make more educated decisions in regards to irrigation application timing and irrigation distribution among crops resulting in potential water savings as reported in the previous section.

CHAPTER 5: Project Administration

METHODOLOGY

TWRI worked with the Texas Water Development Board to refine the schedule during which quarterly reports should be submitted and worked with project leaders to develop four quarterly reports. TWRI also requested final project materials from project leaders to be incorporated into this final report. TWRI compiled reports of data gathered in each task, prepared publications, conducted meetings, and served as the primary outreach and media outlet for PIN. TWRI ensured each task was completed and all contractual deliverables were met.

RESULTS

Quarterly reports were submitted in a timely fashion to the TWDB. In addition, TWRI set up individual accounts for each task administrator and ensured adequate use of funds. TWRI maintained regular communication with all of the researchers to ensure collaboration among project tasks. Several newspaper reporters contacted TWRI regarding PIN efforts; TWRI provided background materials and contact information. Several news releases were developed. In addition, a PIN brochure was developed to describe the program to interested growers and other agencies. TWRI project manager worked with all of the PIN project researchers to put together the information contained in the brochure. An electronic version of the brochure can be found at <http://twri.tamu.edu/project-info/PIN/>.

CONCLUSION

The use of an external project administrator, such as TWRI, benefited the project team and achievements. TWRI served as the liaison between the TWDB and the scientists for all tasks related to this program. TWRI's role allowed the project researchers and scientists the ability to focus on specific tasks and project deliverables while maintaining communication and cooperation with other members of the project team and the TWDB.

EDUCATION AND OUTREACH

Field Days

PIN II researchers in coordination with county Extension agents and other agencies have hosted field days for area growers. These field days were conducted to inform growers on the use of irrigation scheduling tools. AgriLife Research and Extension personnel also visited individual farms to demonstrate use of electronic technology to obtain potential evapotranspiration (PET) and crop water requirements from weather stations in each region. An ET irrigation scheduling user's guide was developed and prepared for growers to inform them on wise and efficient use of ET-based irrigation scheduling, even in limited water capacity or allocation scenarios.

The impact of these field days reached beyond just those involved in the PIN demonstrations. Area growers not currently involved in the project attended and gained interest in these technologies and irrigation scheduling methods. In addition, growers noticed what their neighbors were doing and became interested in learning more about the different methods their neighbors were using.

Presentations & Publications

During the course of the project, researchers have presented their progress and results at various meetings across the state, and some out of state and internationally. These presentations provided various audiences with information and results of these research demonstrations that could be applicable in their regions or areas. Resulting questions and discussions helped researchers better tailor their efforts and helped others learn from the researchers' experiences and gave them new, more efficient ideas for working with growers to better manage their irrigation. Most of those contacted through these presentations were irrigation professionals and researchers.

At least three news articles about the PIN II project have been written and published through TWRI and its newsletters and Web sites. TWRI along with PIN researchers also developed a brochure to be distributed to potential demonstration growers, agencies and others interested in learning more about the PIN program. The brochure outlines the background and need for the project and explains the demonstration process. The brochure was given to growers who were interested in either being part of this demonstration or implementing more efficient and precise irrigation methods. Researchers have since been contacted by growers for additional information.

The following educational and outreach events were held during the PIN II project period. Events included field days, grower meetings, demonstrations, conferences and numerous other presentations and group meetings.

Event Date	Type of Educational Event
End of PIN I and beginning of PIN II Late-2006	Results from DSS calibration, soil moisture analysis and yield predictions were discussed during the PIN I workshop held at the Uvalde Research and Extension Center, where benchmarked data from the 2006 cropping season were discussed with the participants.
January 16, 2007	Grower meeting in Uvalde to discuss the 2007 crop season plans. (80 growers between this and Devine meeting)
February 21, 2007	Grower meeting in Devine to discuss the 2007 crop season plans (80 growers between this and Uvalde meeting)

May 24, 2007	Conducted a North Plains Research Field Small Grains Field Day
June 12, 2007	Researchers hosted TWDB (Aung Hla and Kate McAfee) at the Blackland Research and Extension Center in Temple to discuss in detail the decision support system component of the project.
June 21, 2007	Uvalde County Field Day and PIN farms tour were held (Approximately 35 growers)
July 26, 2007	Medina County Field Day and PIN farms tour were held (Approximately 180 growers)
January 7, 2008	PIN project meeting with TWRI and TWDB personnel at Texas A&M in College Station
February 19, 2008	TAIA 2008 South Texas Conference at Uvalde. Results and demonstrations on 2007 'Precision Irrigation for Vegetable and Agronomic Crops' and DSS modeling were presented and displayed at the field tour.
March 18, 2008	Results and demonstrations on "Irrigation, Specialty Crops and Nitrogen Management for Vegetable Crops" were presented in a field day in conjunction with local, regional and 23rd District Congressional officials (Congressman Ciro Rodriguez) at the Texas AgriLife Research and Extension Center at Uvalde
March/April 2008	Similarly, results were presented to the 23rd District Congressman Larson at Texas A&M, College Station.
May 21-22, 2008	Field day depicting the PIN project, held in conjunction with the Consortium for Irrigation Research and Education (CIRE) meeting
August 7, 2008	Texas Corn Producers Field Day at North Plains Research Field (Approximately 62 growers)
August 19, 2008	Irrigation results on quality and phytochemicals presented at American Chemical Society Meeting
August 27, 2008	Results and demonstrations on "Irrigation and Specialty Crops" were presented in a field day to 23rd District Congressional officials (Robin Lloyd and Cesar Blanco, Office from Congressman Ciro Rodriguez) at the Texas AgriLife Research and Extension Center at Uvalde

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http://www.twdb.state.tx.us/mapping/maps/pdf/rwpg/letter_size/Region%20A%208x11.pdf
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APPENDIX A

NPRF TEST PLOT DATA



• 2007 Year

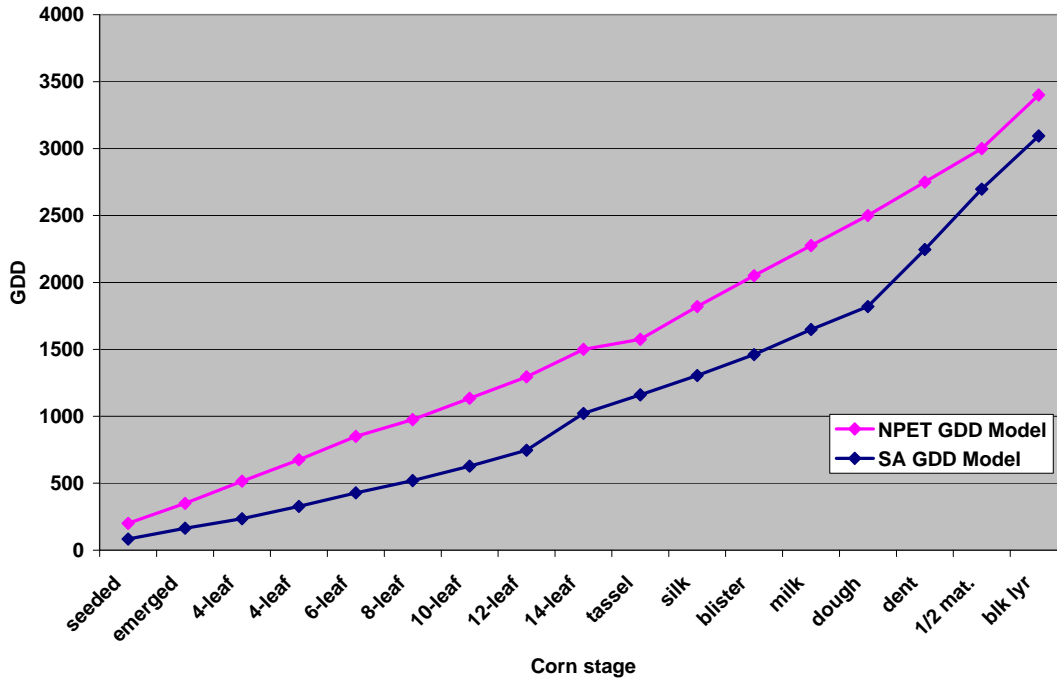


Figure A-1. 2007 GDD Comparison for Planting Date 2.

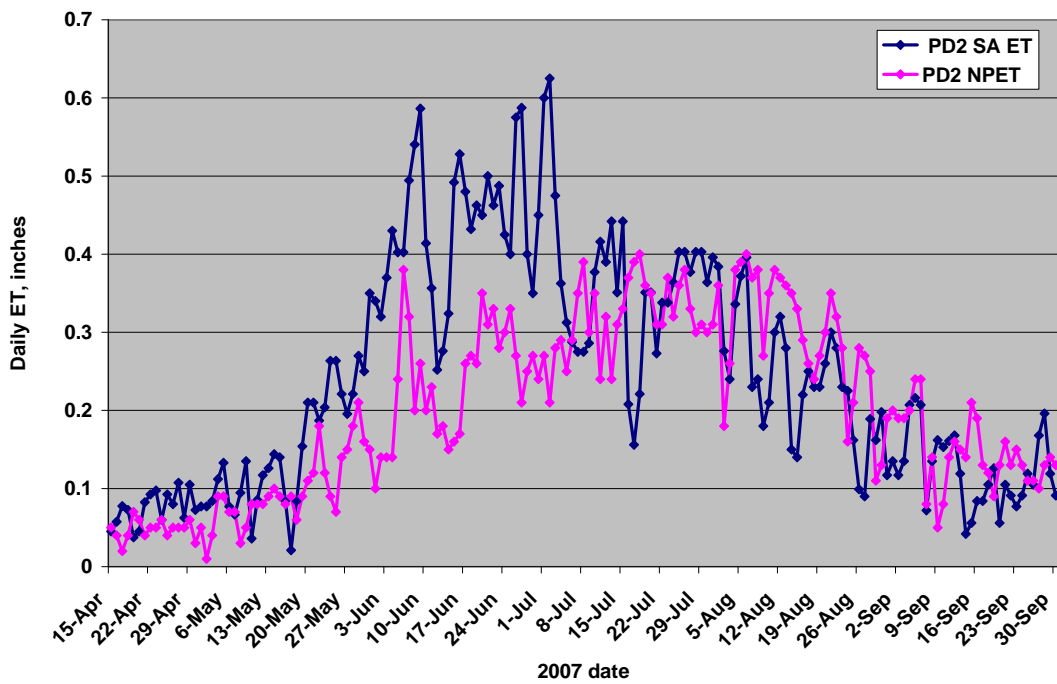


Figure A-2. 2007 Daily ET Comparison for Planting Date 2.

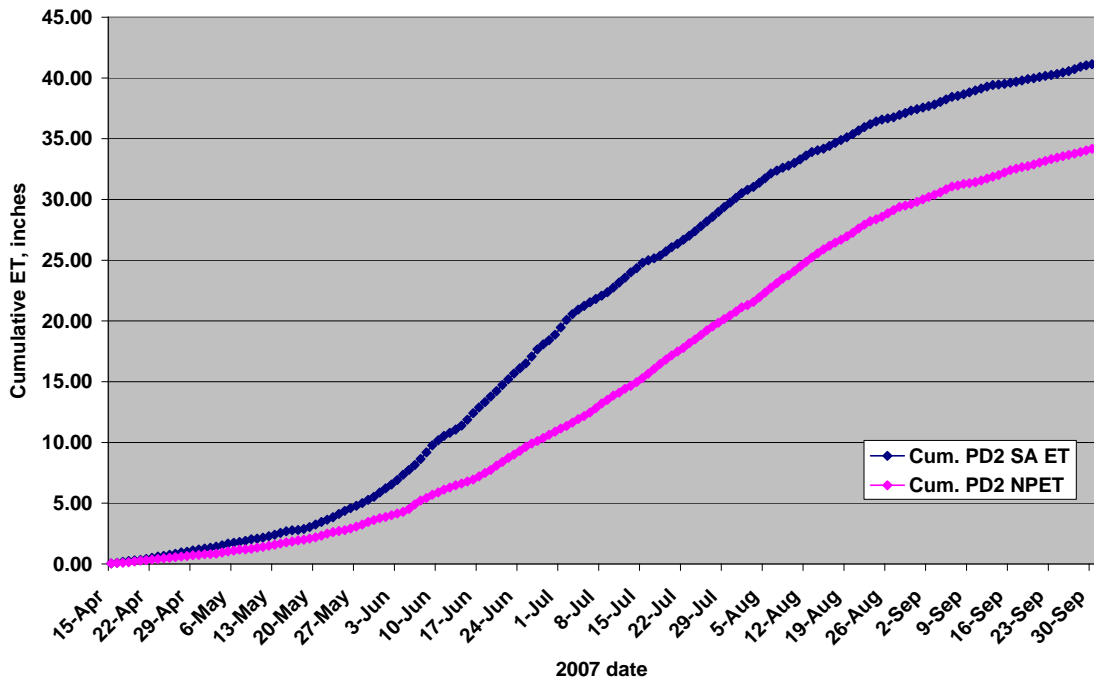


Figure A-3. 2007 Cumulative ET Comparison for Planting Date 2.

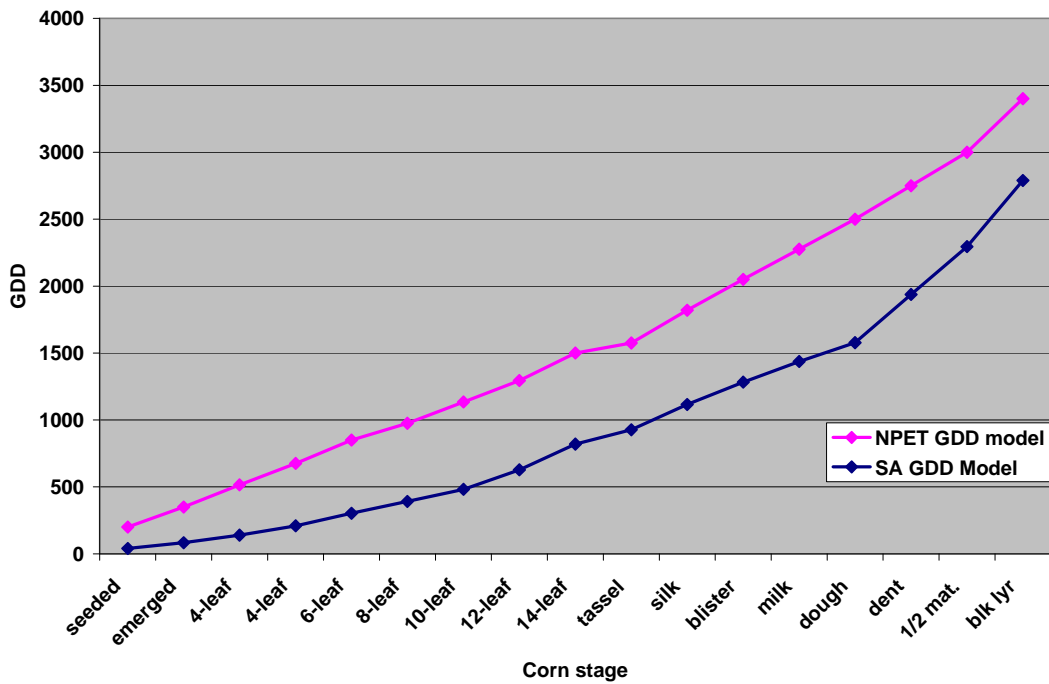


Figure A-4. 2007 GDD Comparison for Planting Date 3.

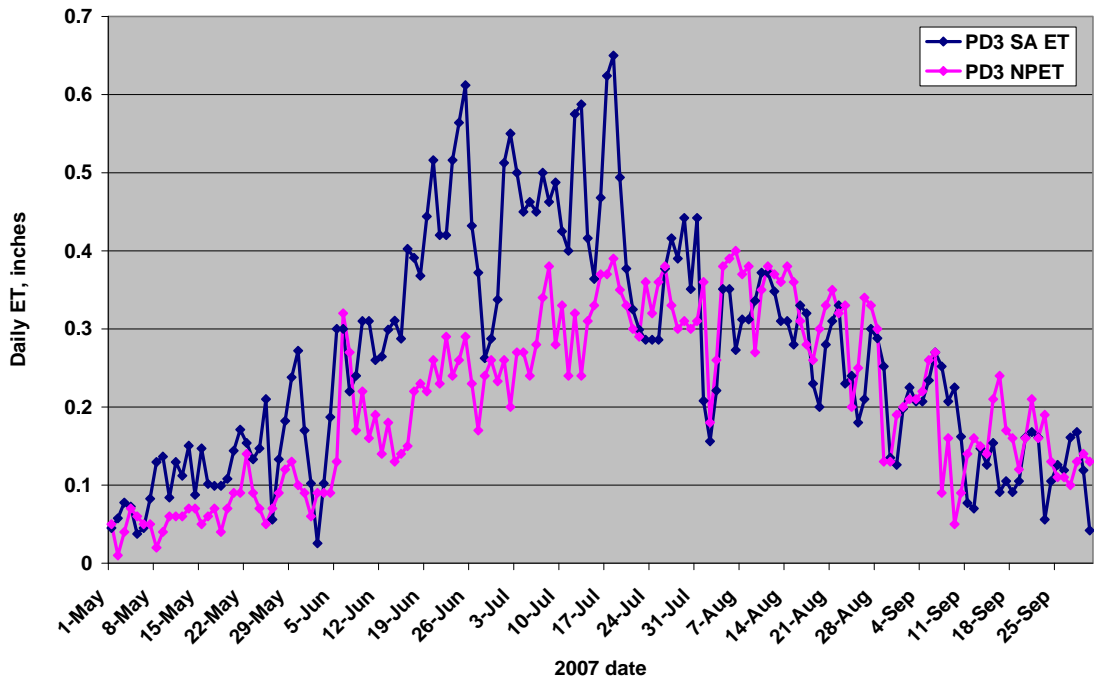


Figure A-5. 2007 Daily ET Comparison for Planting Date 3.

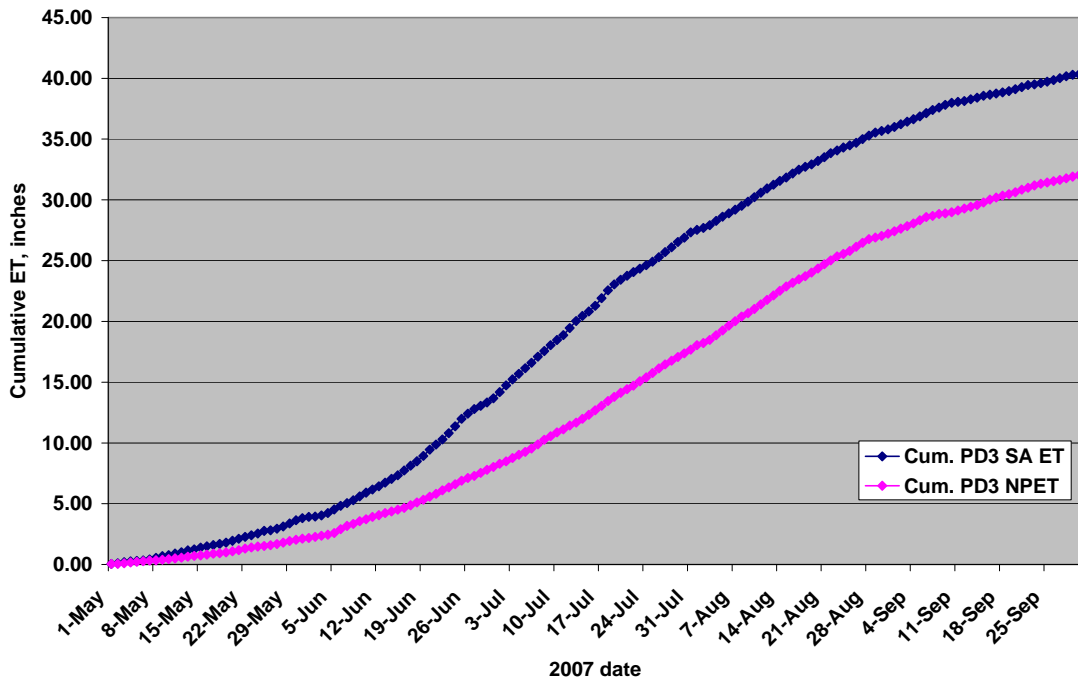


Figure A-6. 2007 Cumulative ET Comparison for Planting Date 3.

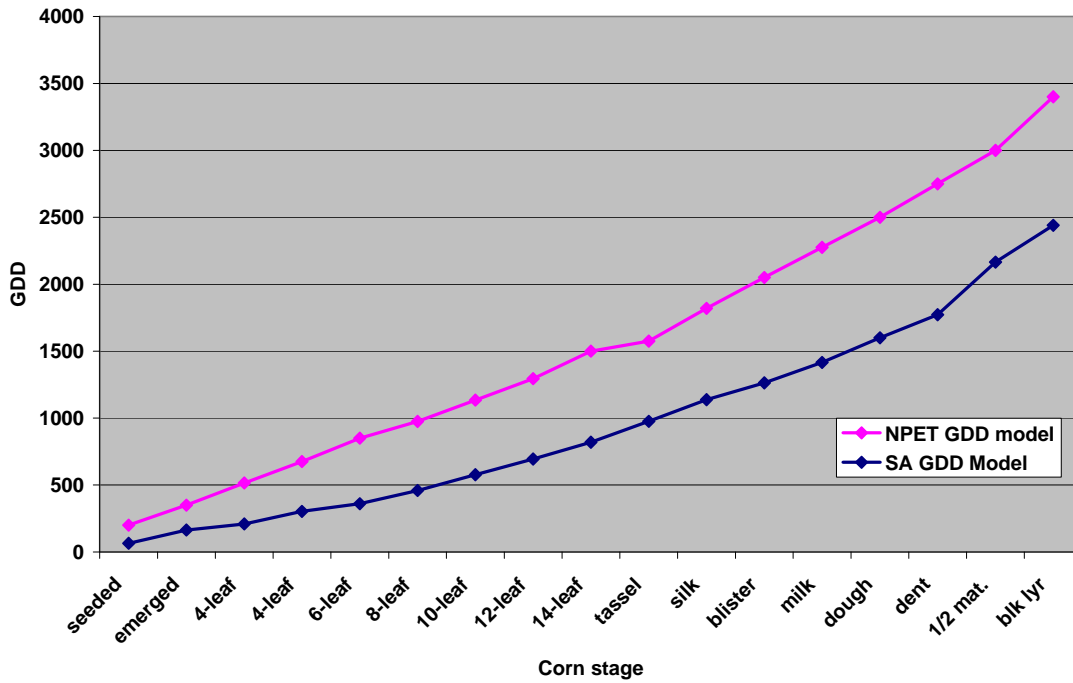


Figure A-7. 2007 GDD Comparison for Planting Date 4.

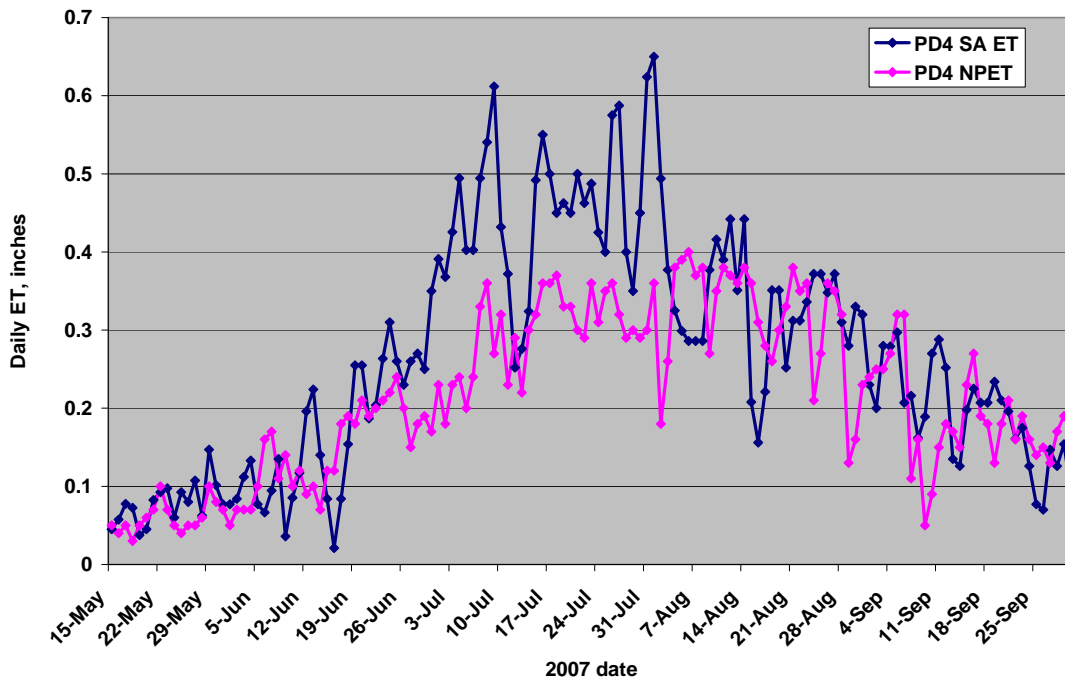


Figure A-8. 2007 Daily ET Comparison for Planting Date 4.

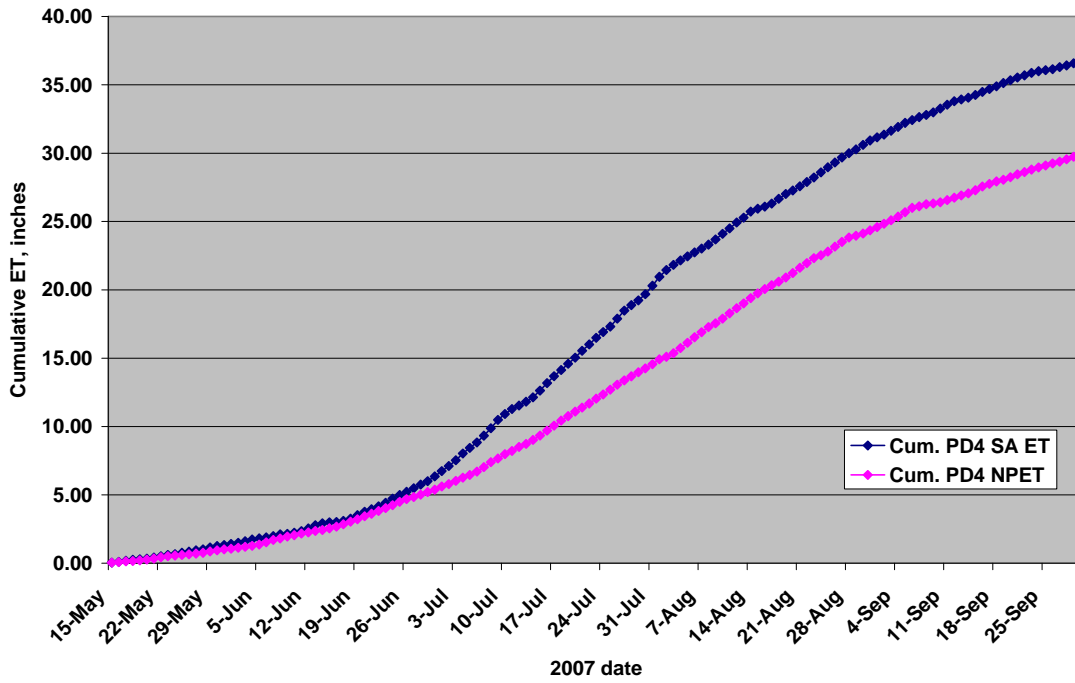


Figure A-9. 2007 Cumulative ET Comparison for Planting Date 4.

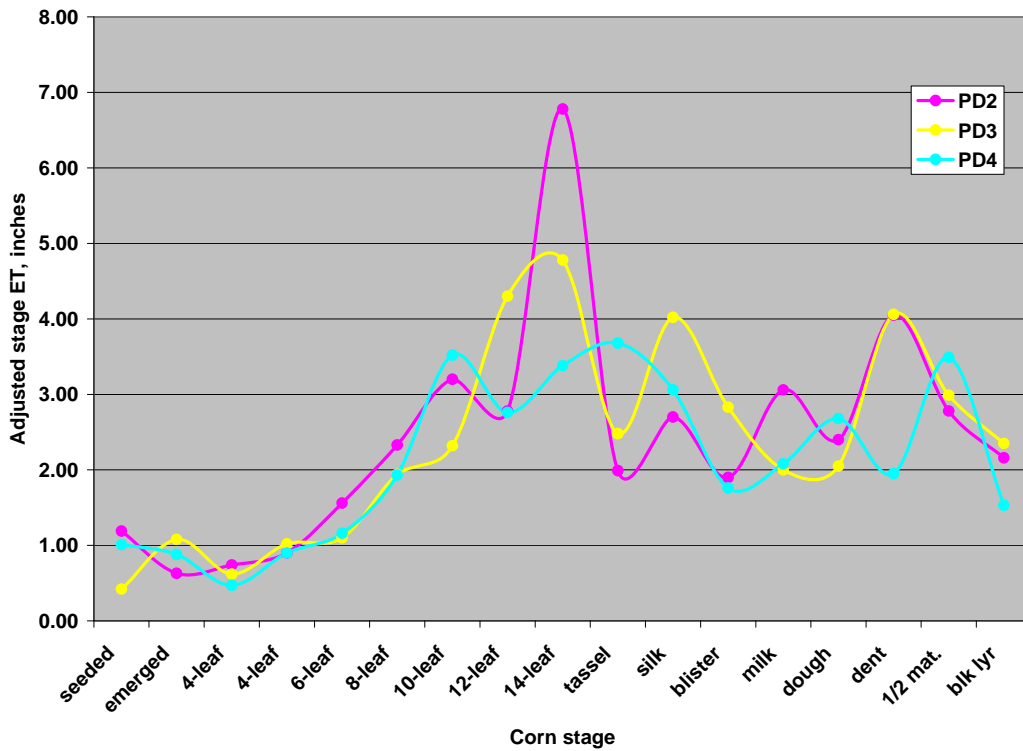


Figure A-10. 2007 Comparison of the Stage Adjusted Corn ET_{co} per Stage per Planting Date.

Table A-1. Table of observed versus adjusted corn ET for planting date 2, 2007.

Crop stage	NPET model ET, inches	Stage adjusted ET, inches	Difference, Inches*
seeded	0.76	1.19	-0.43
emerged	0.42	0.63	-0.21
4-leaf	0.51	0.74	-0.23
4-leaf	0.64	0.90	-0.26
6-leaf	0.93	1.56	-0.63
8-leaf	1.04	2.33	-1.29
10-leaf	1.83	3.20	-1.37
12-leaf	1.36	2.78	-1.42
14-leaf	3.88	6.78	-2.90
tassel	1.85	1.99	-0.14
silk	2.09	2.70	-0.61
blister	2.49	1.90	0.59
milk	2.67	3.06	-0.39
dough	2.28	2.40	-0.12
dent	5.47	4.05	1.42
1/2 mat.	3.21	2.78	0.43
blk lyr	2.75	2.16	0.59
Total	34.18	41.15	-6.97

*Difference is computed with reference to the NPET ETco values.

Table A-2. Table of observed versus adjusted corn ET for planting date 3, 2007.

Crop stage	NPET model ET, inches	Stage adjusted ET, inches	Difference, inches
seeded	0.33	0.42	-0.09
emerged	0.49	1.08	-0.59
4-leaf	0.36	0.62	-0.26
4-leaf	0.63	1.02	-0.39
6-leaf	0.65	1.10	-0.45
8-leaf	1.46	1.94	-0.48
10-leaf	1.19	2.32	-1.13
12-leaf	2.19	4.30	-2.11
14-leaf	2.97	4.78	-1.81
tassel	1.41	2.48	-1.07
silk	3.04	4.02	-0.98
blister	2.66	2.83	-0.17
milk	2.28	2.00	0.28
dough	2.12	2.05	0.07
dent	4.70	4.06	0.64
1/2 mat.	2.51	2.99	-0.48
blk lyr	3.06	2.35	0.71
Total	32.05	40.36	-8.31

*Difference is computed with reference to the NPET ETco values.

Table A-3. Table of observed versus adjusted corn ET for planting date 4, 2007.

Crop stage	NPET model ET, inches	Stage adjusted ET, inches	Difference, inches
seeded	0.77	1.01	-0.24
emerged	0.77	0.88	-0.11
4-leaf	0.64	0.47	0.17
4-leaf	0.87	0.90	-0.03
6-leaf	0.99	1.16	-0.17
8-leaf	1.35	1.93	-0.58
10-leaf	2.01	3.52	-1.51
12-leaf	1.95	2.76	-0.81
14-leaf	2.34	3.38	-1.04
tassel	2.58	3.68	-1.10
silk	1.87	3.06	-1.19
blister	2.12	1.76	0.36
milk	2.25	2.08	0.17
dough	2.61	2.68	-0.07
dent	1.58	1.95	-0.37
1/2 mat.	2.97	3.49	-0.52
blk lyr	1.85	1.53	0.32
Total	29.52	36.24	-6.72

*Difference is computed with reference to the NPET ETco values.

• **2008 Year**

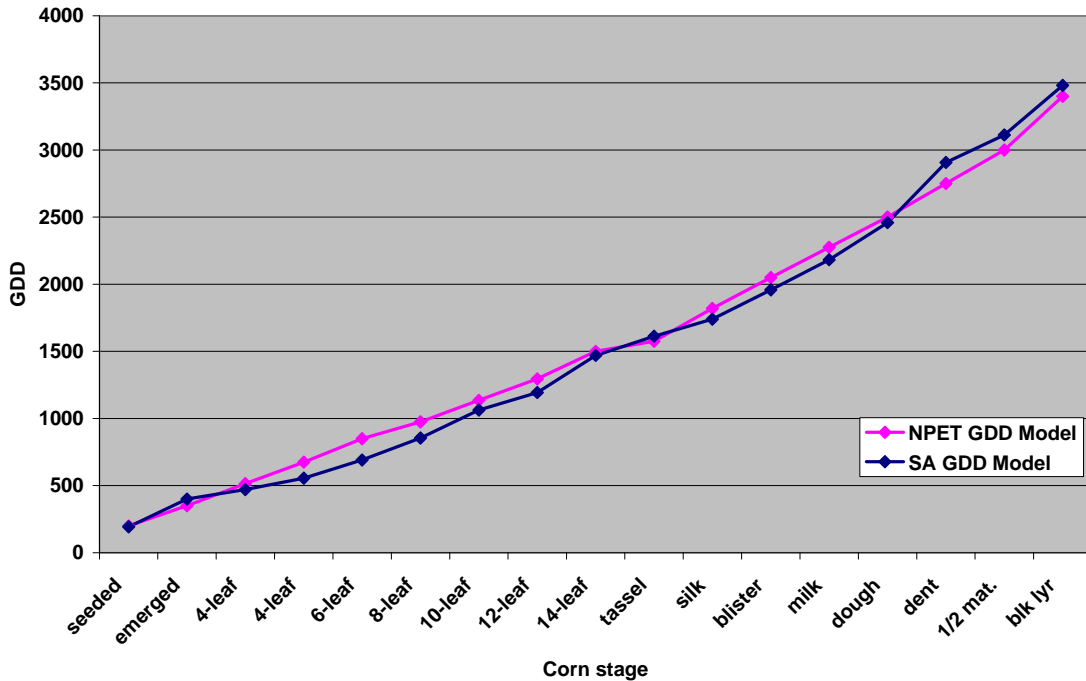


Figure A-11. 2008 GDD Comparison for Planting Date 1.

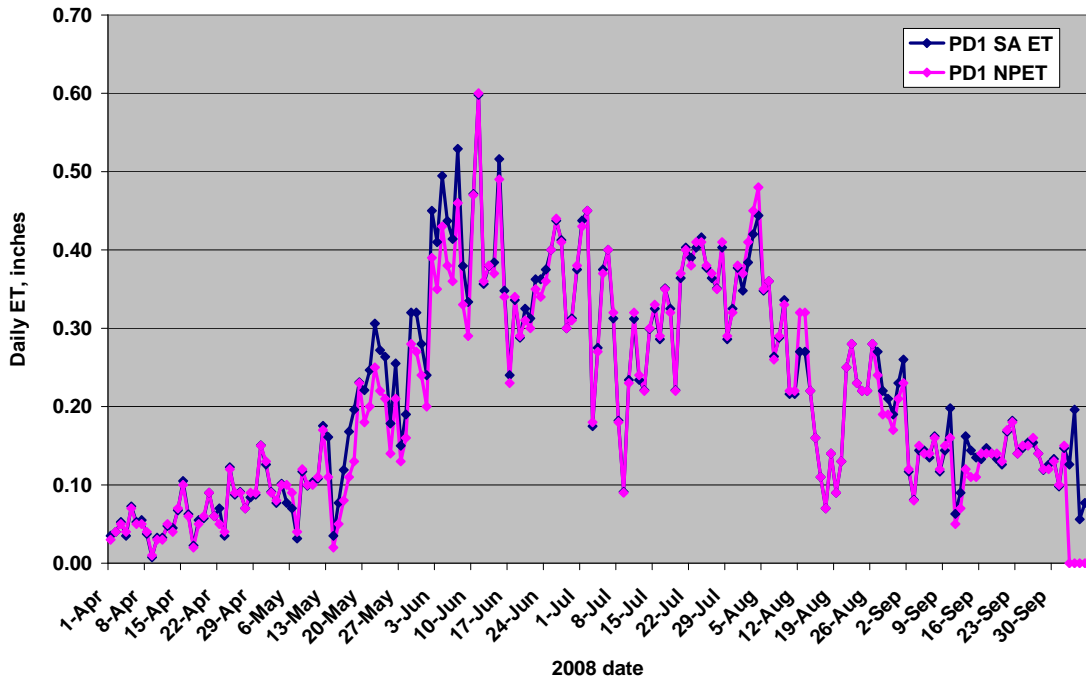


Figure A-12. 2008 Daily ET Comparison for Planting Date 1.

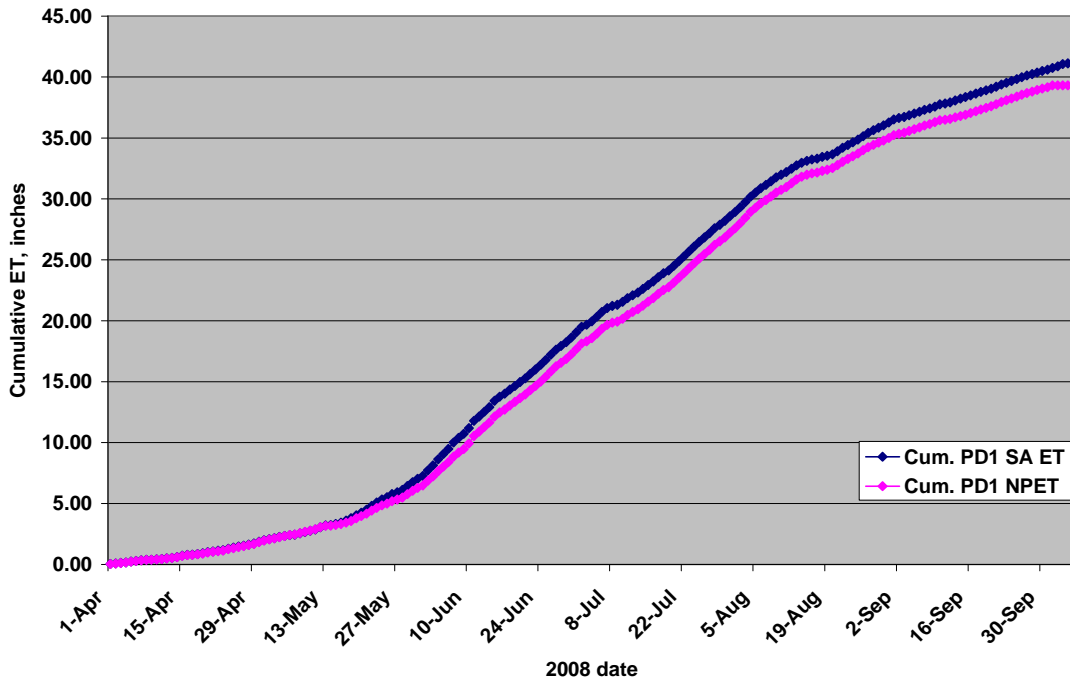


Figure A-13. 2008 Cumulative ET Comparison for Planting Date 1.

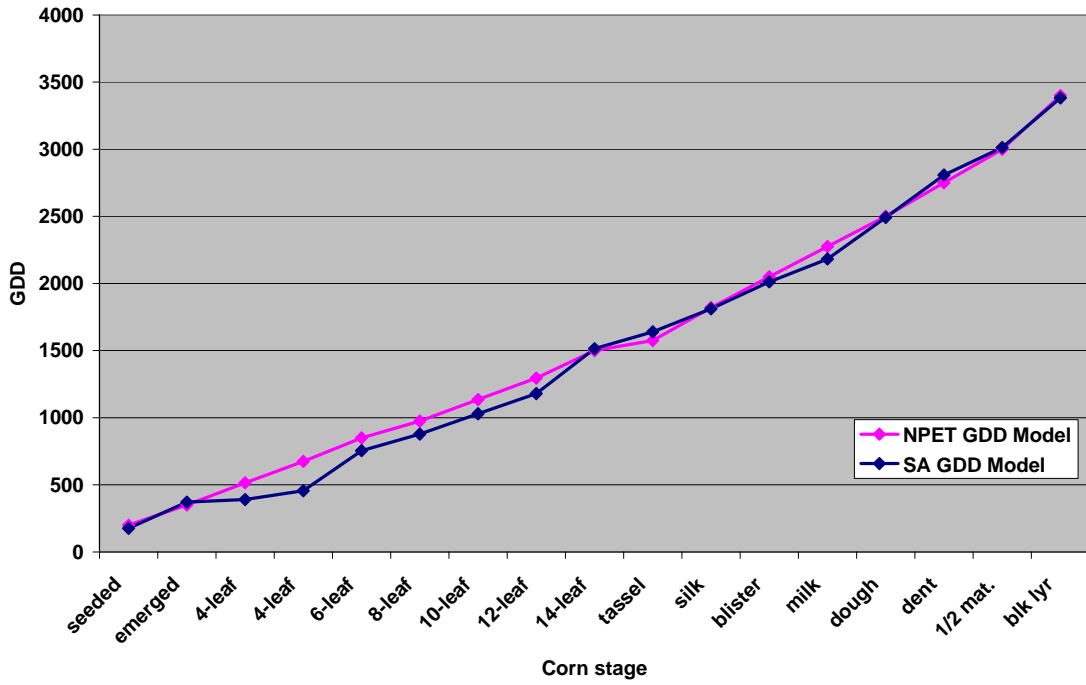


Figure A-14. 2008 GDD Comparison for Planting Date 2.

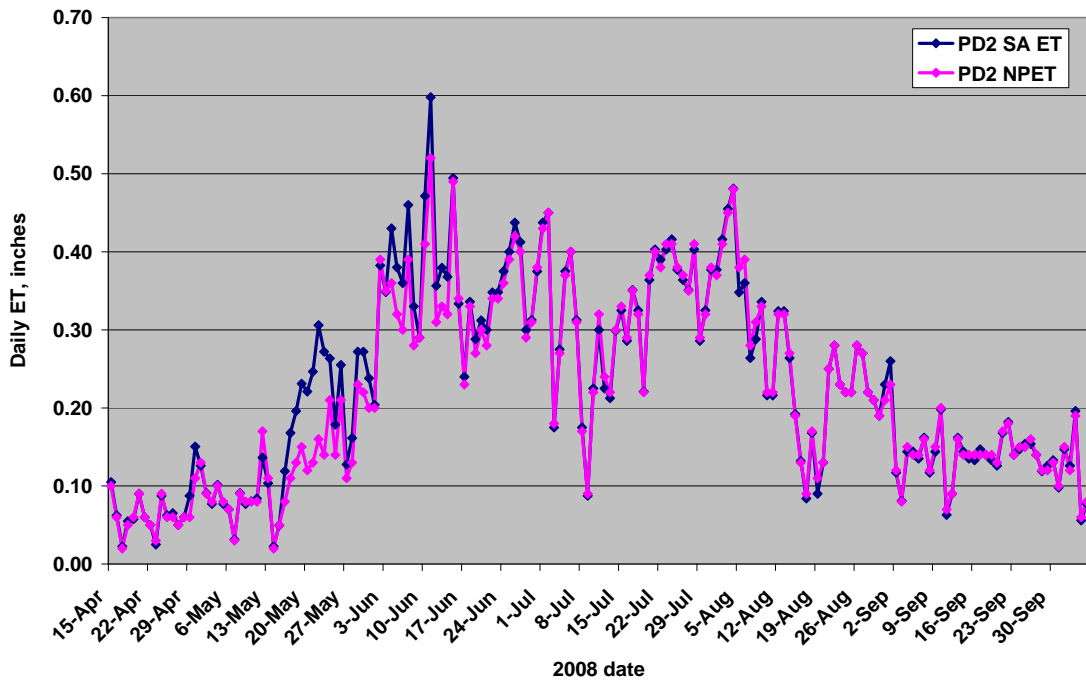


Figure A-15. 2008 Daily ET Comparison for Planting Date 2.

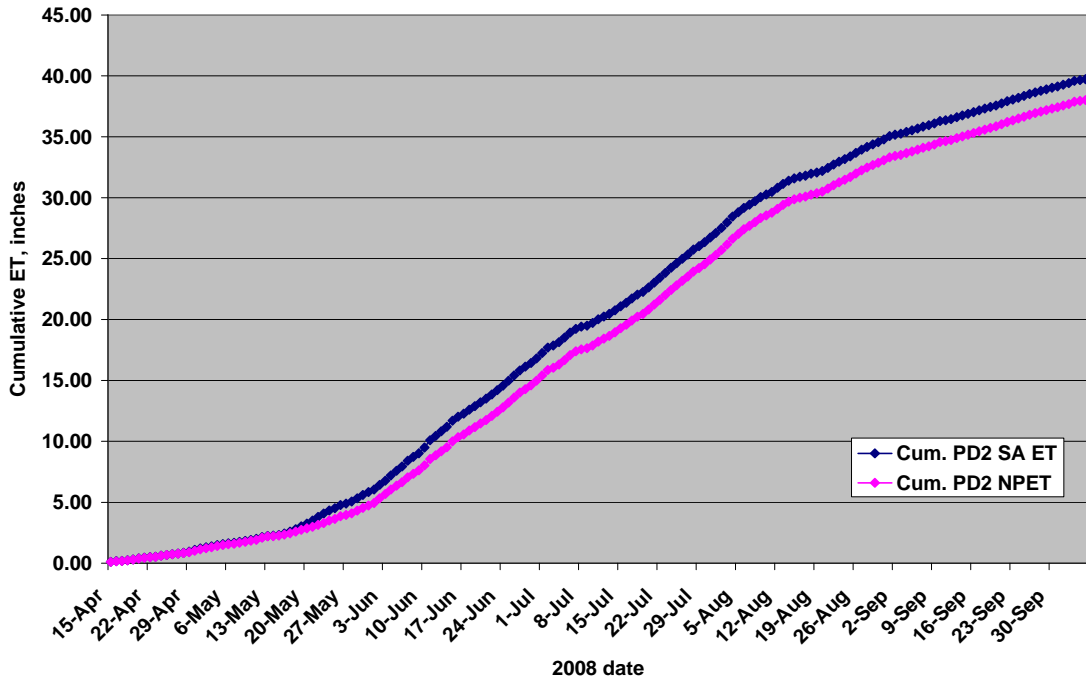


Figure A-16. 2008 Cumulative ET Comparison for Planting Date 2.

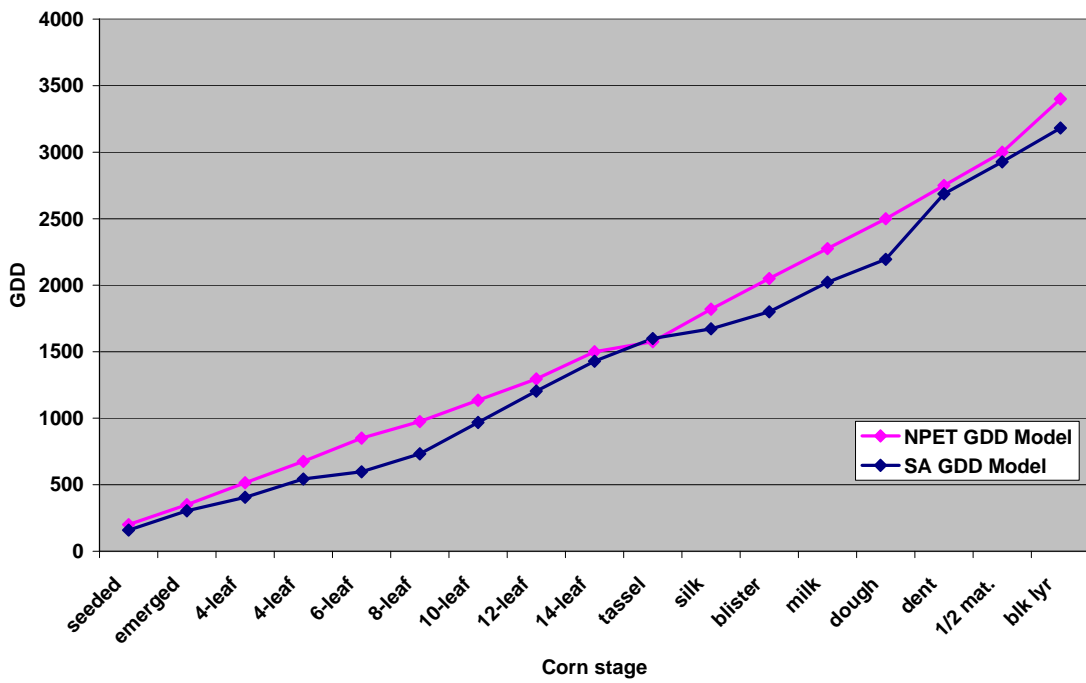


Figure A-17. 2008 GDD Comparison for Planting Date 3.

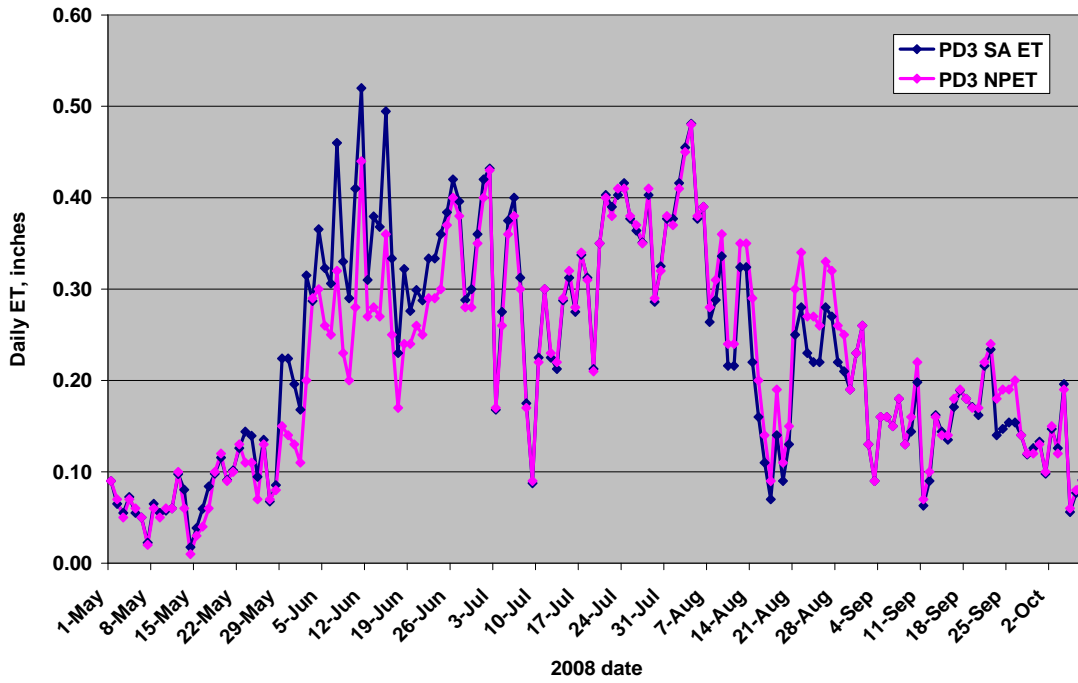


Figure A-18. 2008 Daily ET Comparison for Planting Date 3.

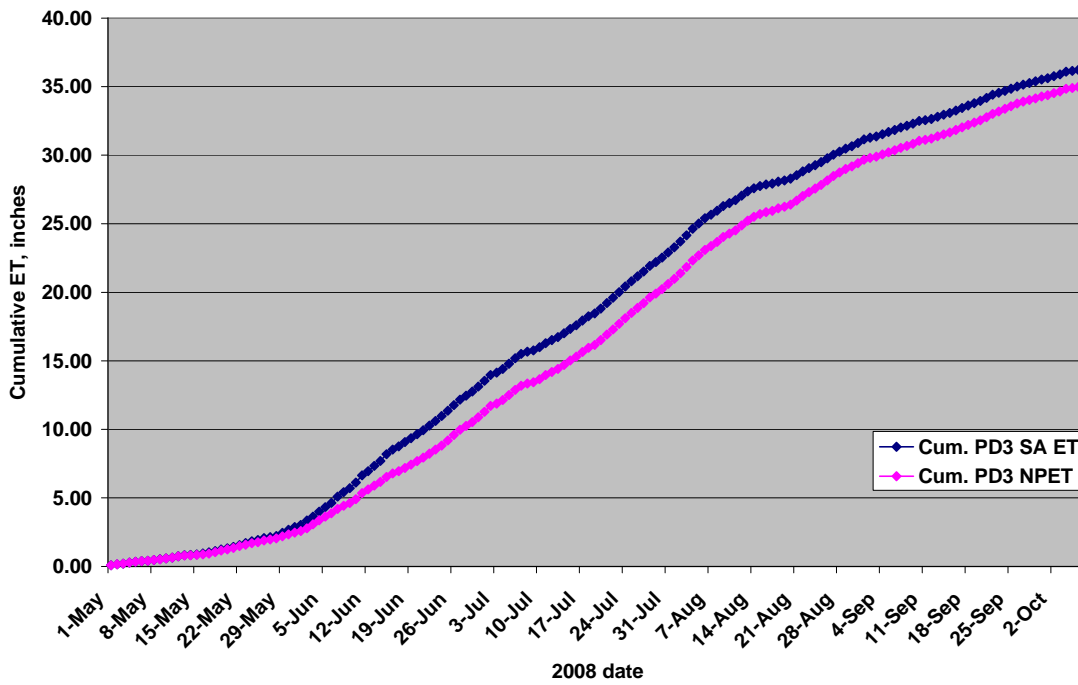


Figure A-19. 2008 Cumulative ET Comparison for Planting Date 3.

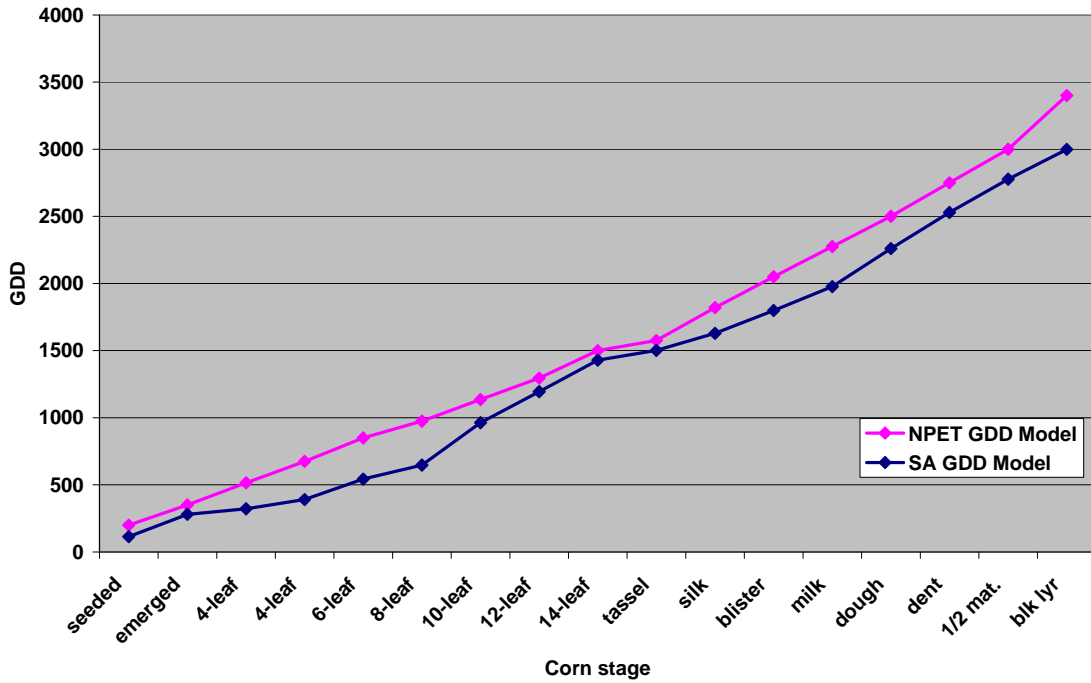


Figure A-20. 2008 GDD Comparison for Planting Date 4.

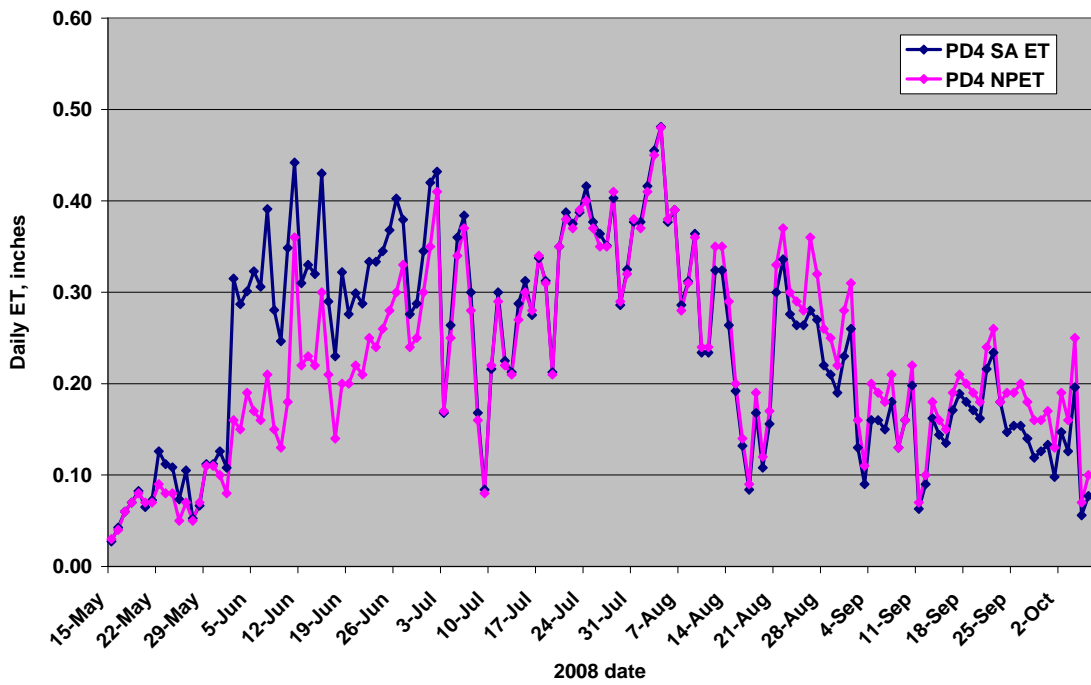


Figure A-21. 2008 Daily ET Comparison for Planting Date 4.

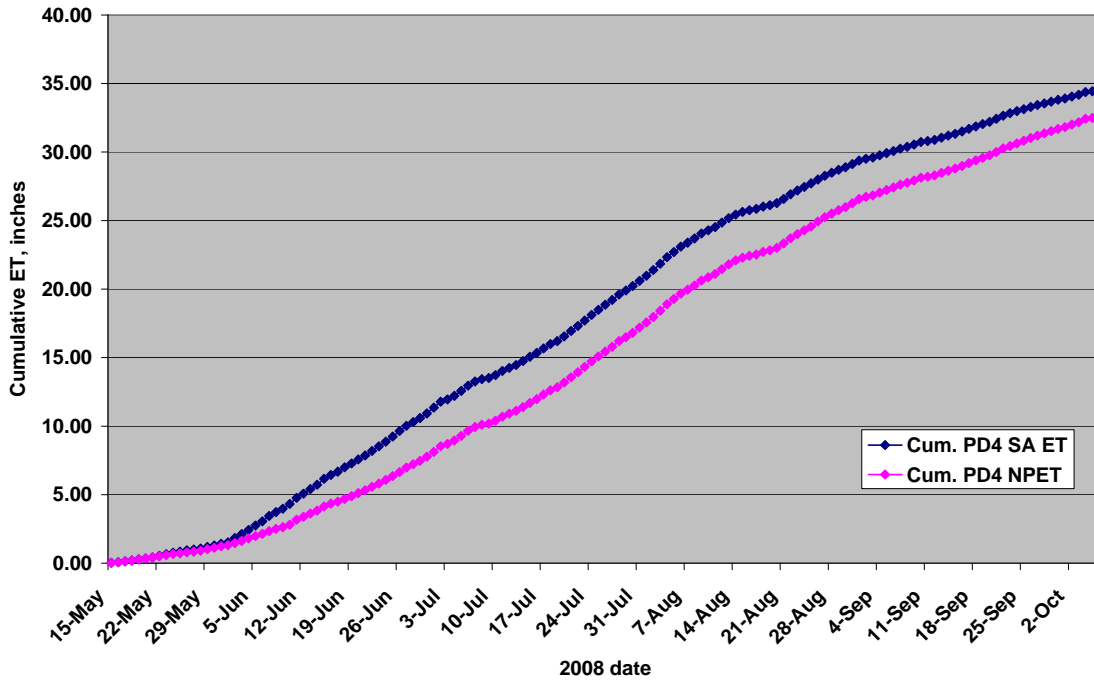


Figure A-22. 2008 Cumulative ET Comparison for Planting Date 4.

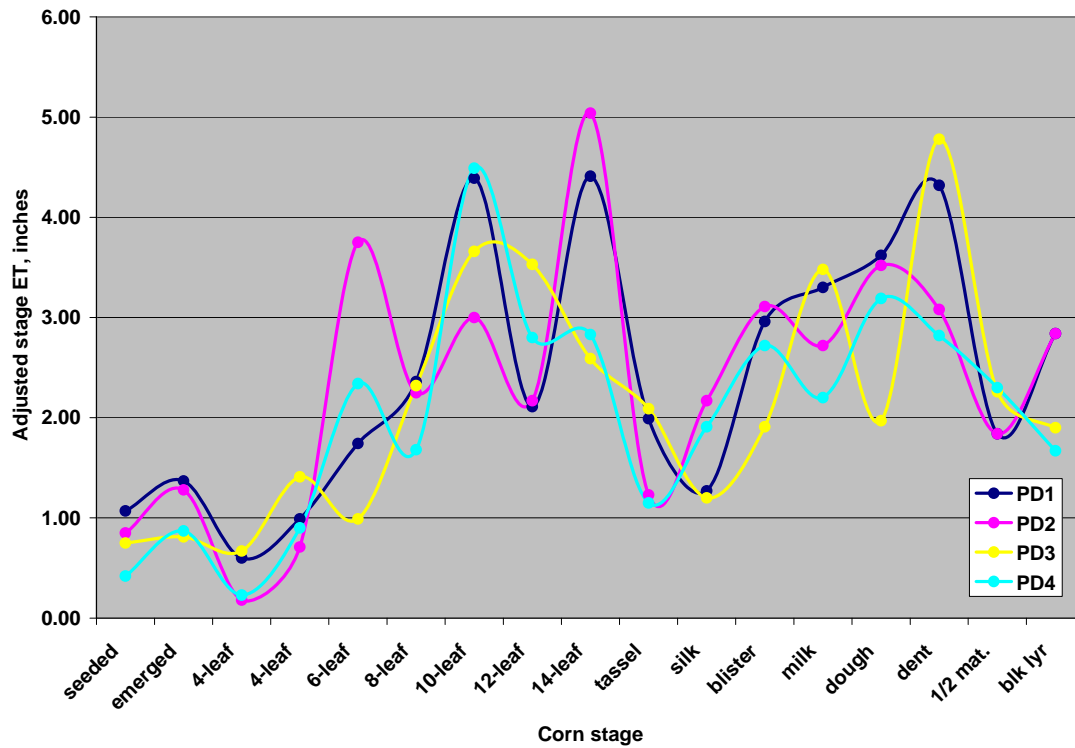


Figure A-23. 2008 Comparison of the Stage Adjusted Corn ET_{co} per Stage per Planting Date.

Table A-4. Table of observed versus adjusted corn ET for planting date 1, 2008.

Crop stage	NPET model ET, inches	Stage adjusted ET, inches	Difference, inches
seeded	1.04	1.07	-0.03
emerged	1.42	1.37	0.05
4-leaf	0.60	0.60	0.00
4-leaf	0.73	0.99	-0.26
6-leaf	1.41	1.74	-0.33
8-leaf	2.02	2.36	-0.34
10-leaf	4.06	4.39	-0.33
12-leaf	2.06	2.11	-0.05
14-leaf	4.33	4.41	-0.08
tassel	1.99	1.99	0.00
silk	1.28	1.27	0.01
blister	2.96	2.96	0.00
milk	3.32	3.30	0.02
dough	3.74	3.62	0.12
dent	4.27	4.32	-0.05
1/2 mat.	1.68	1.84	-0.16
blk lyr	2.40	2.84	-0.44
Total	39.31	41.18	-1.87

*Difference is computed with reference to the NPET ETco values.

Table A-5. Table of observed versus adjusted corn ET for planting date 2, 2008.

Crop stage	NPET model ET, inches	Stage adjusted ET, inches	Difference, inches
seeded	0.84	0.85	-0.01
emerged	1.25	1.28	-0.03
4-leaf	0.18	0.18	0.00
4-leaf	0.47	0.71	-0.24
6-leaf	2.94	3.75	-0.81
8-leaf	1.94	2.25	-0.31
10-leaf	2.72	3.00	-0.28
12-leaf	2.09	2.17	-0.08
14-leaf	4.96	5.04	-0.08
tassel	1.26	1.23	0.03
silk	2.18	2.17	0.01
blister	3.11	3.11	0.00
milk	2.70	2.72	-0.02
dough	3.62	3.52	0.10
dent	3.05	3.08	-0.03
1/2 mat.	1.86	1.84	0.02
blk lyr	2.85	2.84	0.01
Total	38.02	39.74	-1.72

*Difference is computed with reference to the NPET ETco values.

Table A-6. Table of observed versus adjusted corn ET for planting date 3, 2008.

Crop stage	NPET model ET, inches	Stage adjusted ET , inches	Difference, inches
seeded	0.74	0.75	-0.01
emerged	0.74	0.81	-0.07
4-leaf	0.57	0.67	-0.10
4-leaf	1.02	1.41	-0.39
6-leaf	0.81	0.99	-0.18
8-leaf	1.74	2.32	-0.58
10-leaf	2.90	3.66	-0.76
12-leaf	3.36	3.53	-0.17
14-leaf	2.53	2.59	-0.06
tassel	2.10	2.09	0.01
silk	1.19	1.20	-0.01
blister	1.92	1.91	0.01
milk	3.47	3.48	-0.01
dough	2.13	1.97	0.16
dent	5.45	4.78	0.67
1/2 mat.	2.34	2.26	0.08
blk lyr	2.06	1.90	0.16
Total	35.07	36.32	-1.25

*Difference is computed with reference to the NPET ETco values.

Table A-7. Table of observed versus adjusted corn ET for planting date 4, 2008.

Crop stage	NPET model ET, inches	Stage adjusted ET , inches	Difference, inches
seeded	0.42	0.42	0.00
emerged	0.71	0.87	-0.16
4-leaf	0.18	0.23	-0.05
4-leaf	0.50	0.90	-0.40
6-leaf	1.36	2.34	-0.98
8-leaf	1.18	1.68	-0.50
10-leaf	3.42	4.49	-1.07
12-leaf	2.63	2.80	-0.17
14-leaf	2.78	2.83	-0.05
tassel	1.14	1.15	-0.01
silk	1.88	1.91	-0.03
blister	2.70	2.72	-0.02
milk	2.20	2.20	0.00
dough	3.47	3.19	0.28
dent	3.34	2.82	0.52
1/2 mat.	2.53	2.30	0.23
blk lyr	2.15	1.67	0.48
Total	32.59	34.52	-1.93

*Difference is computed with reference to the NPET ETco values.

PRODUCER DATA

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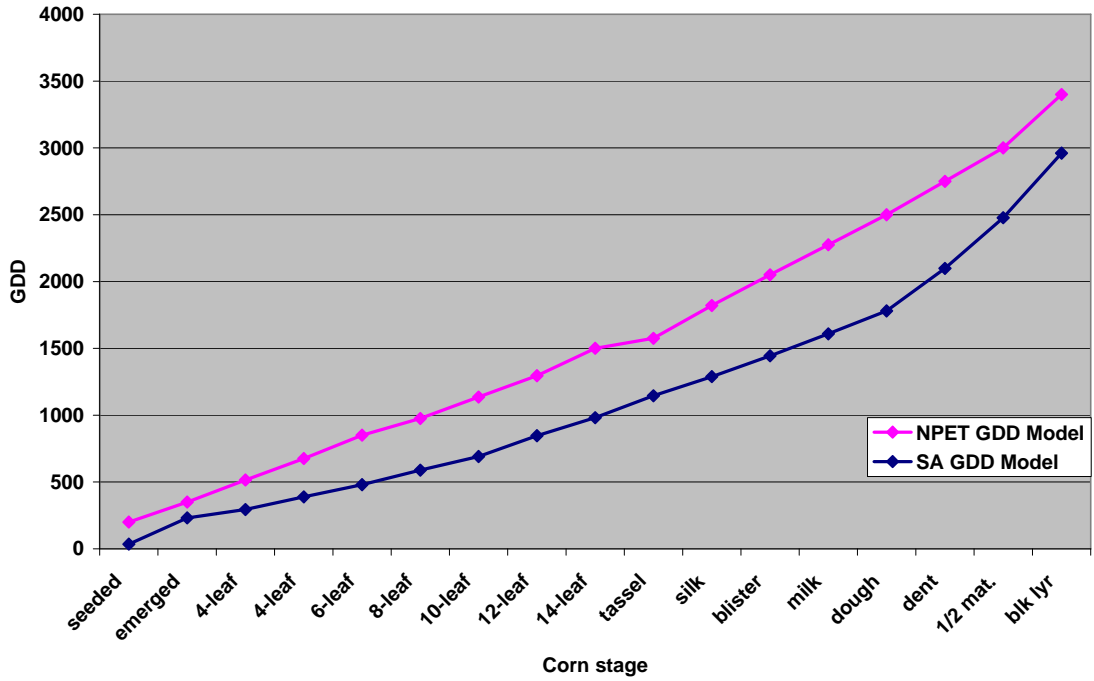


Figure A-24. 2007 Producer Field #1 Corn GDD Comparison.

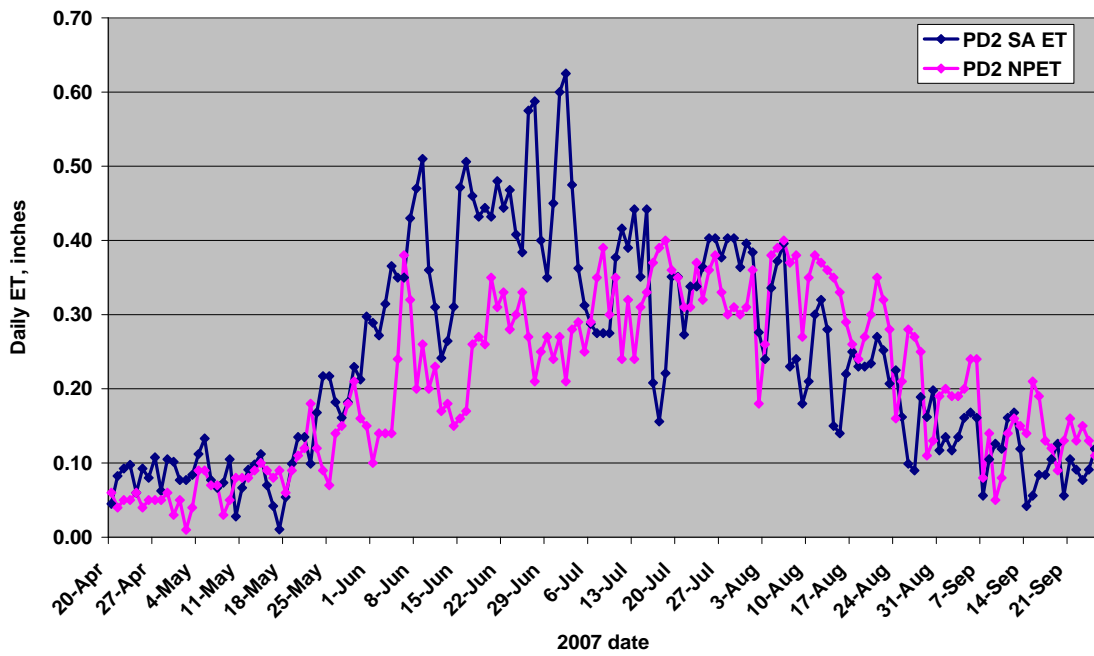


Figure A-25. 2007 Producer Field #1 Corn Daily ET Comparison.

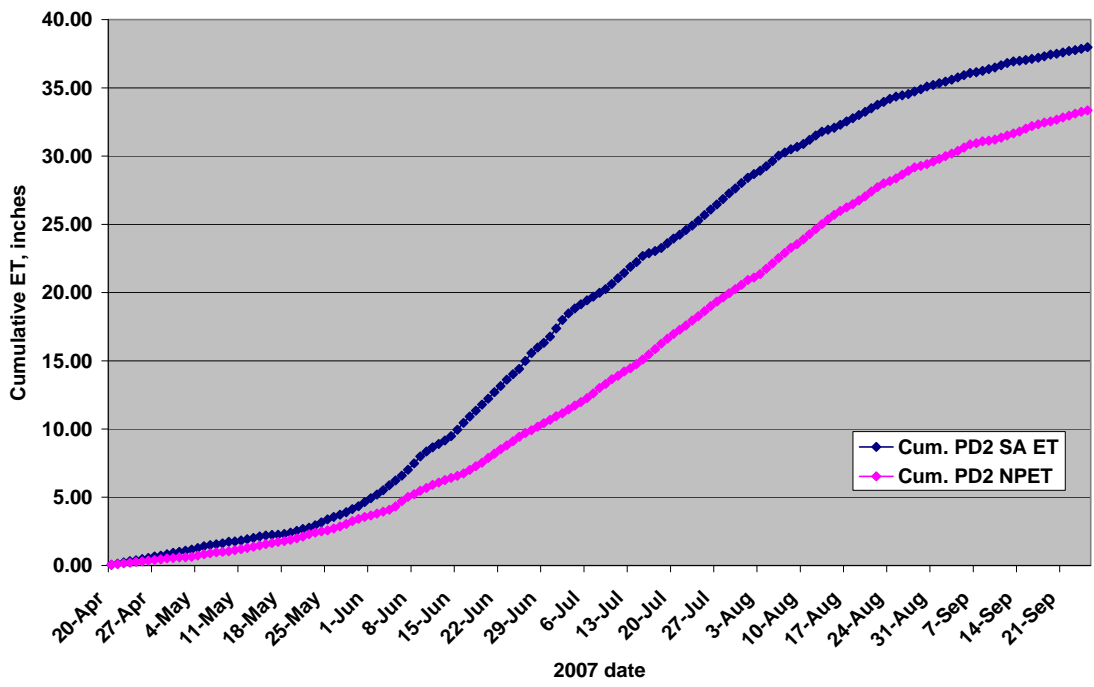


Figure A-26. 2007 Producer Field #1 Corn Cumulative ET Comparison.

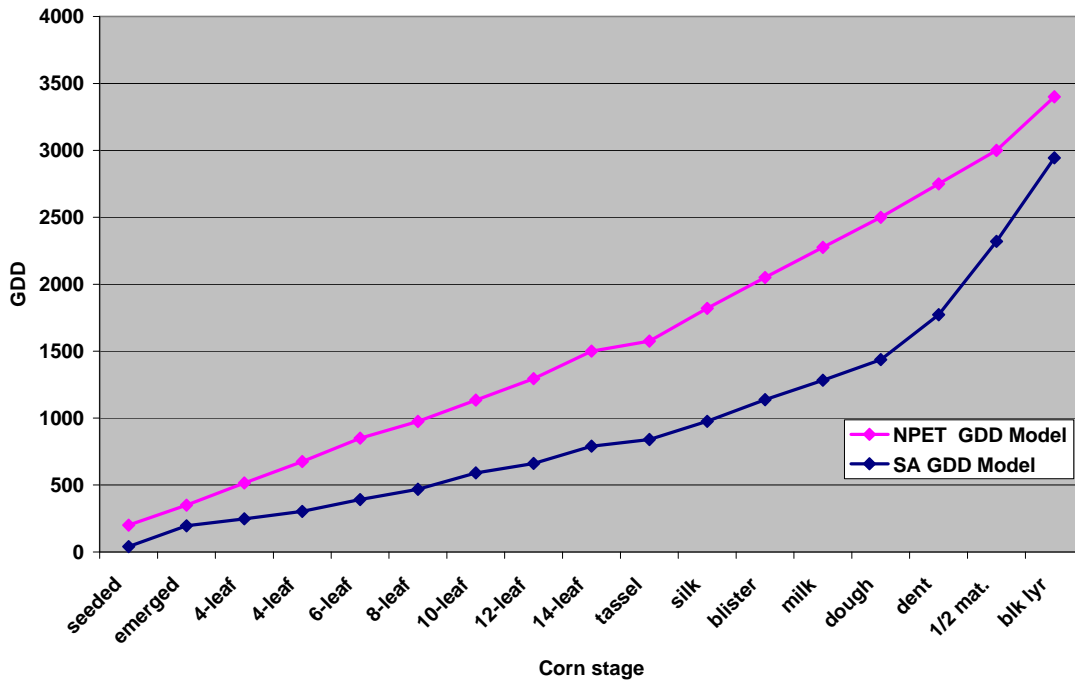


Figure A-27. 2007 Producer Field #2 Corn GDD Comparison.

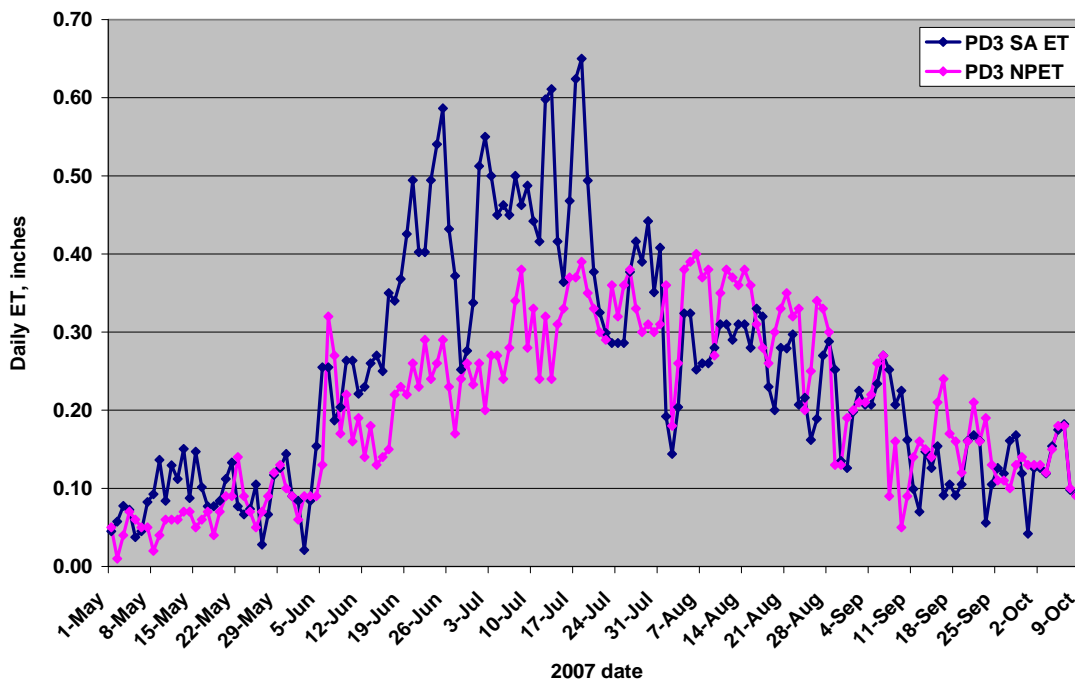


Figure A-28. 2007 Producer Field #2 Corn Daily ET Comparison.

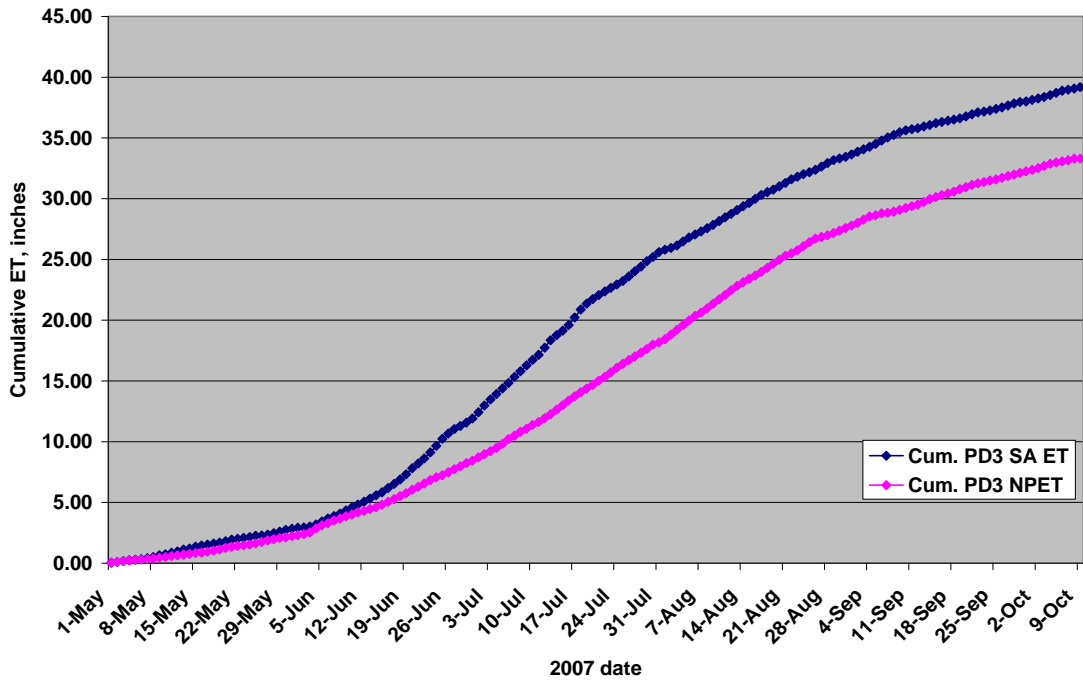


Figure A-29. 2007 Producer Field #2 Corn Cumulative ET Comparison.

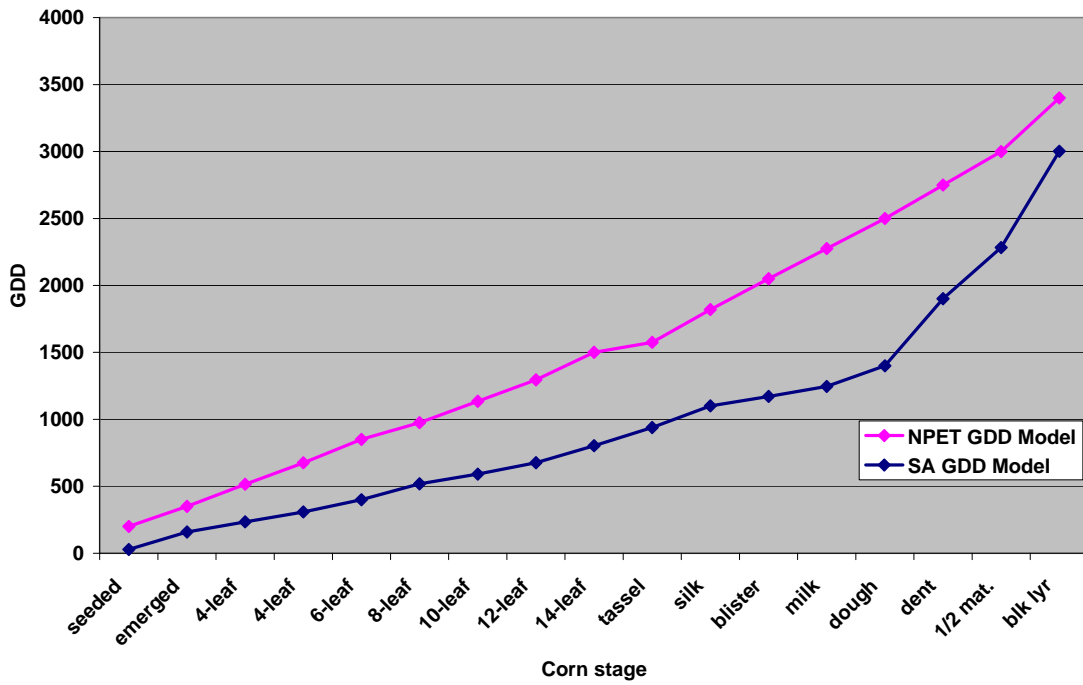


Figure A-30. 2007 Producer Field #3 Corn GDD Comparison.

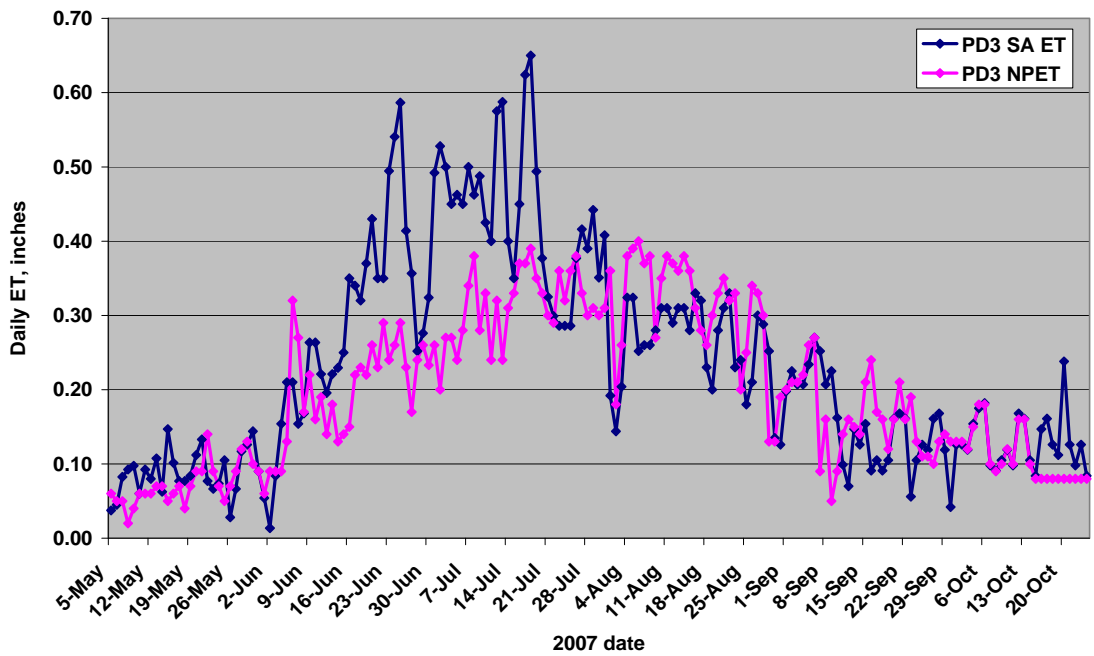


Figure A-31. 2007 Producer Field #3 Corn Daily ET Comparison.

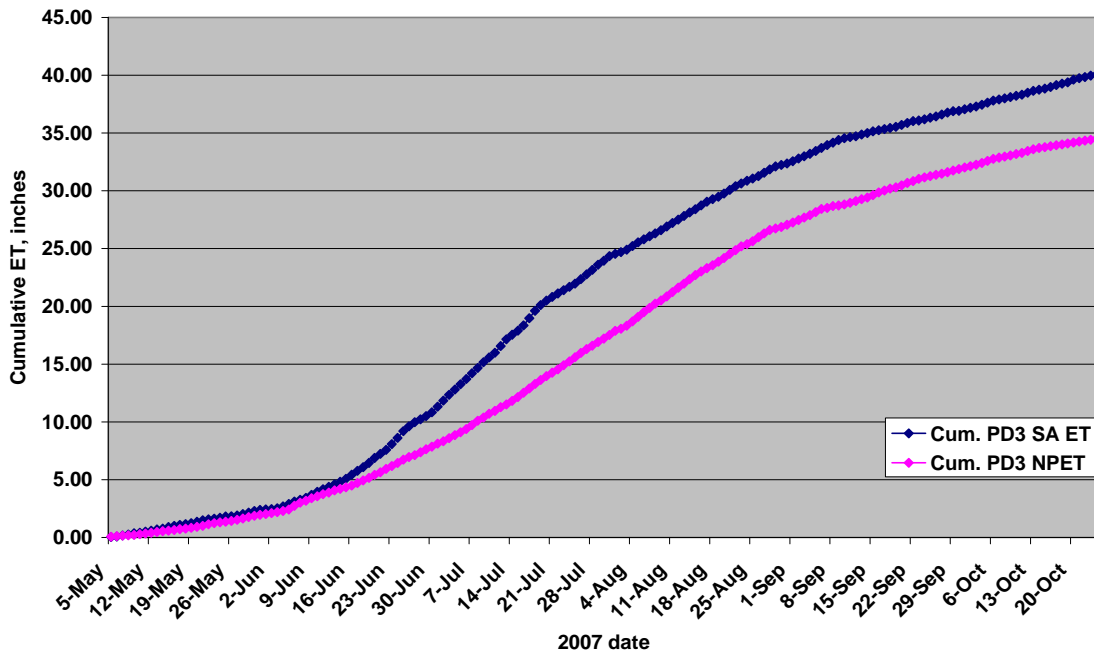


Figure A-32. 2007 Producer Field #3 Corn Cumulative ET Comparison.

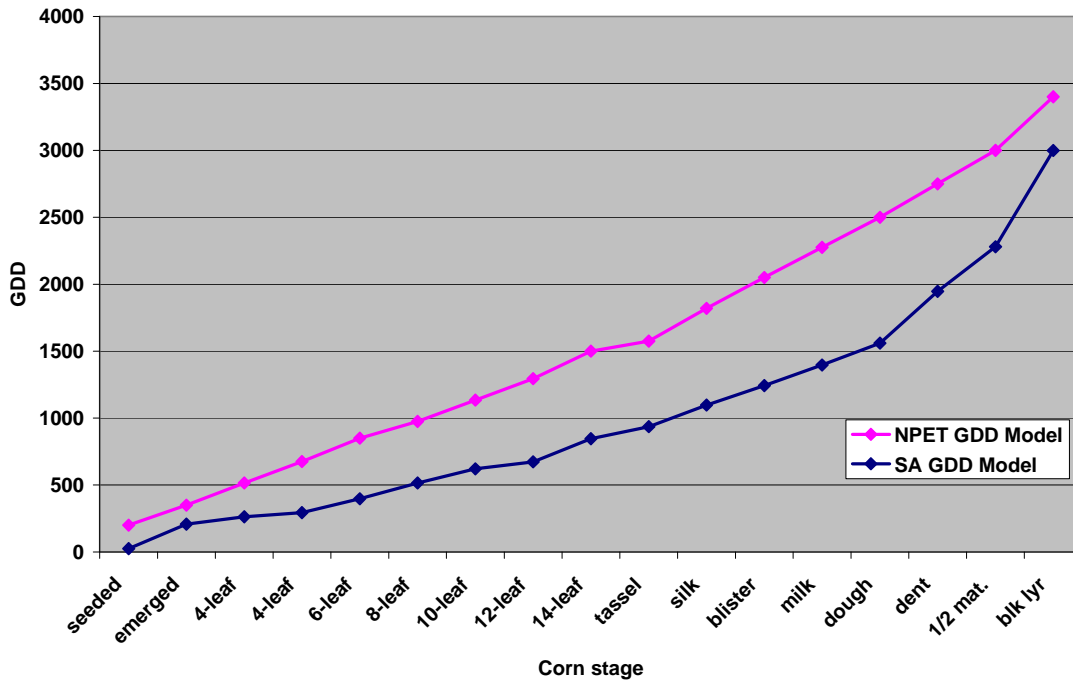


Figure A-33. 2007 Producer Field #4 Corn GDD Comparison.

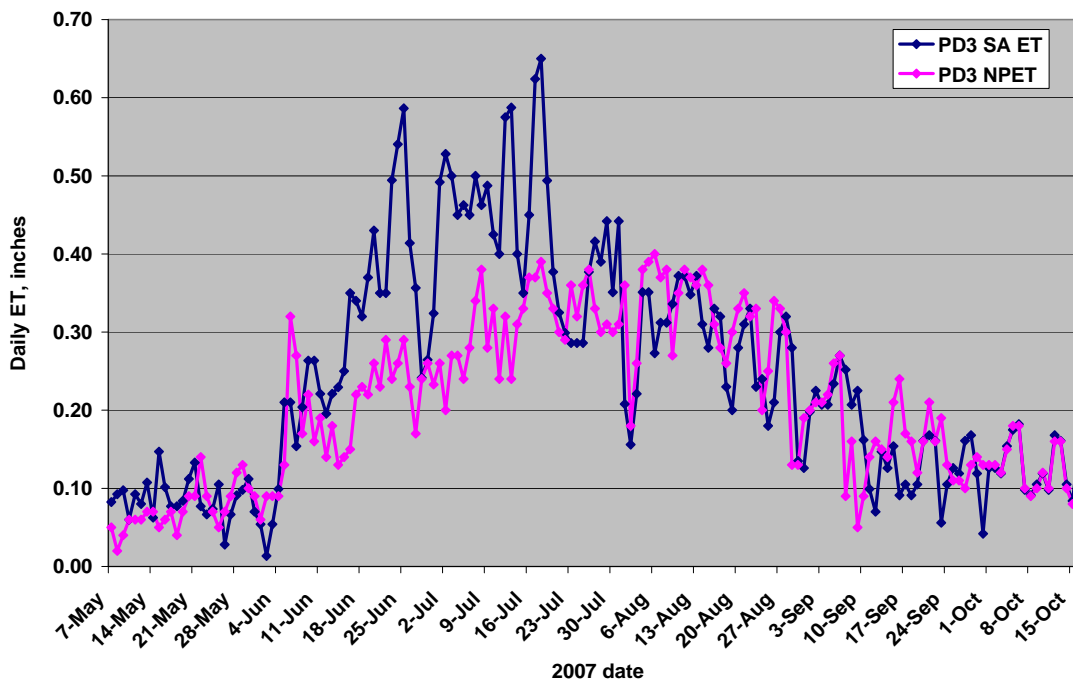


Figure A-34. 2007 Producer Field #4 Corn Daily ET Comparison.

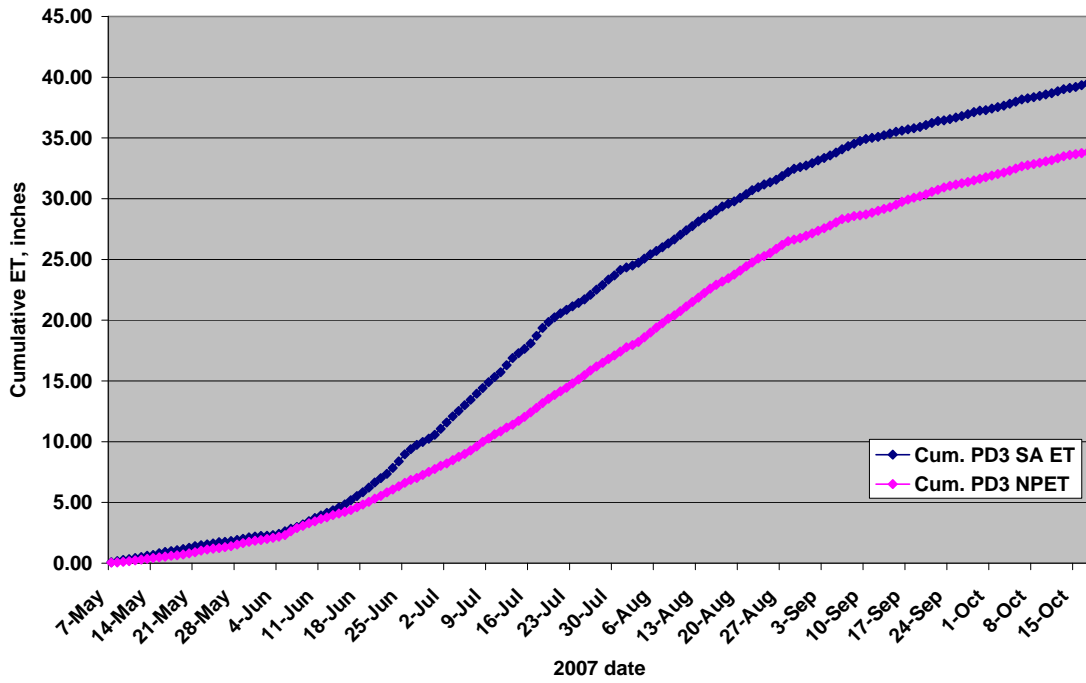


Figure A-35. 2007 Producer Field #4 Corn Cumulative ET Comparison.

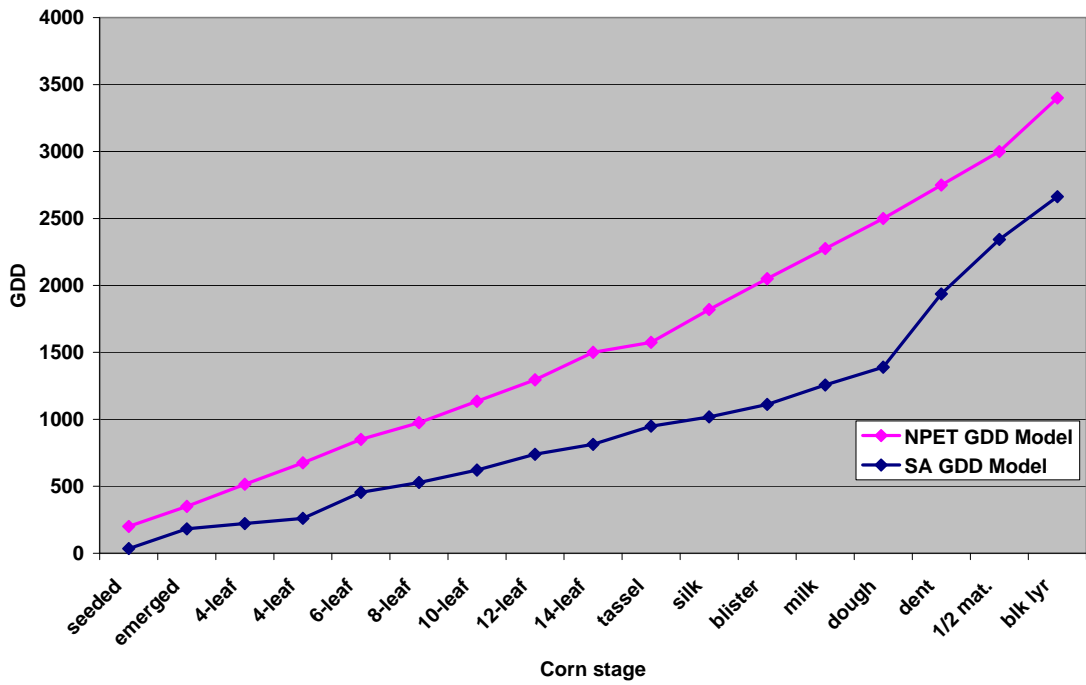


Figure A-36. 2007 Producer Field #5 Corn GDD Comparison.

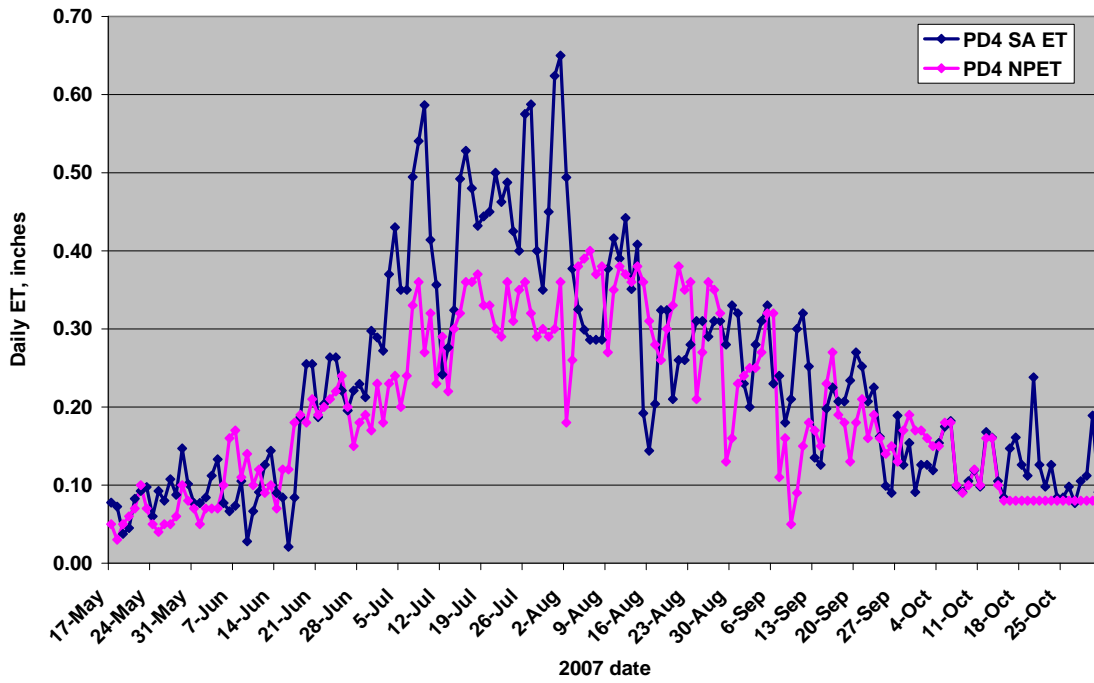


Figure A-37. 2007 Producer Field #5 Corn Daily ET Comparison.

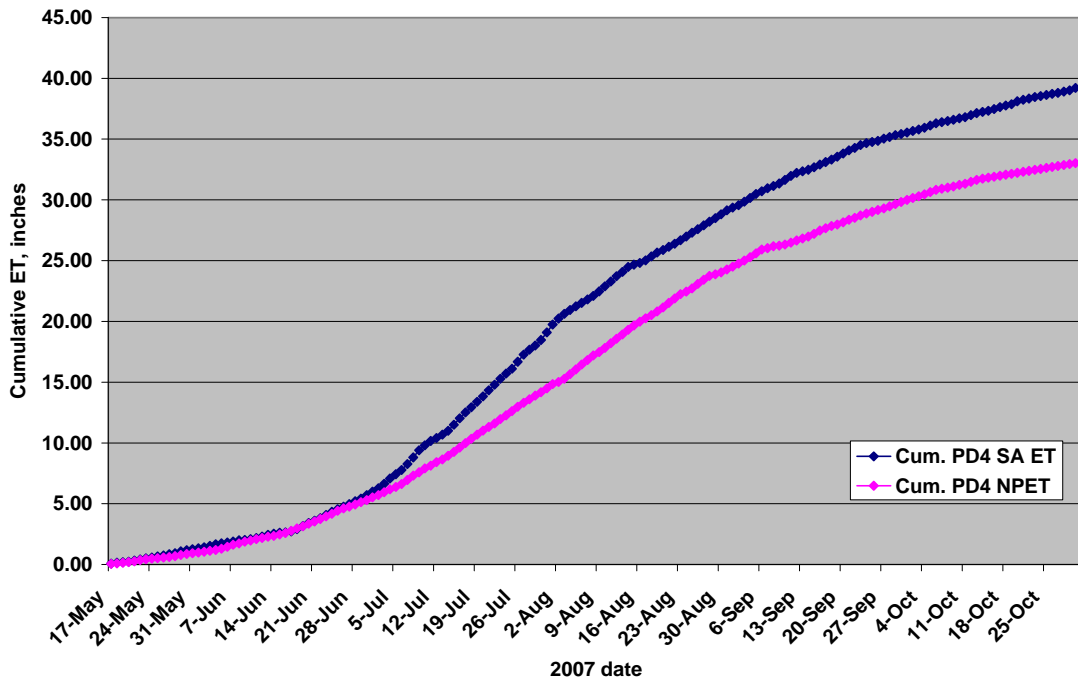


Figure A-38. 2007 Producer Field #5 Corn Cumulative ET Comparison.

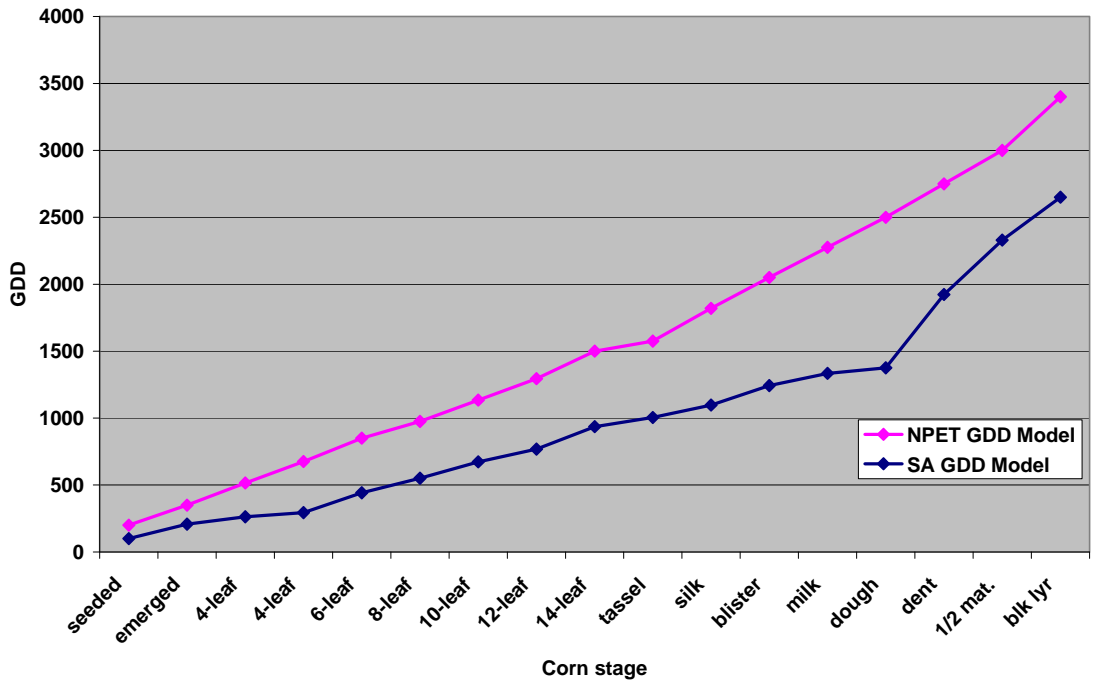


Figure A-39. 2007 Producer Field #6 Corn GDD Comparison.

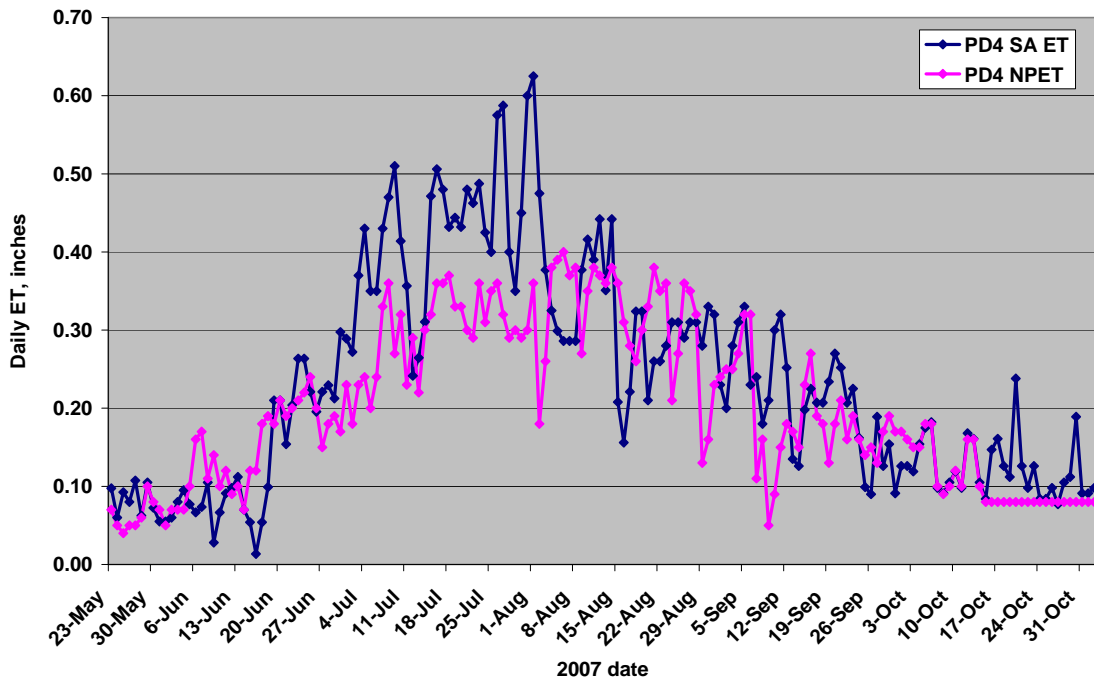


Figure A-40. 2007 Producer Field #6 Corn Daily ET Comparison.

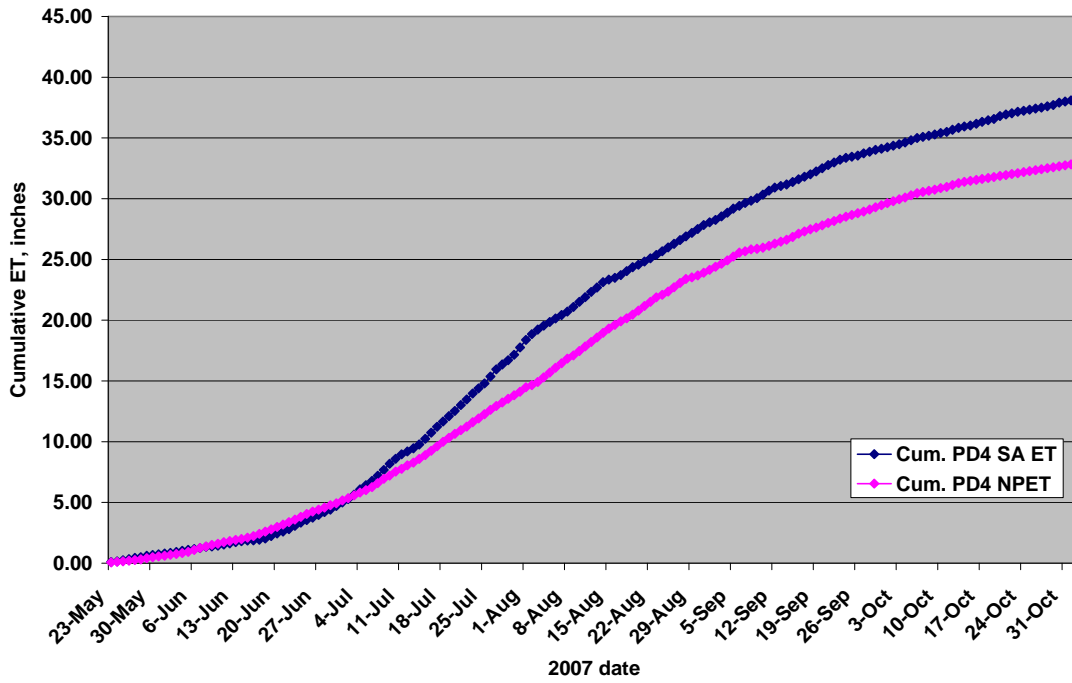


Figure A-41. 2007 Producer Field #6 Corn Cumulative ET Comparison.

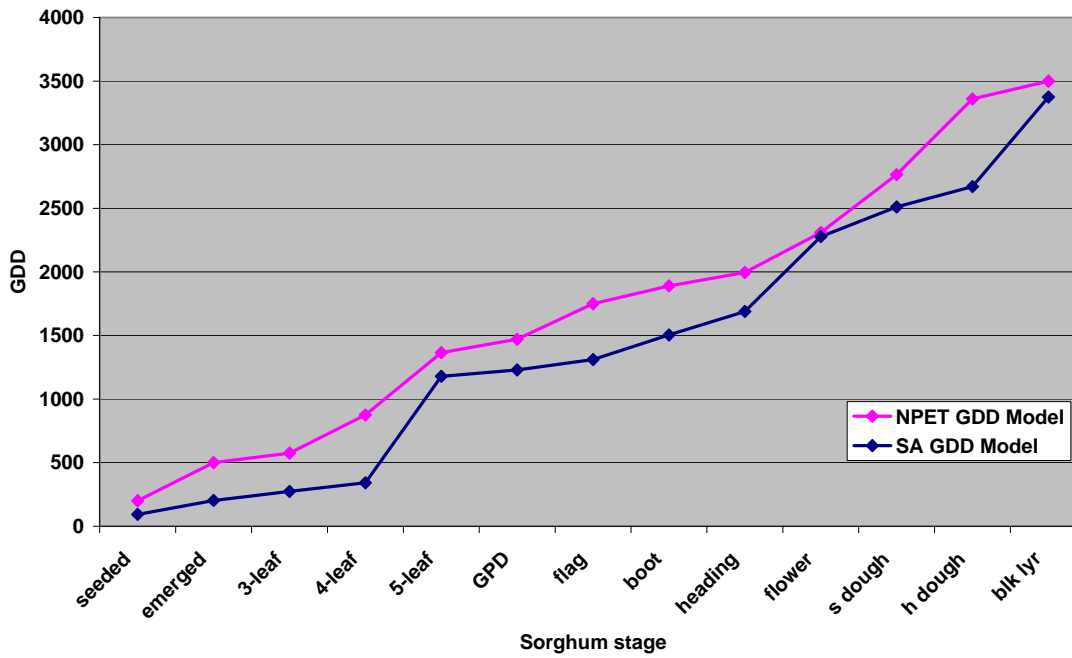


Figure A-42. 2007 Producer Field #1 Sorghum GDD Comparison.

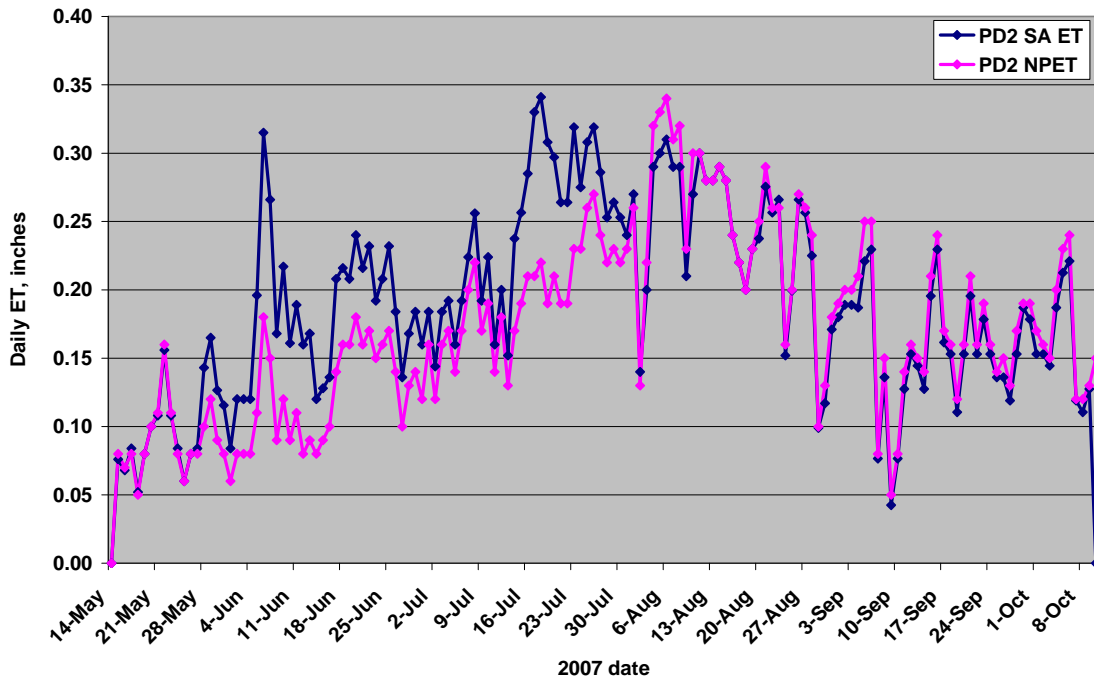


Figure A-43. 2007 Producer Field #1 Sorghum Daily ET Comparison.

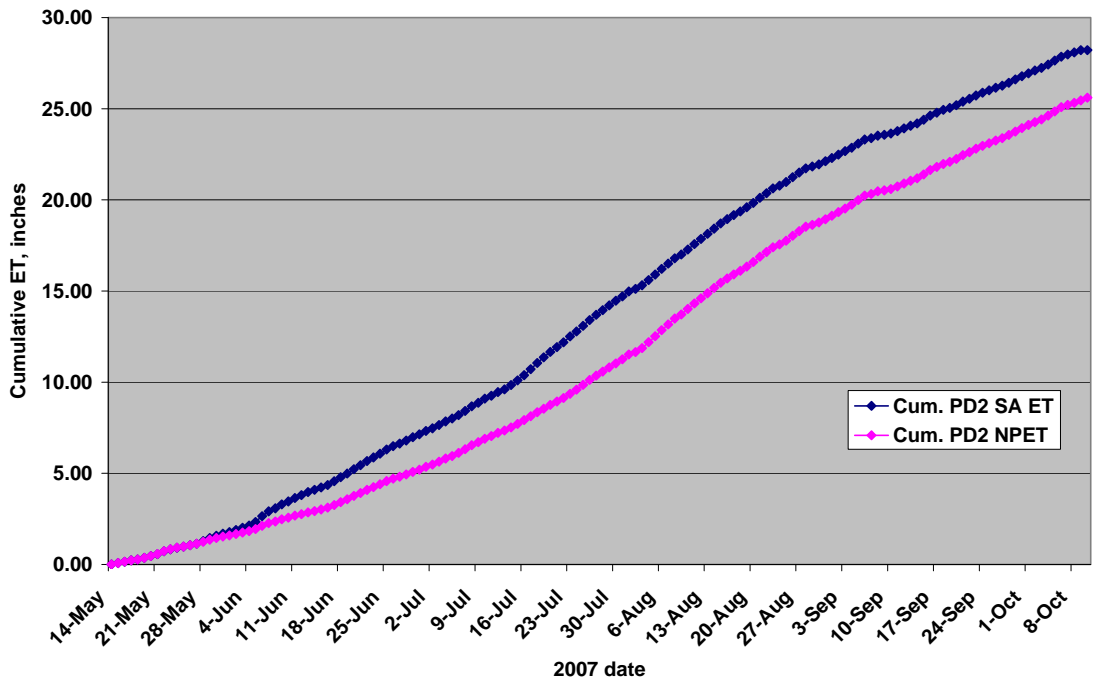


Figure A-44. 2007 Producer Field #1 Sorghum Cumulative ET Comparison.

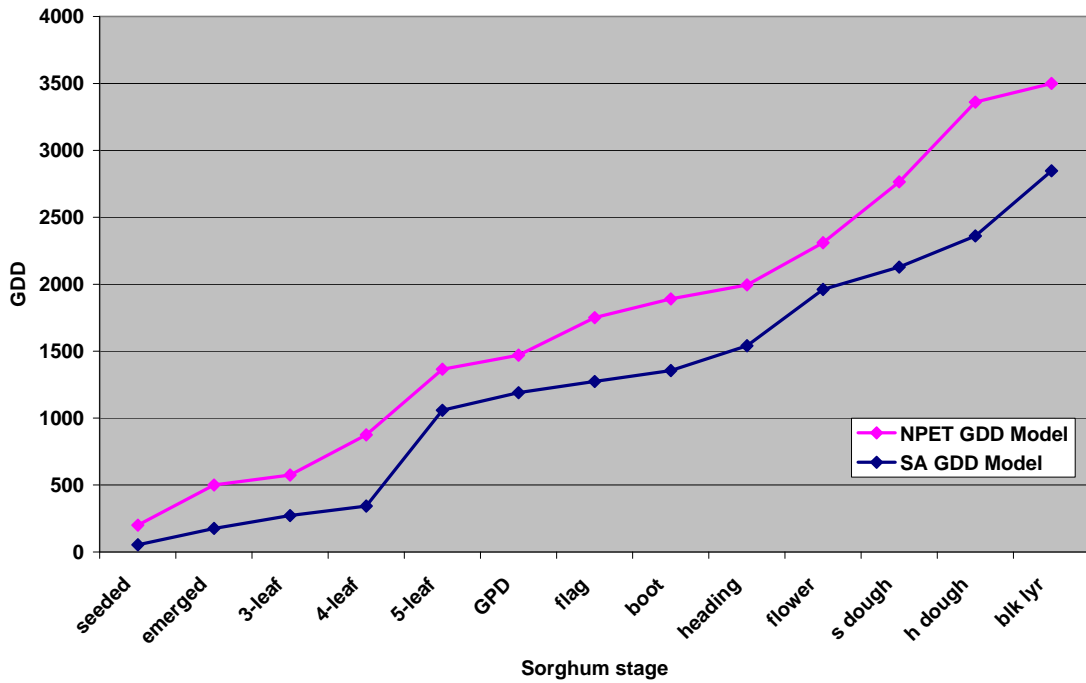


Figure A-45. 2007 Producer Field #2. Sorghum GDD Comparison.

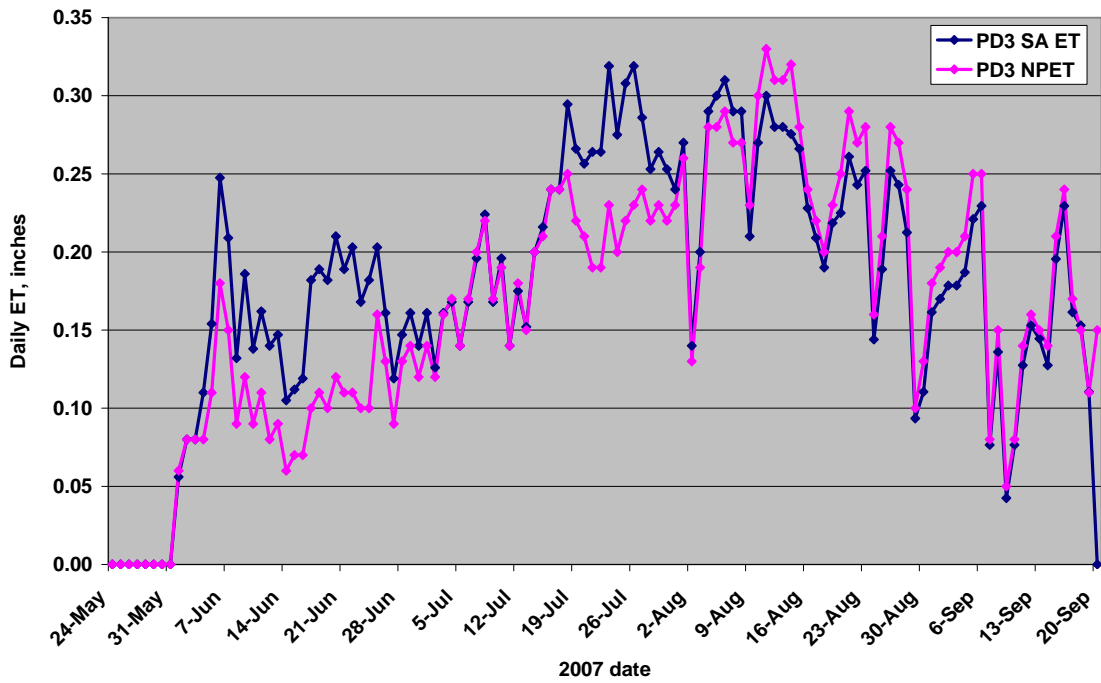


Figure A-46. 2007 Producer Field #2 Sorghum Daily ET Comparison.

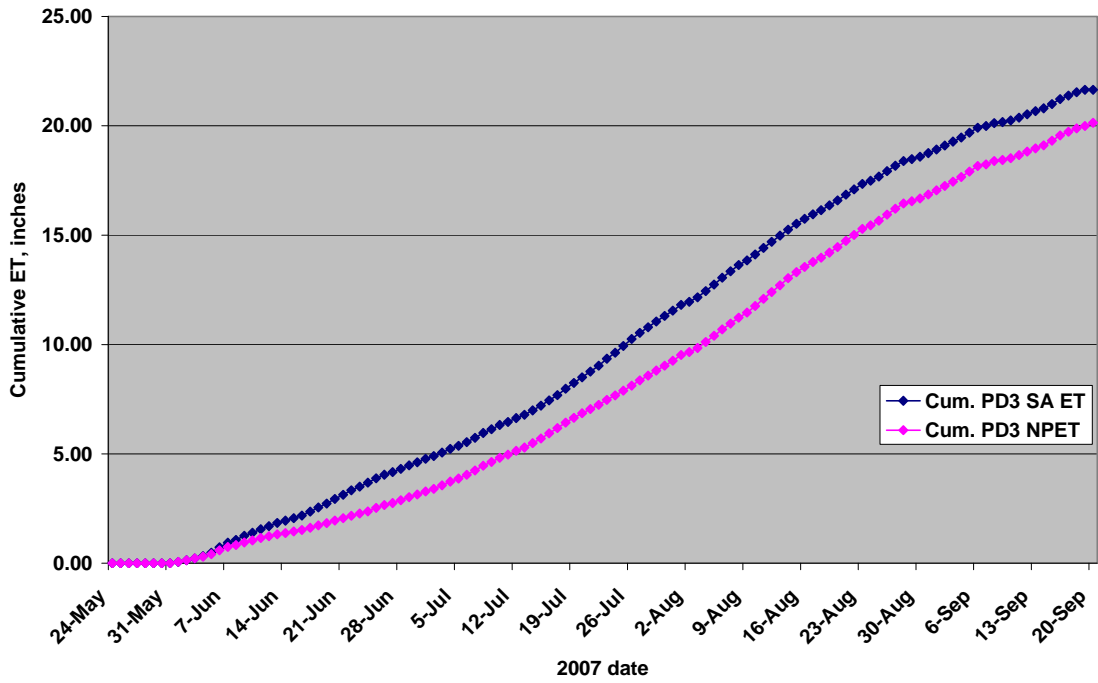


Figure A-47. 2007 Producer Field #2 Sorghum Cumulative ET Comparison.

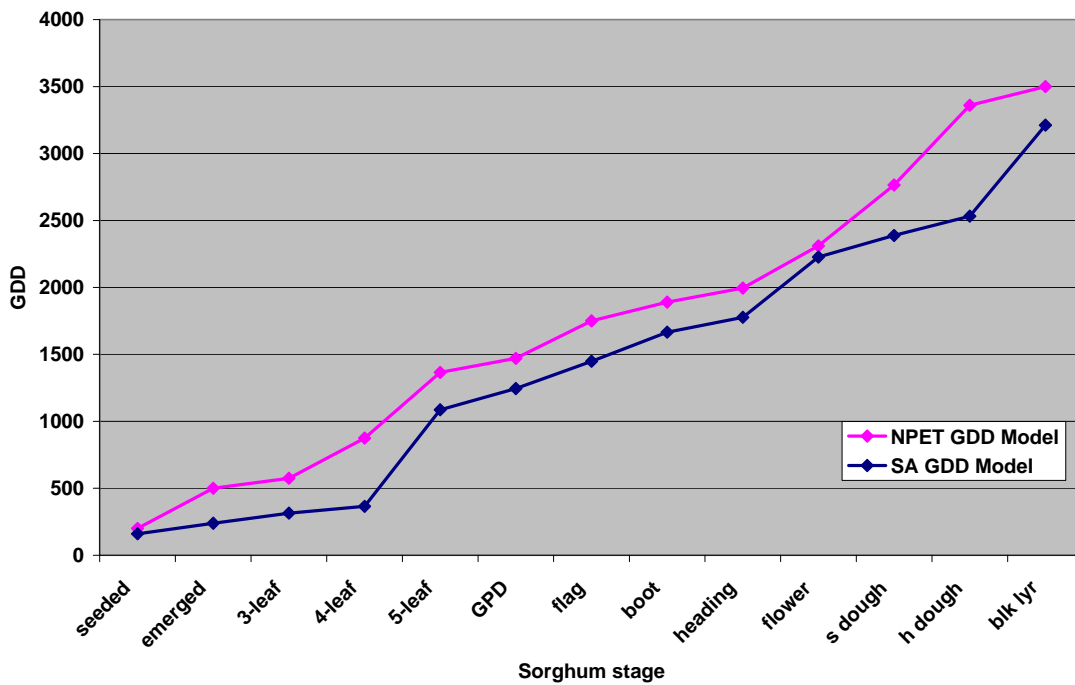


Figure A-48. 2007 Producer Field #3 Sorghum GDD Comparison.

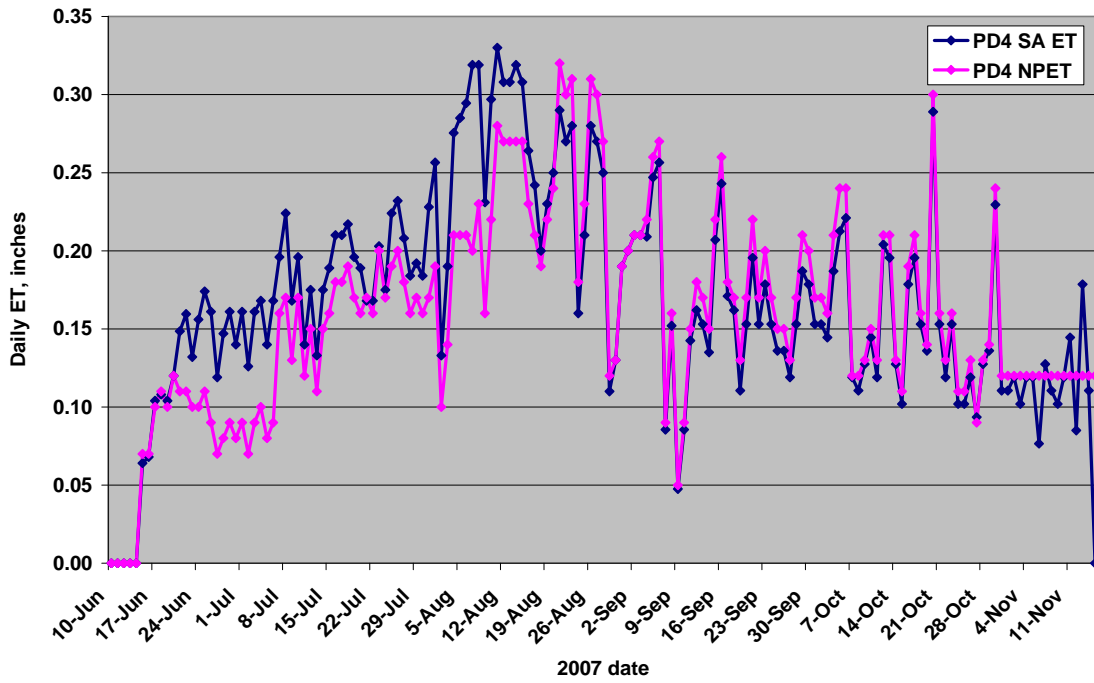


Figure A-49. 2007 Producer Field #3 Sorghum Daily ET Comparison.

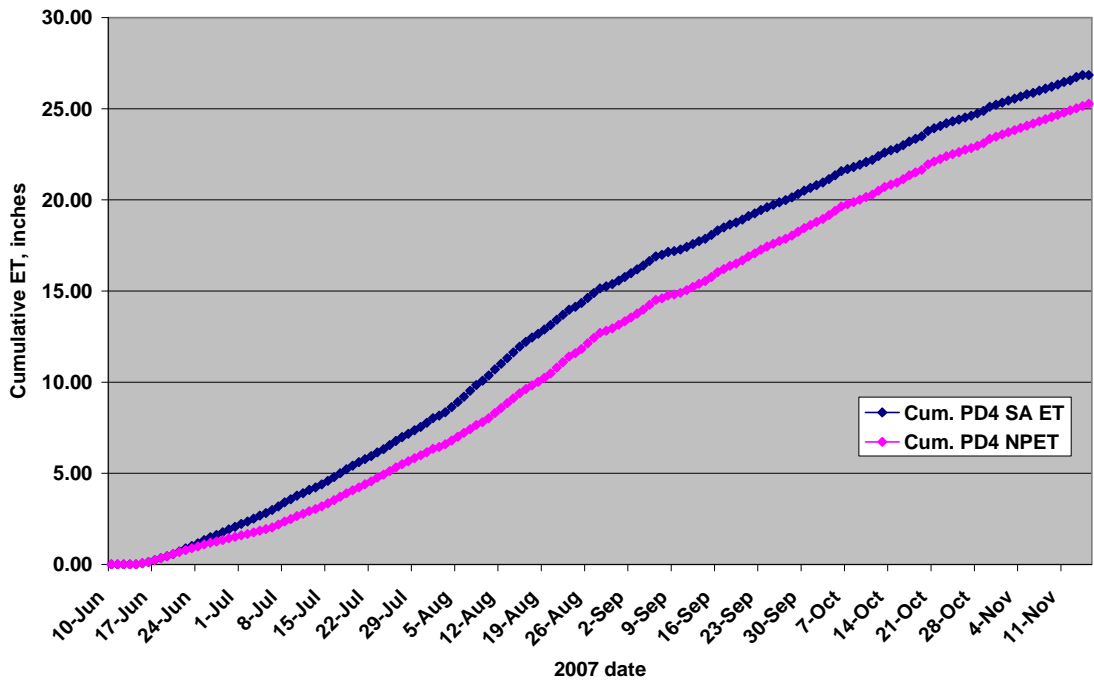


Figure A-50. 2007 Producer Field #3 Sorghum Cumulative ET Comparison.

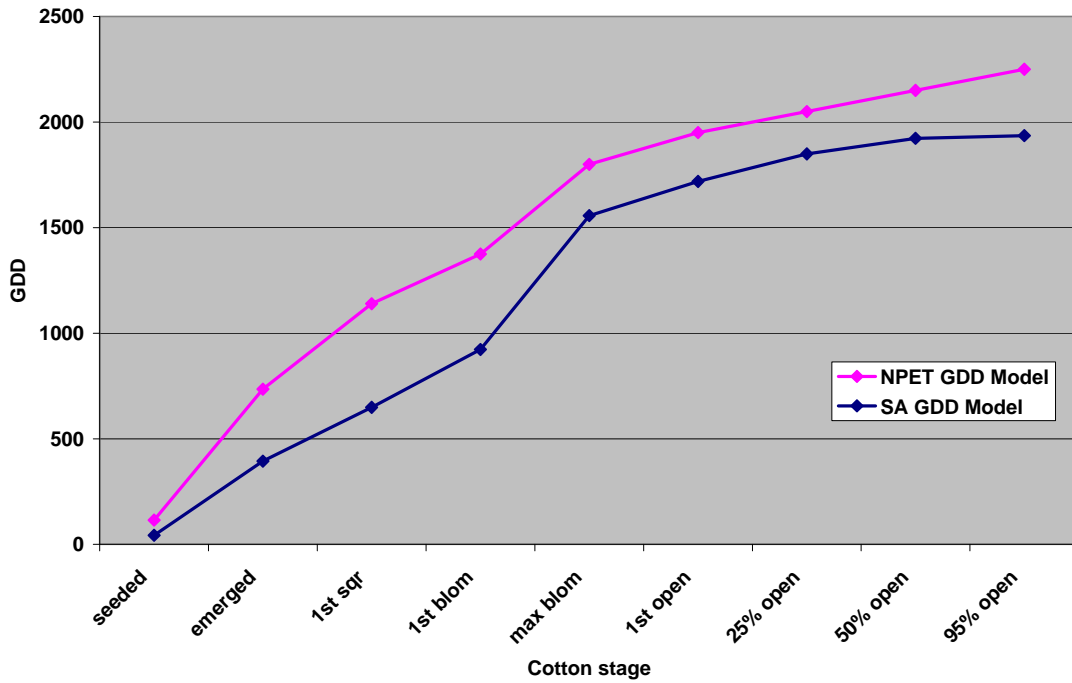


Figure A-51. 2007 Producer Field #1 Cotton GDD Comparison.

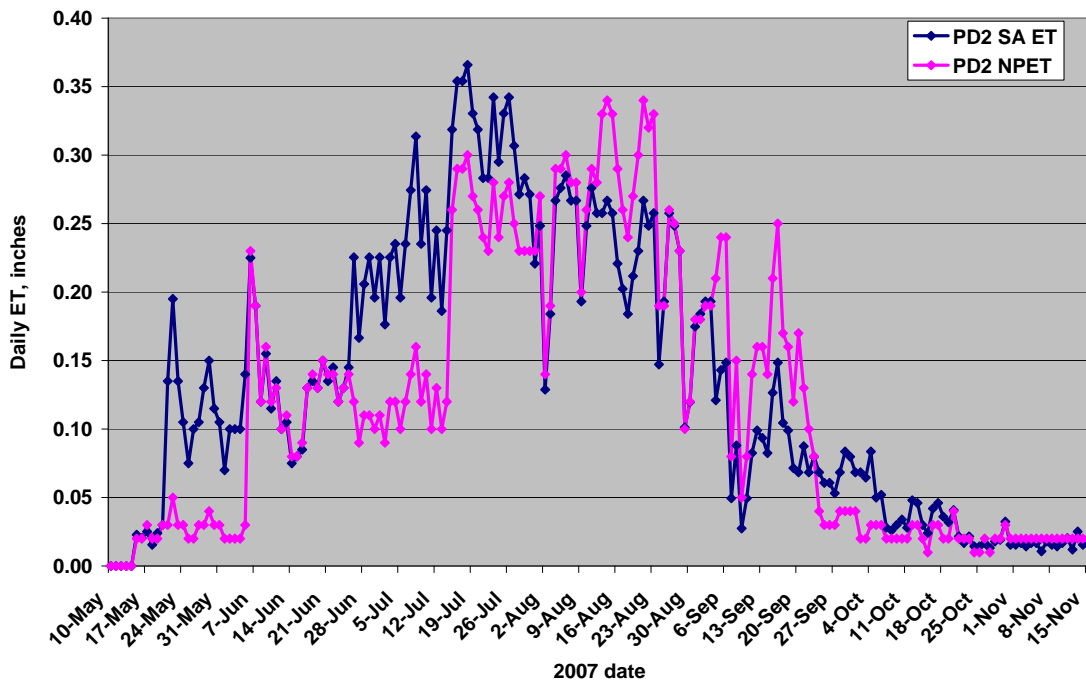


Figure A-52. 2007 Producer Field #1 Cotton Daily ET Comparison.

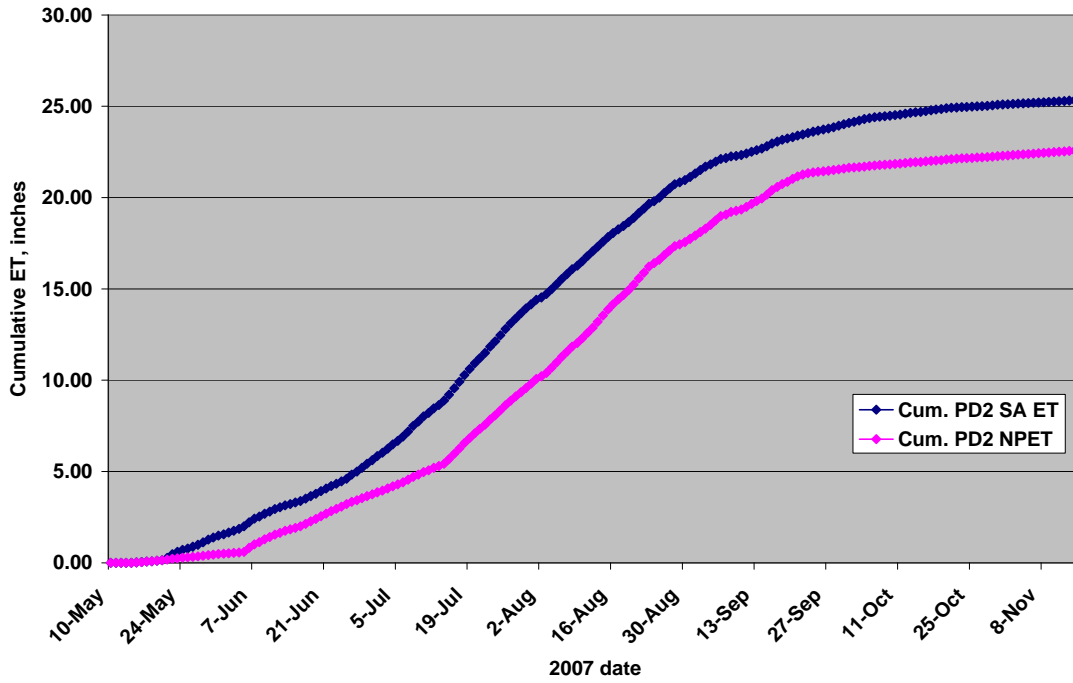


Figure A-53. 2007 Producer Field #1 Cotton Cumulative ET Comparison.

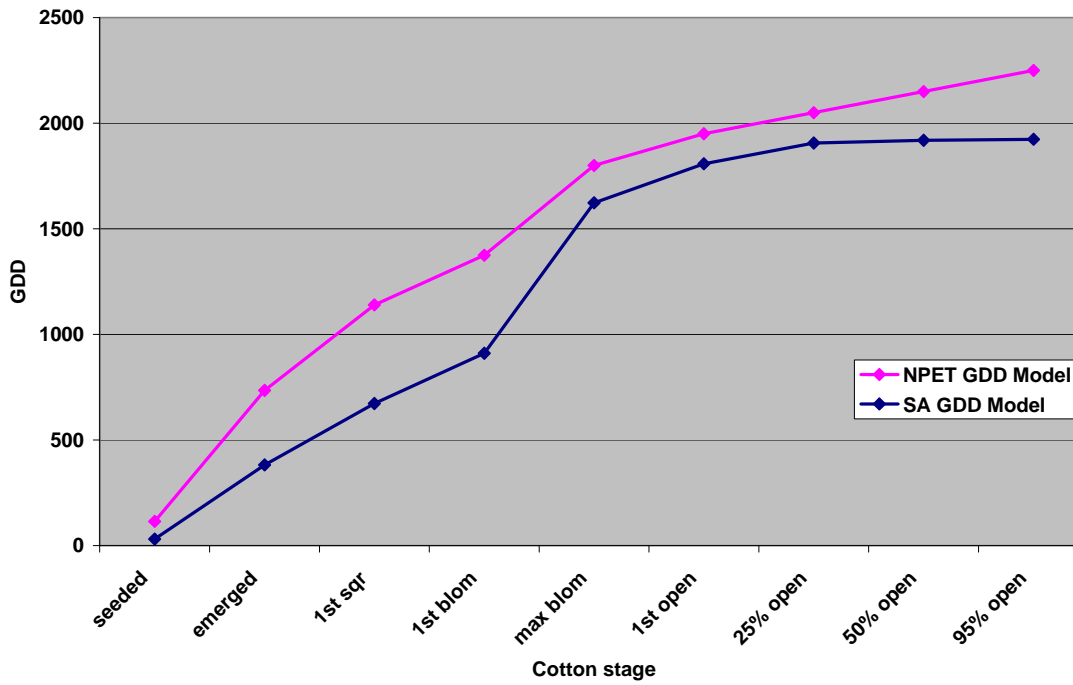


Figure A-54. 2007 Producer Field #2 Cotton GDD Comparison.

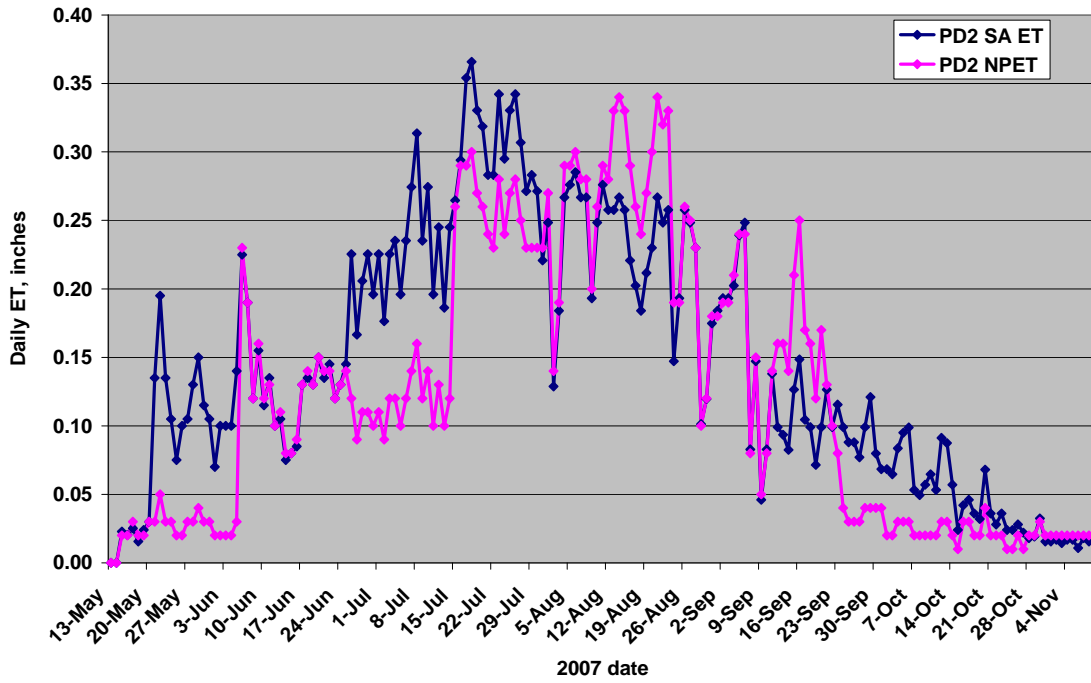


Figure A-55. 2007 Producer Field #2 Cotton Daily ET Comparison.

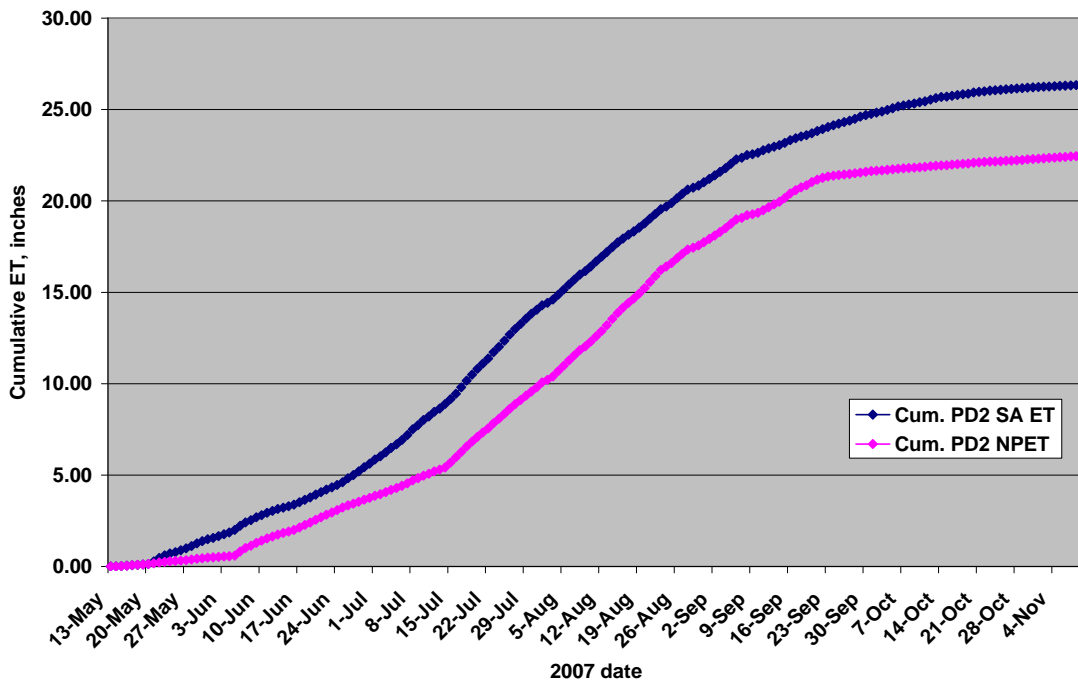


Figure A-56. 2007 Producer Field #2 Cotton Cumulative ET Comparison.

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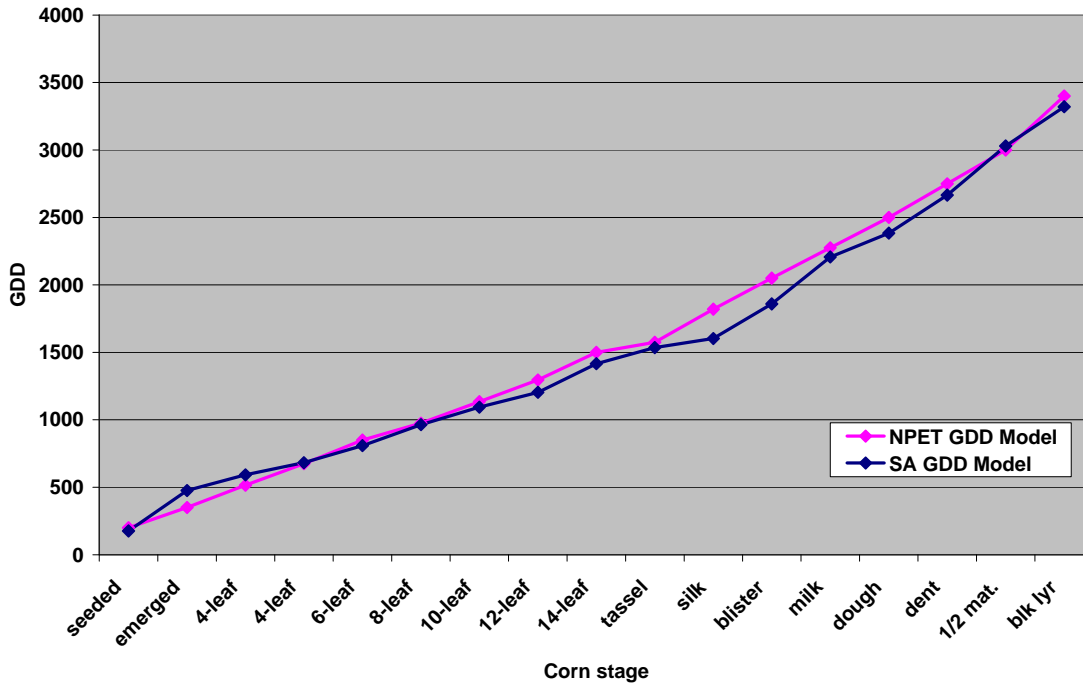


Figure A-57. 2008 Producer Field #1 Corn GDD Comparison.

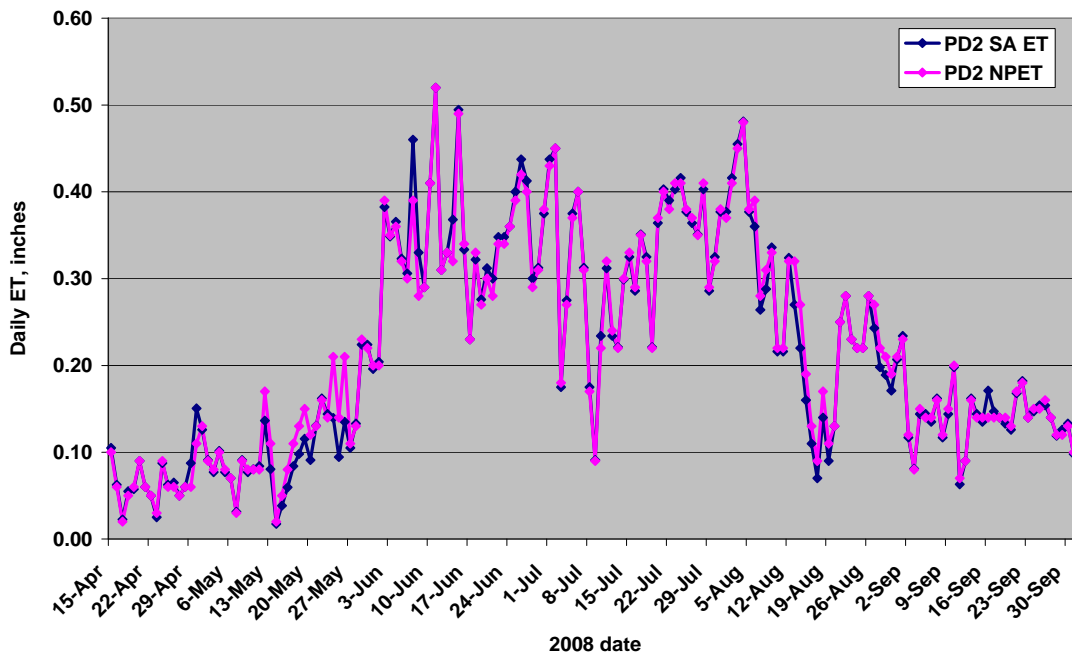


Figure A-58. 2008 Producer Field #1 Corn Daily ET Comparison.

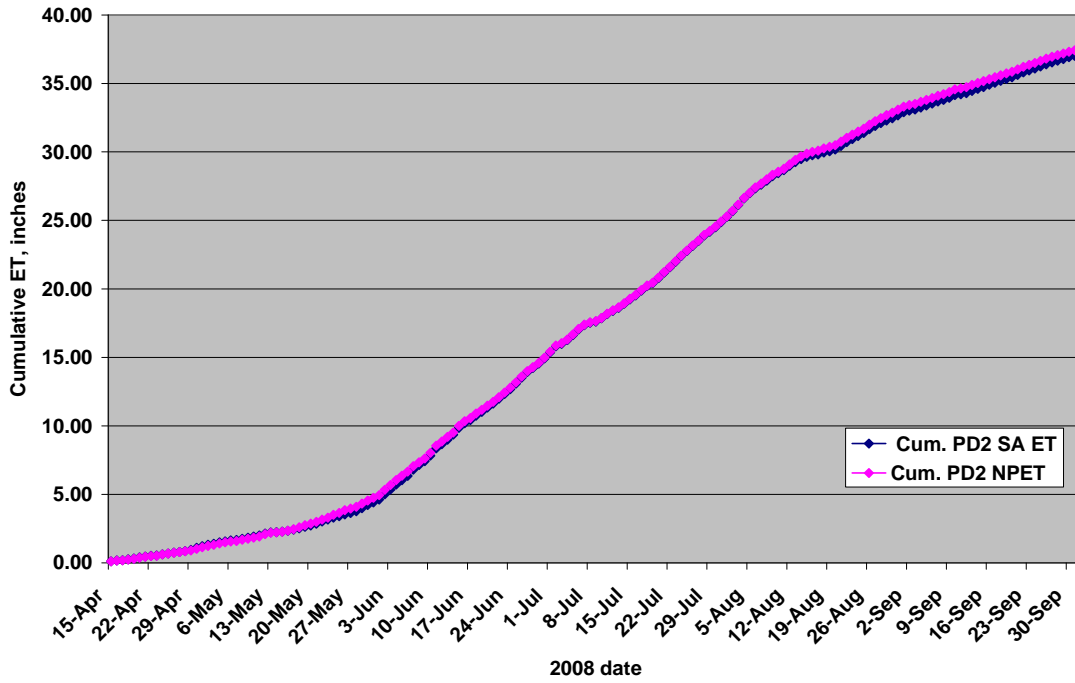


Figure A-59. 2008 Producer Field #1 Corn Cumulative ET Comparison.

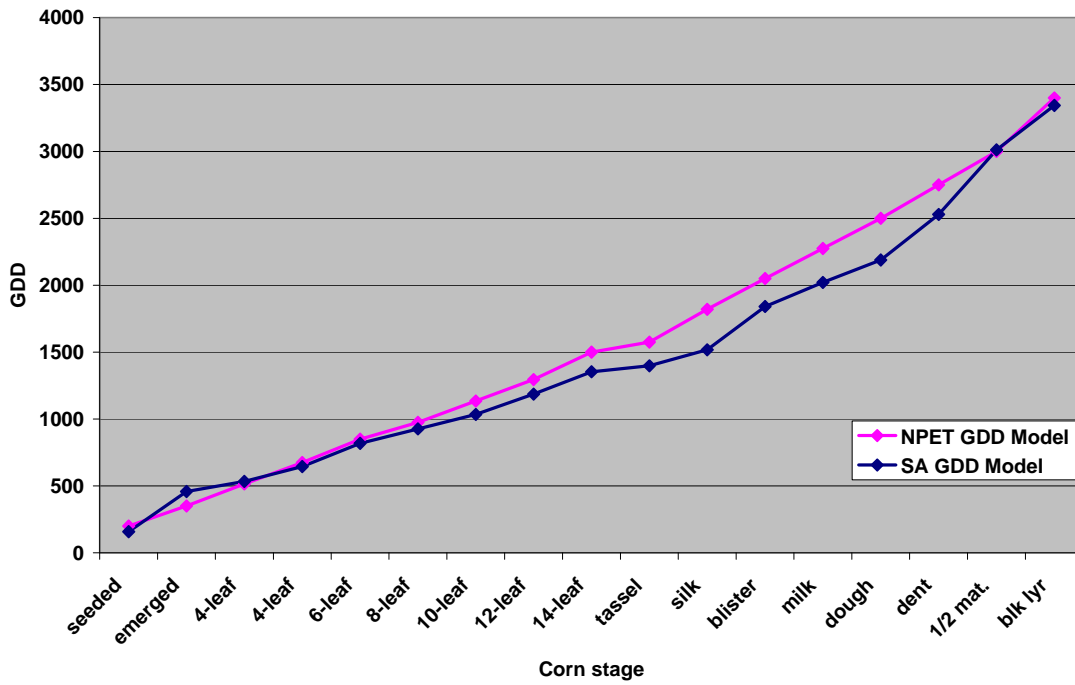


Figure A-60. 2008 Producer Field #2 Corn GDD Comparison.

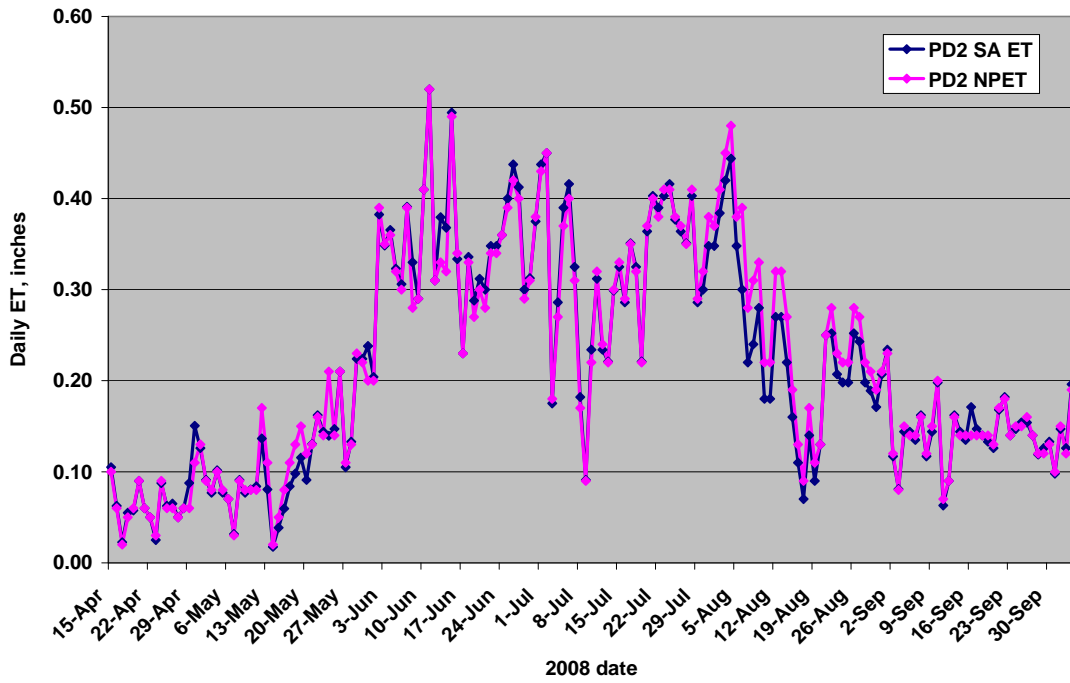


Figure A-61. 2008 Producer Field #2 Corn Daily ET Comparison.

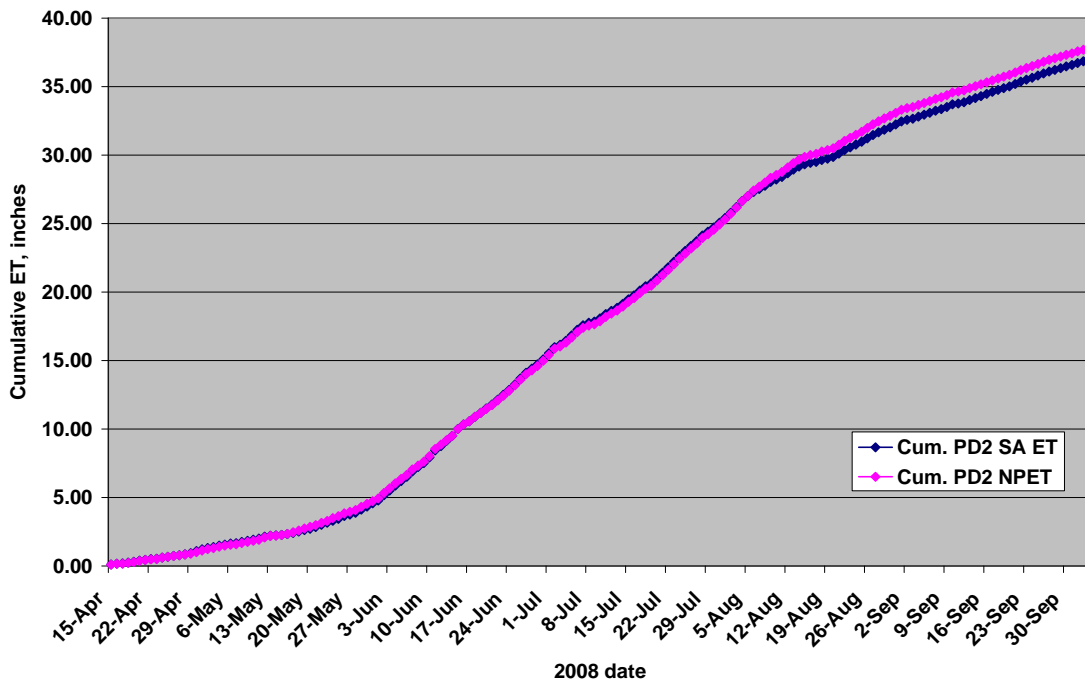


Figure A-62. 2008 Producer Field #2 Corn Cumulative ET Comparison.

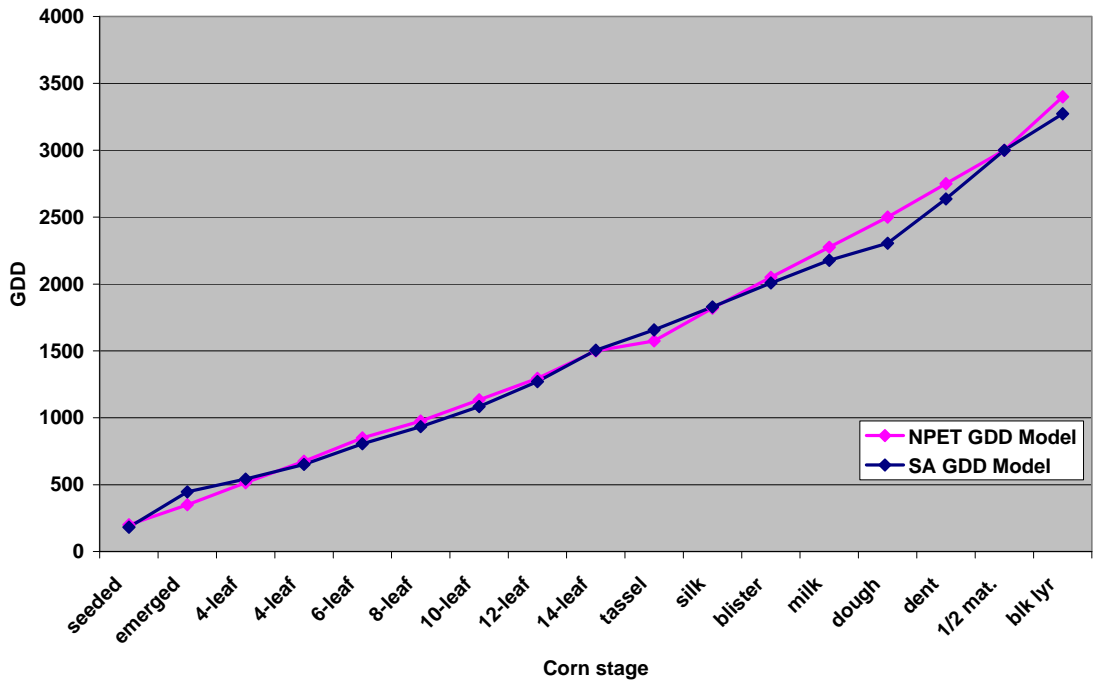


Figure A-63. 2008 Producer Field #3 Corn GDD Comparison.

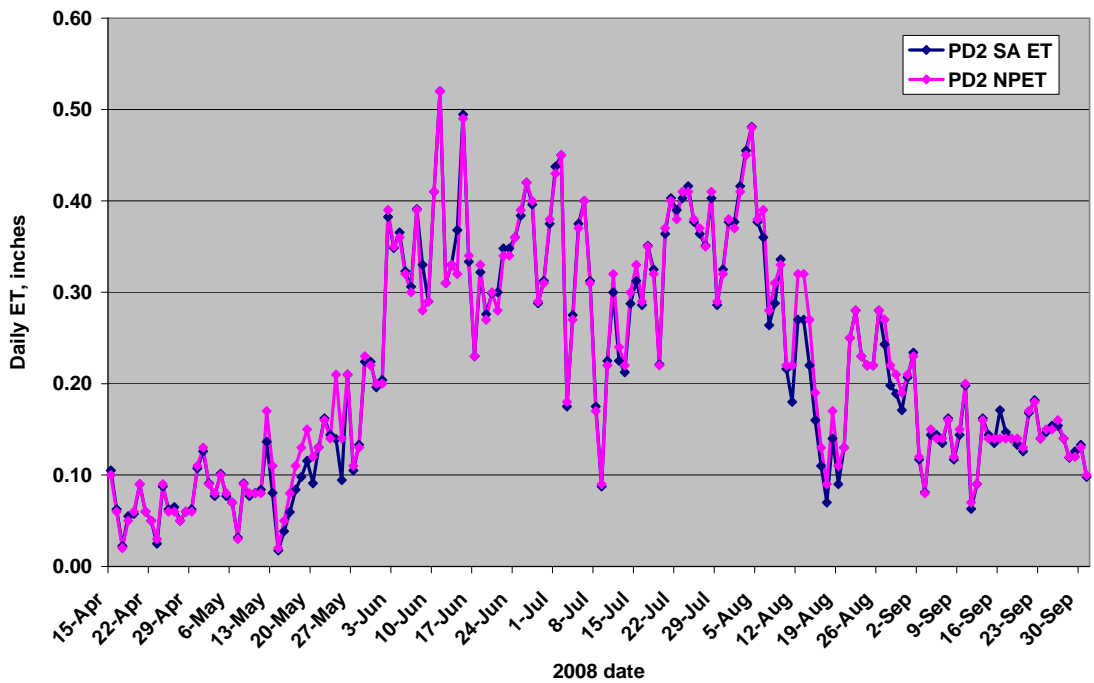


Figure A-64. 2008 Producer Field #3 Corn Daily ET Comparison.

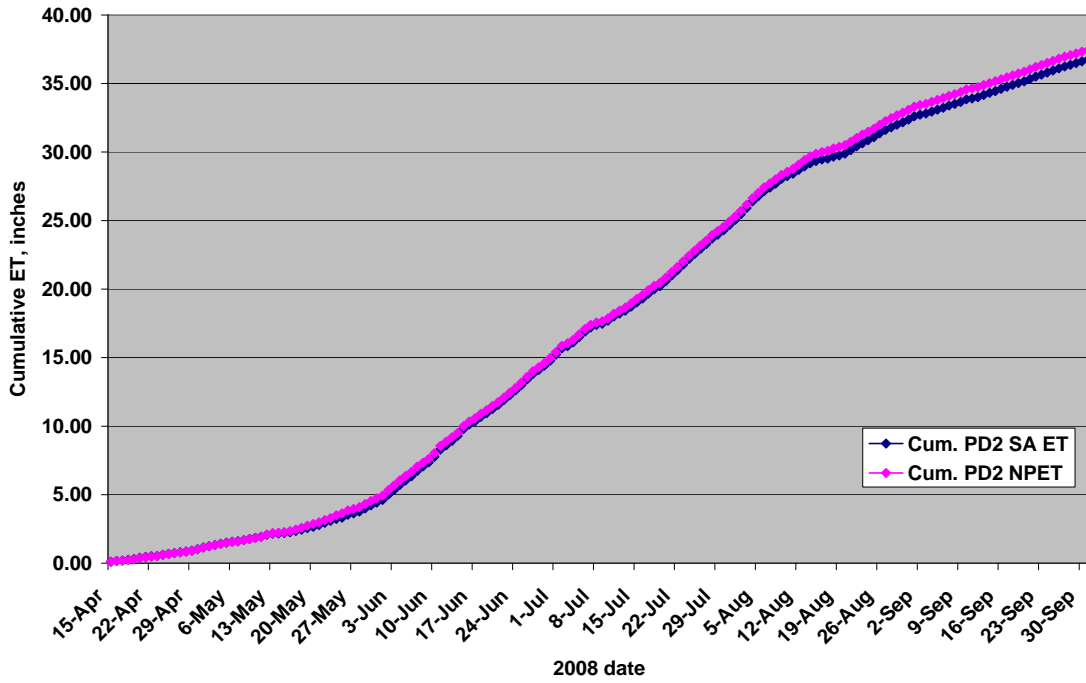


Figure A-65. 2008 Producer Field #3 Corn Cumulative ET Comparison.

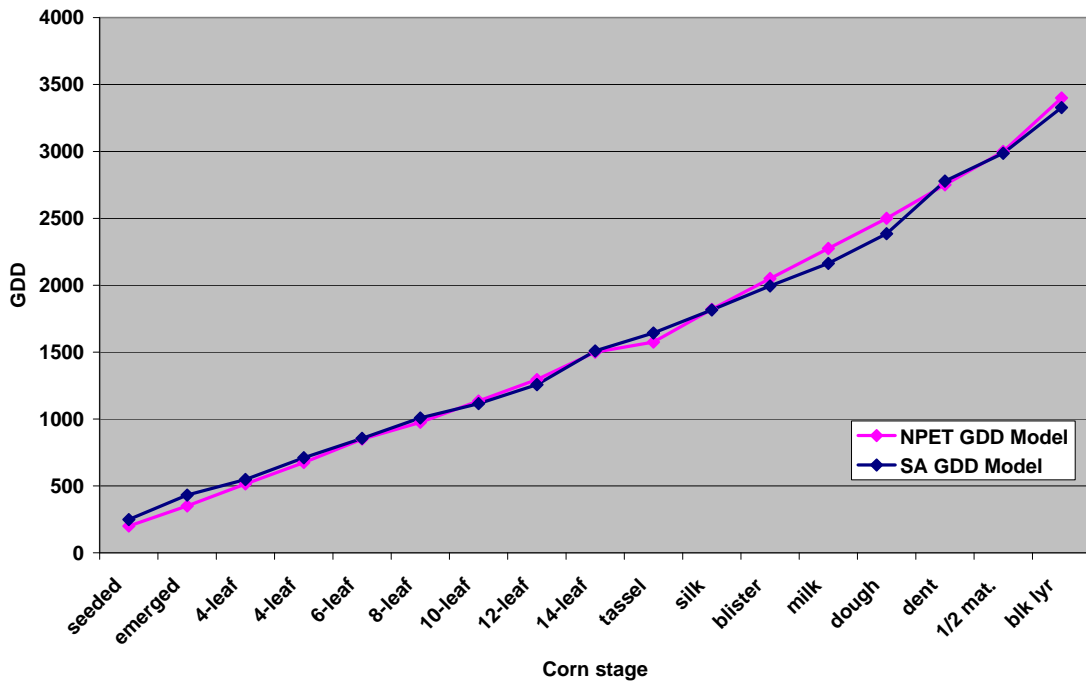


Figure A-66. 2008 Producer Field #4 Corn GDD Comparison.

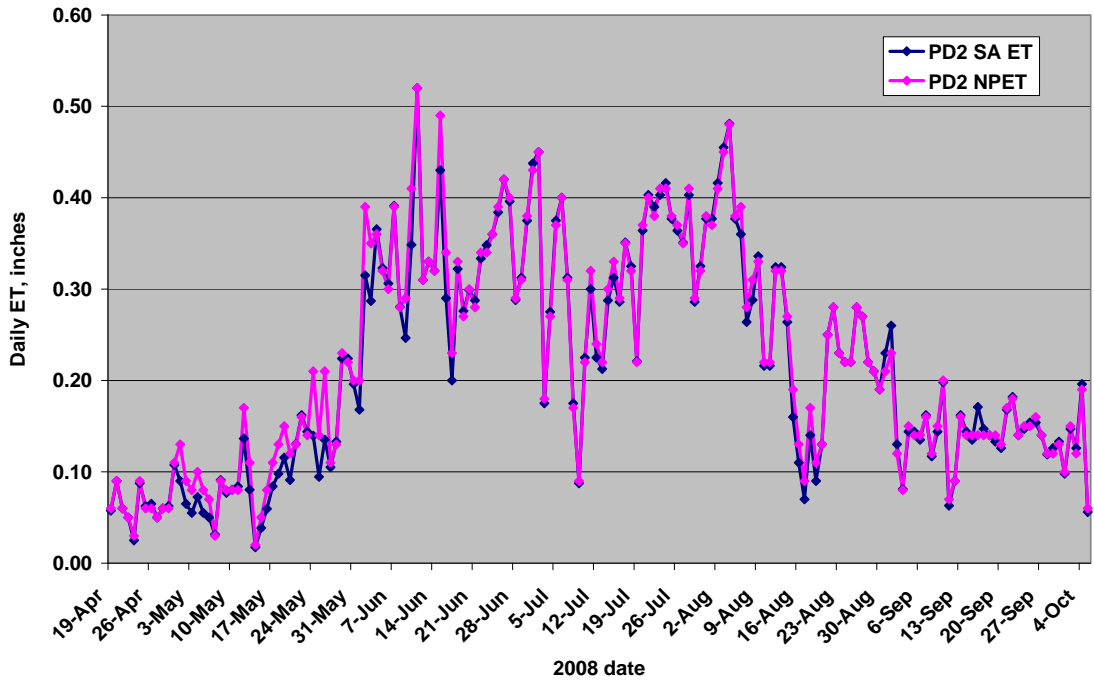


Figure A-67. 2008 Producer Field #4 Corn Daily ET Comparison.

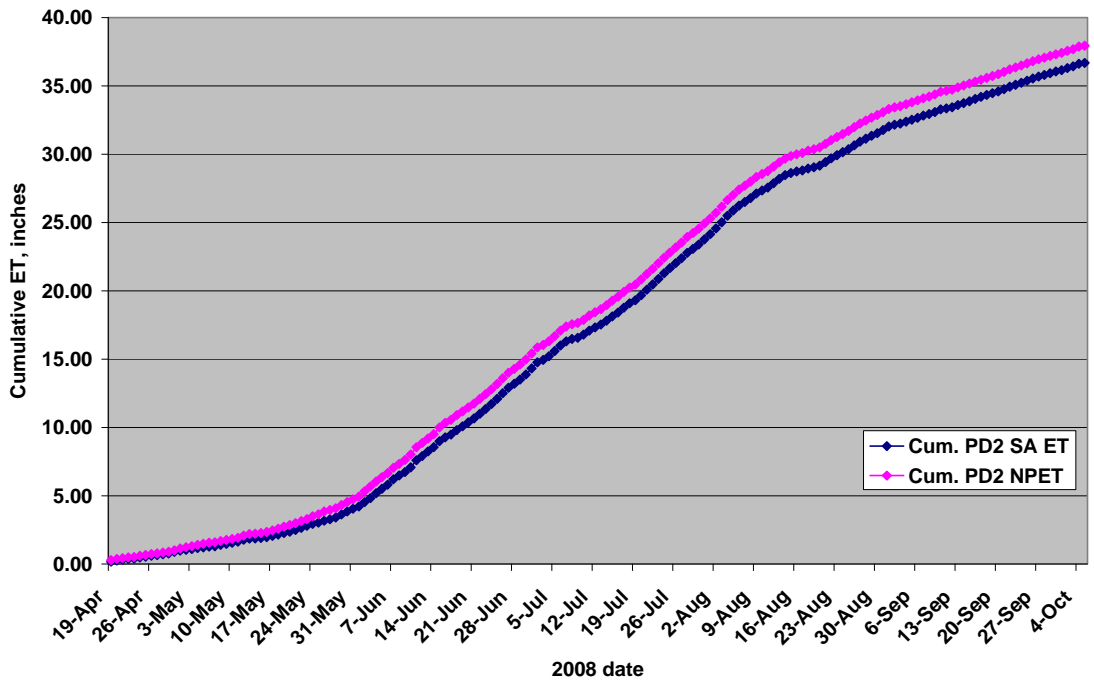


Figure A-68. 2008 Producer Field #4 Corn Cumulative ET Comparison.

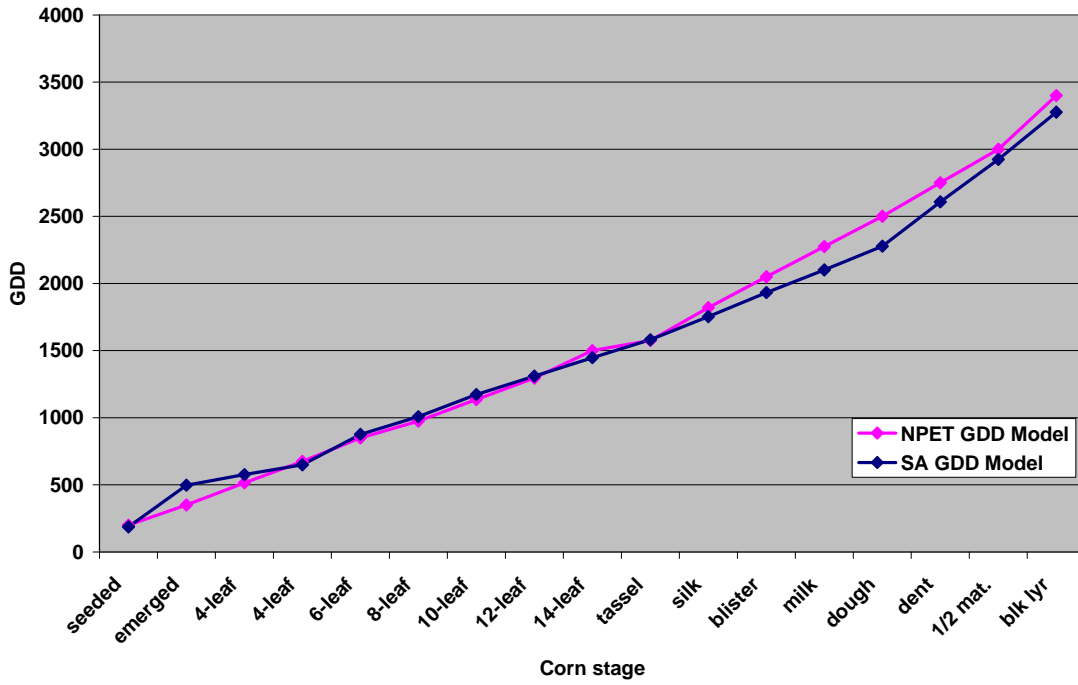


Figure A-69. 2008 Producer Field #5 Corn GDD Comparison.

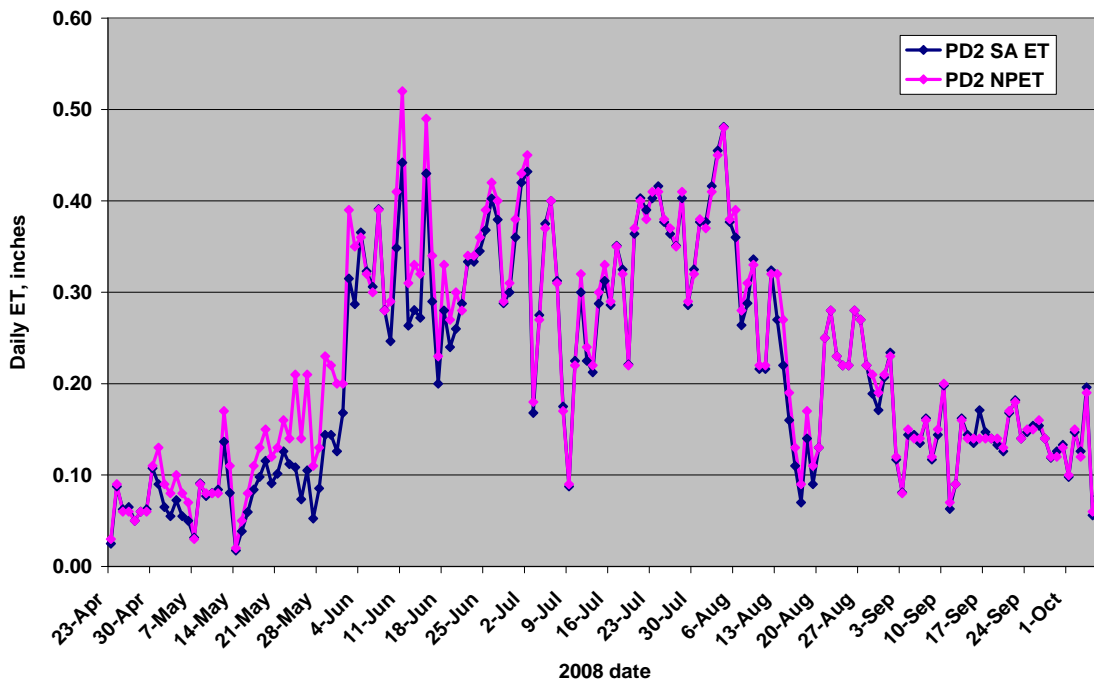


Figure A-70. 2008 Producer Field #5 Corn Daily ET Comparison.

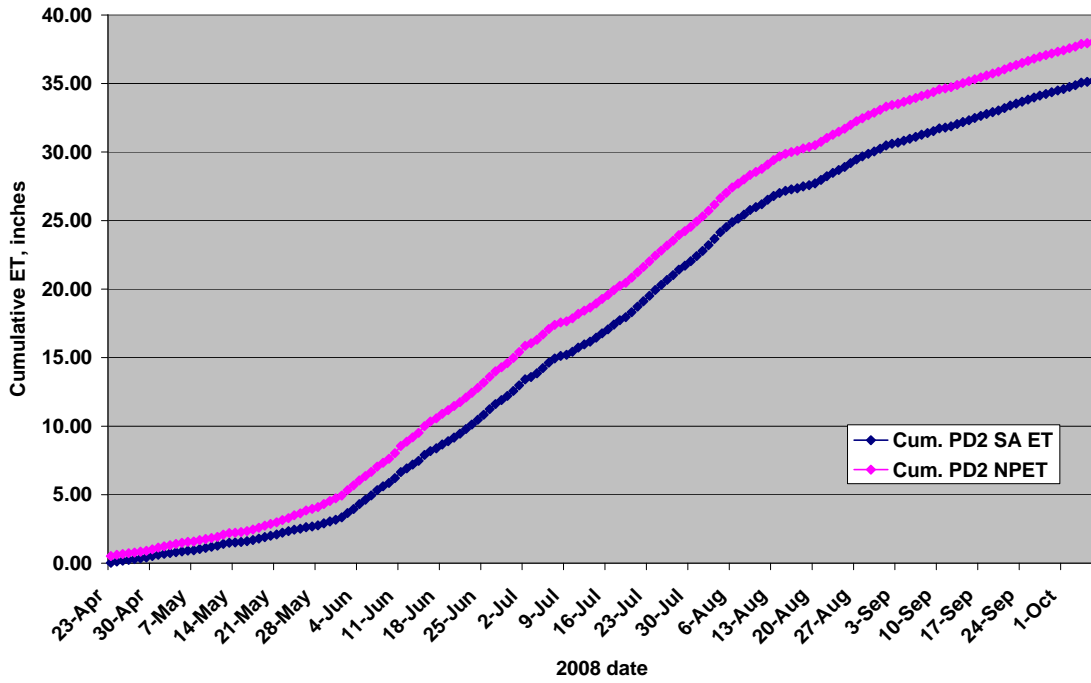


Figure A-71. 2008 Producer Field #5 Corn Cumulative ET Comparison.

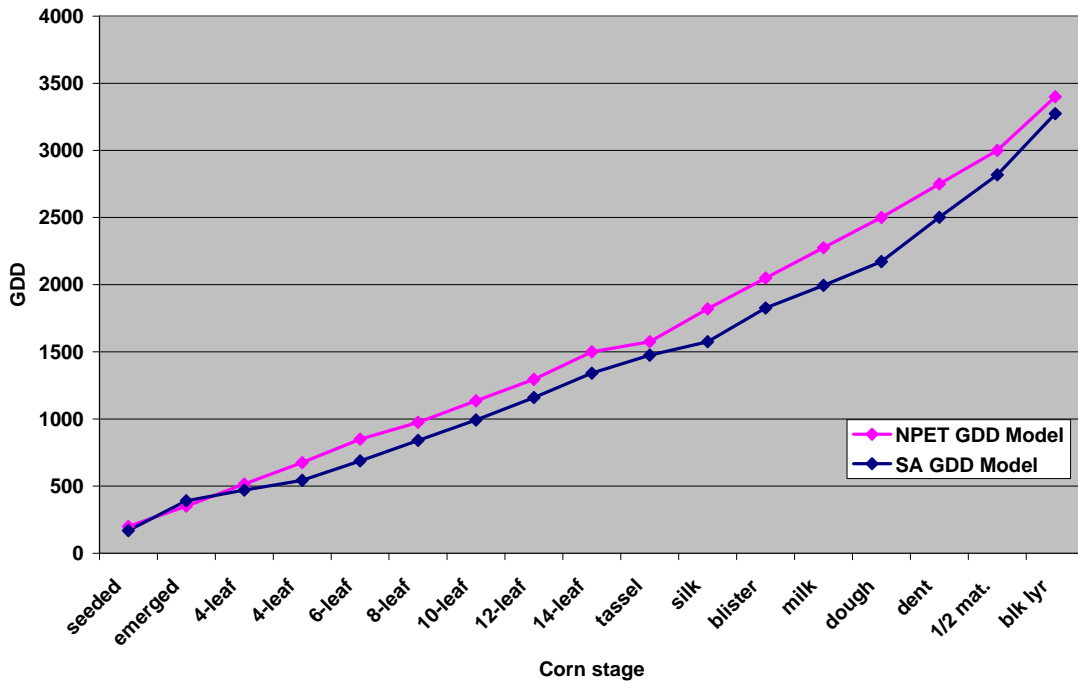


Figure A-72. 2008 Producer Field #6 Corn GDD Comparison.

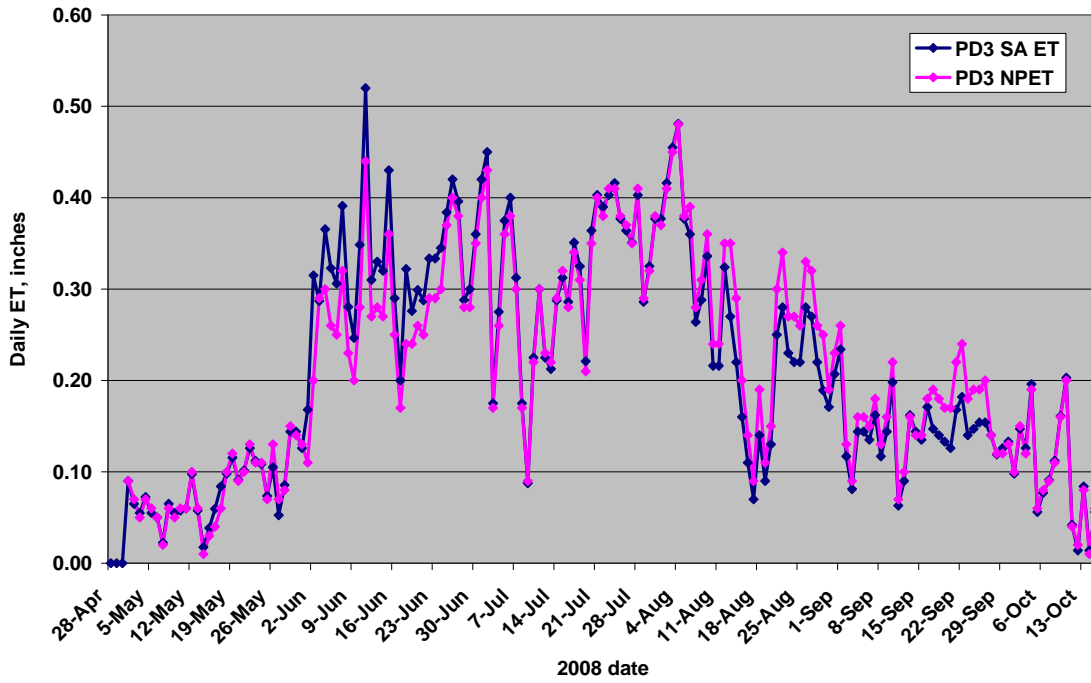


Figure A-73. 2008 Producer Field #6 Corn Daily ET Comparison.

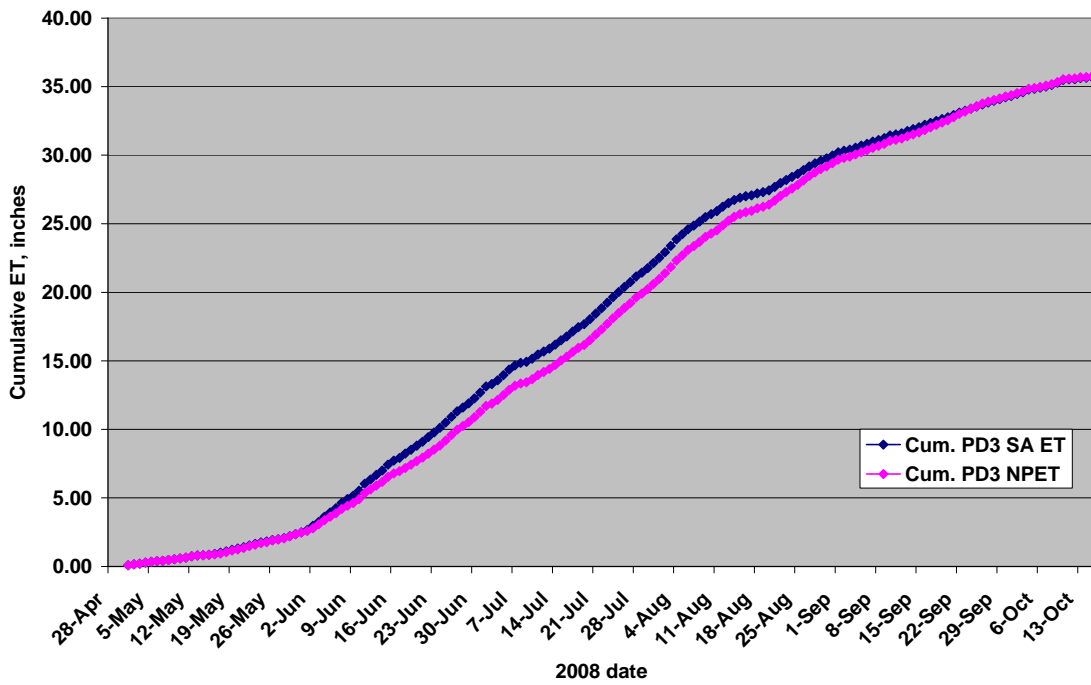


Figure A-74. 2008 Producer Field #6 Corn Cumulative ET Comparison.

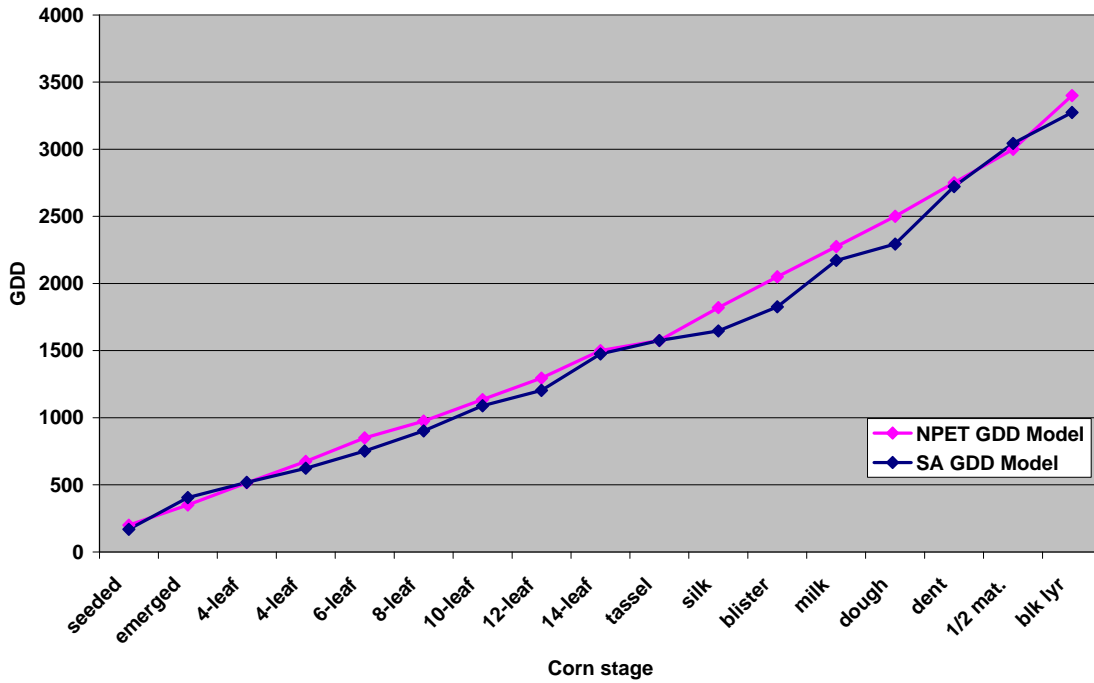


Figure A-75. 2008 Producer Field #7 Corn GDD Comparison.

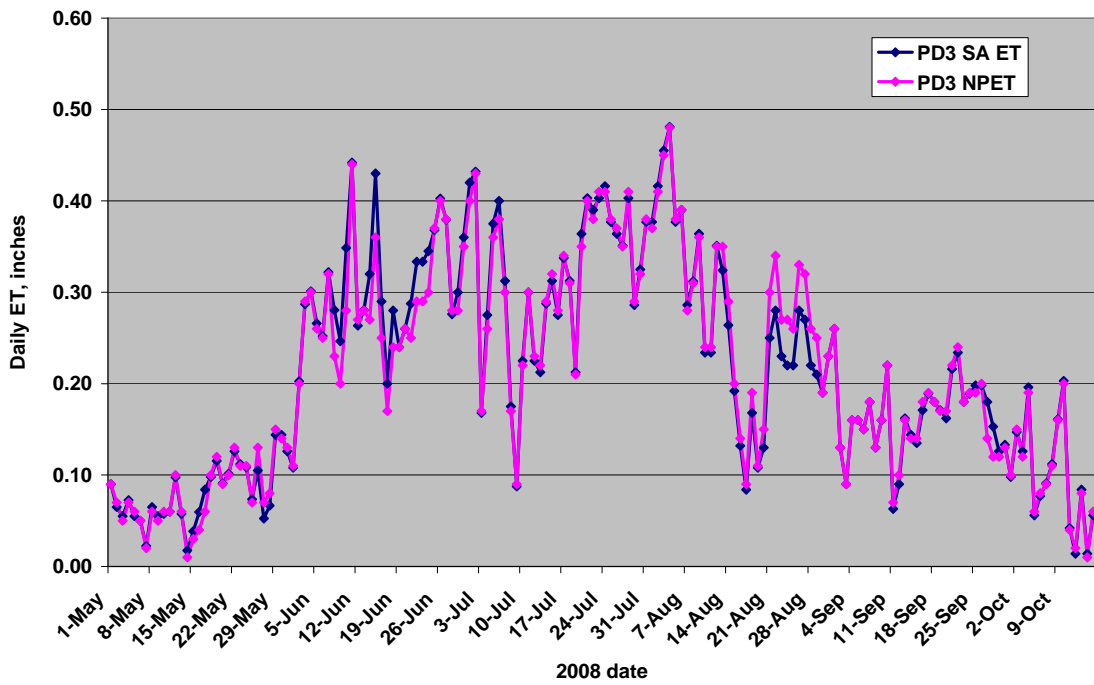


Figure A-76. 2008 Producer Field #7 Corn Daily ET Comparison.

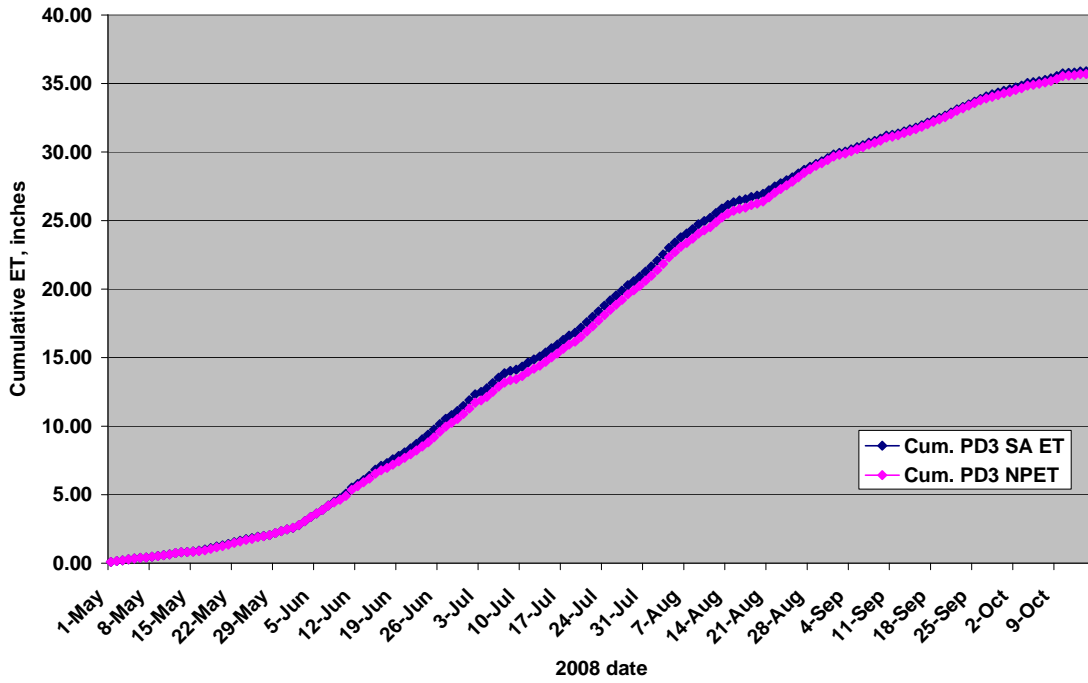


Figure A-77. 2008 Producer Field #7 Corn Cumulative ET Comparison.

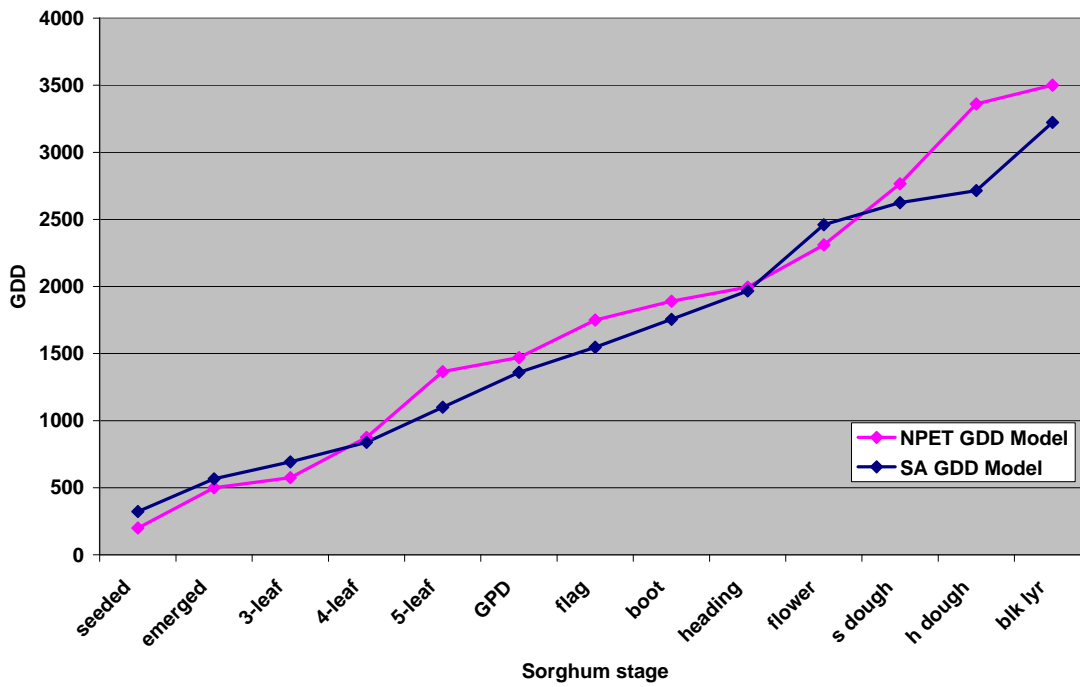


Figure A-78. 2008 Producer Field #1 Sorghum GDD Comparison.

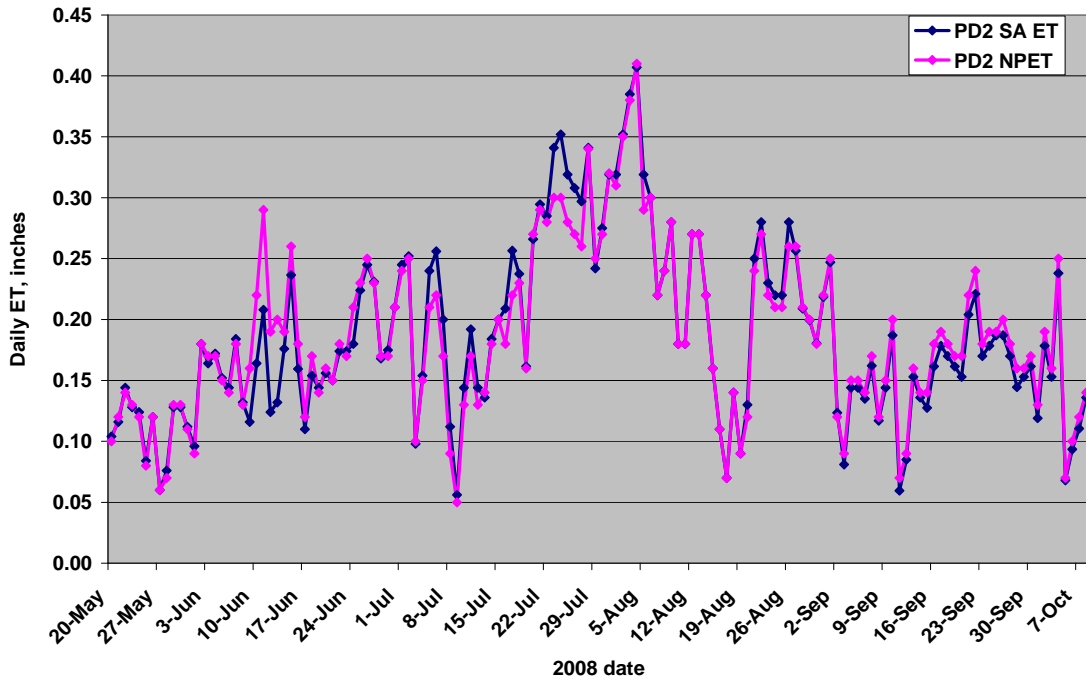


Figure A-79. 2008 Producer Field #1 Sorghum Daily ET Comparison.

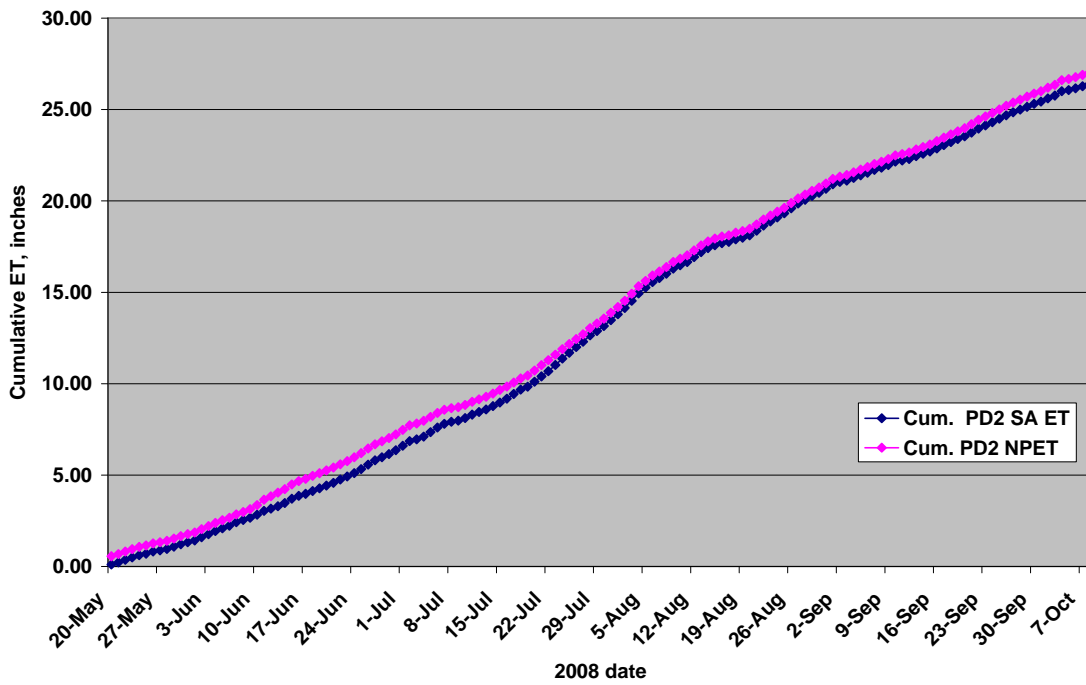


Figure A-80. 2008 Producer Field #1 Sorghum Cumulative ET Comparison.

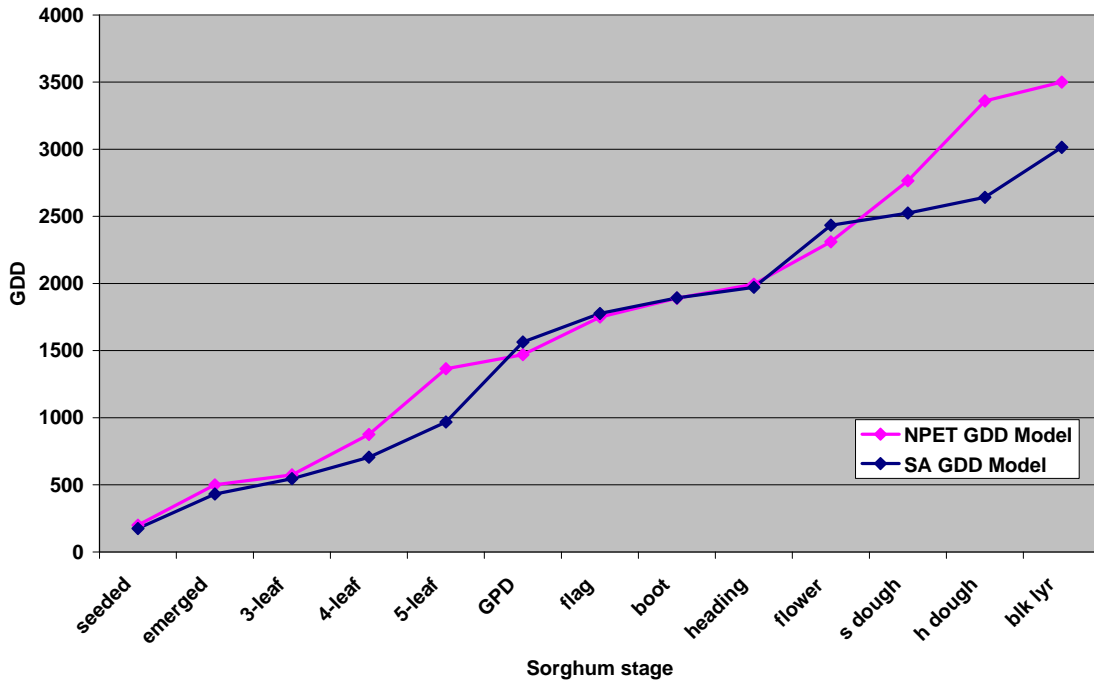


Figure A-81. 2008 Producer Field #2 Sorghum GDD Comparison.

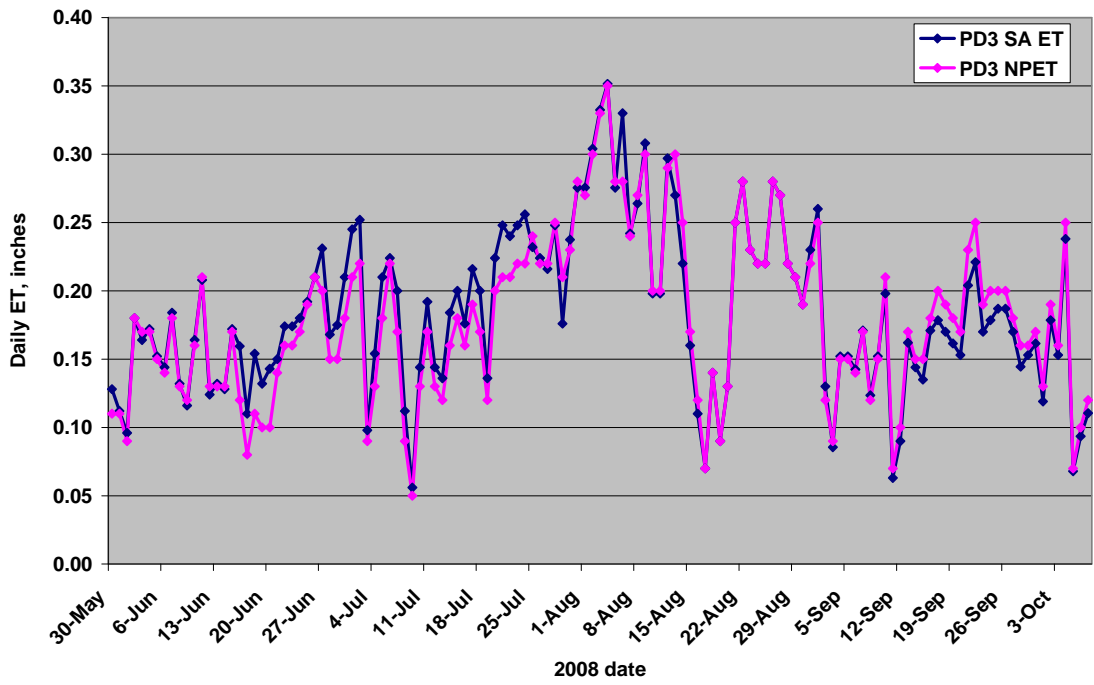


Figure A-82. 2008 Producer Field #2 Sorghum Daily ET Comparison.

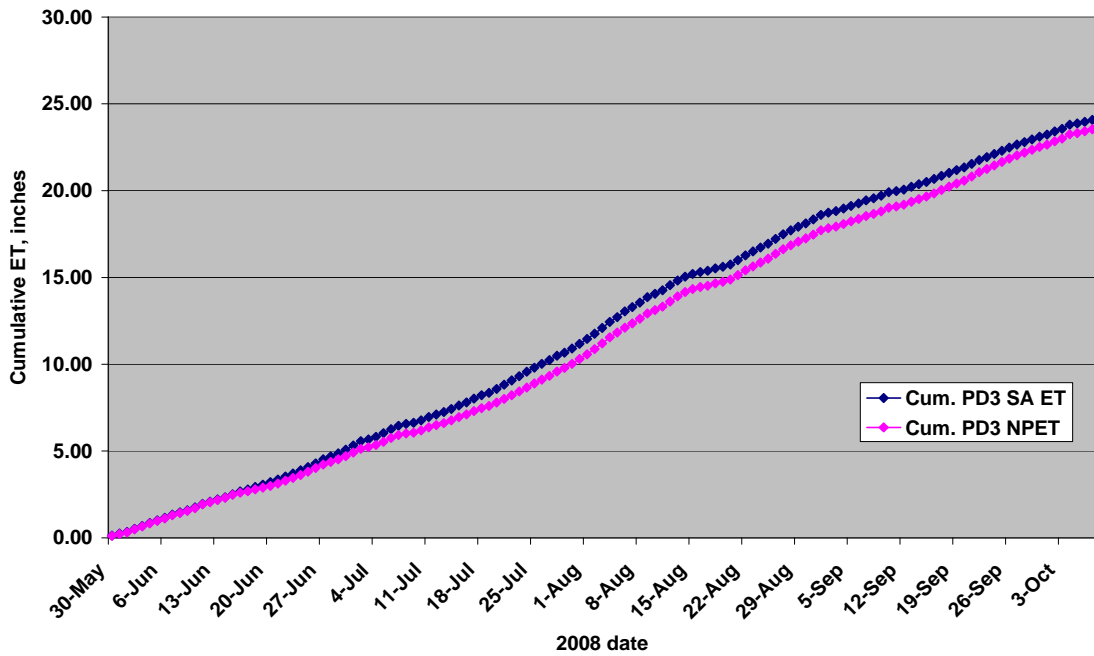


Figure A-83. 2008 Producer Field #2 Sorghum Cumulative ET Comparison.

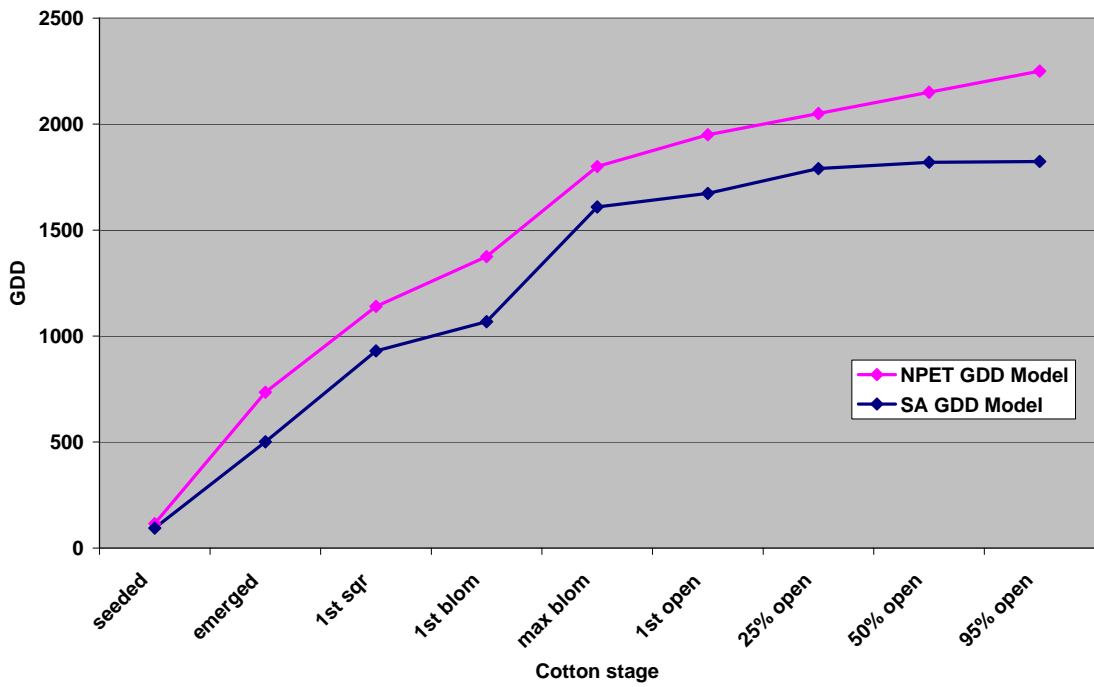


Figure A-84. 2008 Producer Field #1 Cotton GDD Comparison.

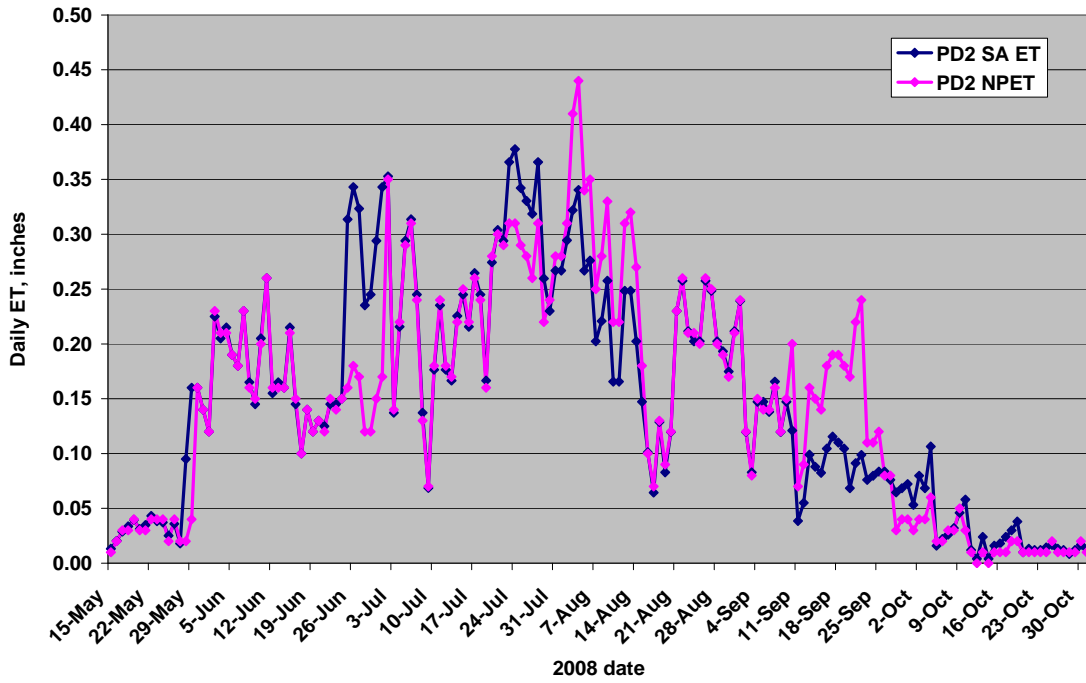


Figure A-85. 2008 Producer Field #1 Cotton Daily ET Comparison.

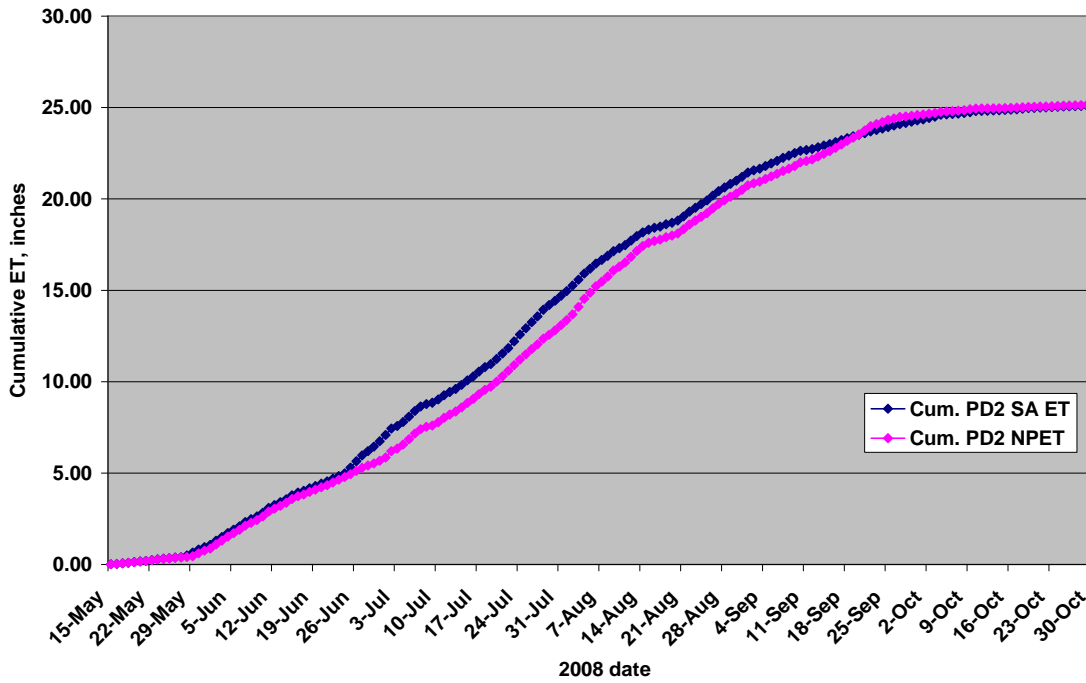


Figure A-86. 2008 Producer Field #1 Cotton Cumulative ET Comparison.

APPENDIX B

User's manual of ET Network

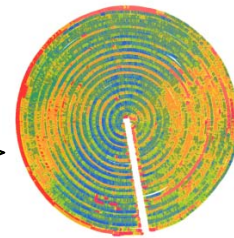
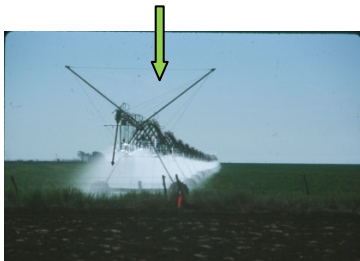
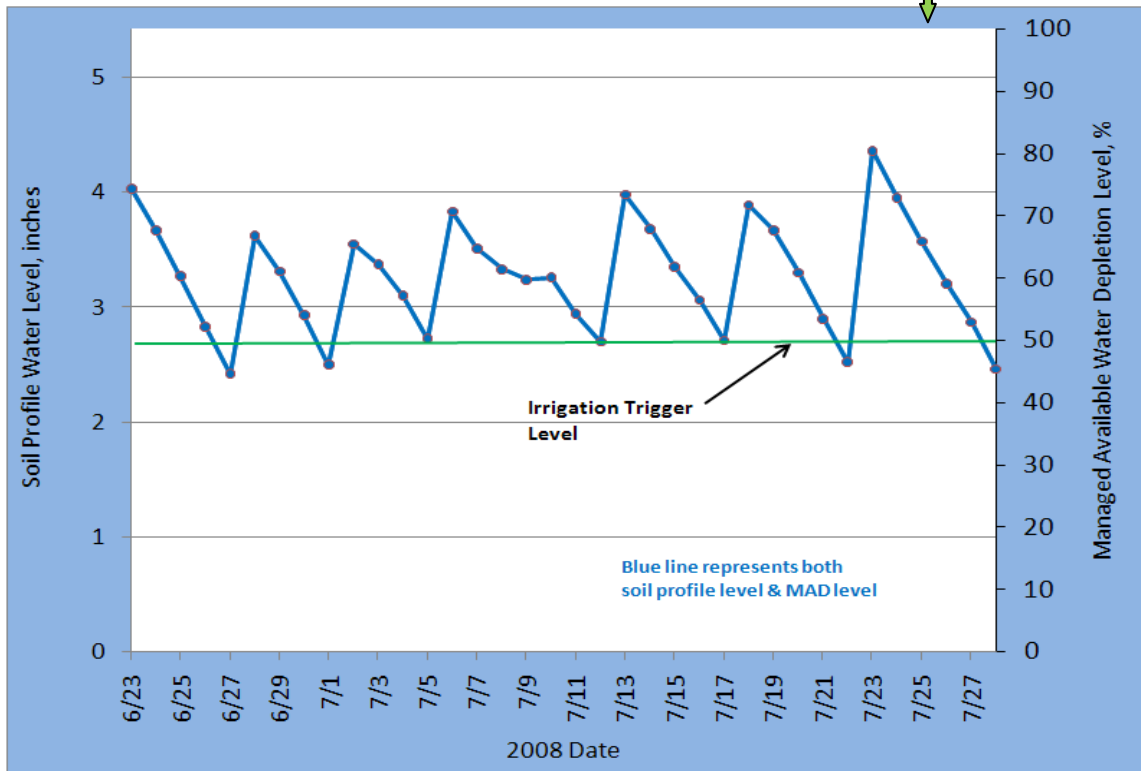
“Understanding ET and Its Use in Irrigation Scheduling”

Understanding ET and Its Use in Irrigation Scheduling

(a TXHPET Network series user manual)



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Manual Version 1.01 October 20, 2008
 Texas AgriLife Research at Amarillo Publication No. 09-02

Understanding ET and Its Use in Irrigation Scheduling

Thomas Marek, Dana Porter, Terry Howell,
Nicholas Kenny and Prasanna Gowda¹

Summary

Irrigation is generally used to sustain or enhance production levels and increase profitability. Knowing how much and when to apply irrigation water have become key concerns of water managers, policy makers, local, regional and state officials as well as irrigators themselves given the recent escalation in pumping costs and possible impending additional regulations on irrigation pumping volume and/or rate. Competition from municipal and other water use sectors are increasingly placing demands on irrigation resources since in most cases irrigated production profits typically have lower values compared with possible sellouts of water rights to the competing sector(s). Thus, to sustain a regional and state produced food/feed/fiber supply, increased implementation of the use of evapotranspiration (ET) data and efficient irrigation scheduling techniques along with other conservation measures is required.

This article describes a simple checkbook method for irrigation scheduling using daily input data from a large, regional scale ET data network located in the Texas's High Plains. Increased use of the scheduling method will result in the reduction of irrigation water pumping in some cases and document production status in many others, resulting in enhanced production and profitability assessment records for producers. Additionally, when combined with other information such as yield mapping, a history of production can be maintained which could be useful in future analyses for further improvements in crop production strategies.

Background Science of the Water Process

As related to the hydrologic cycle (Figure 1 - the process where water is cycled through the atmosphere and the earth's system), one of the basic principles of physics states that energy

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transfers from a higher to lower state. This principle governs the atmospheric demands

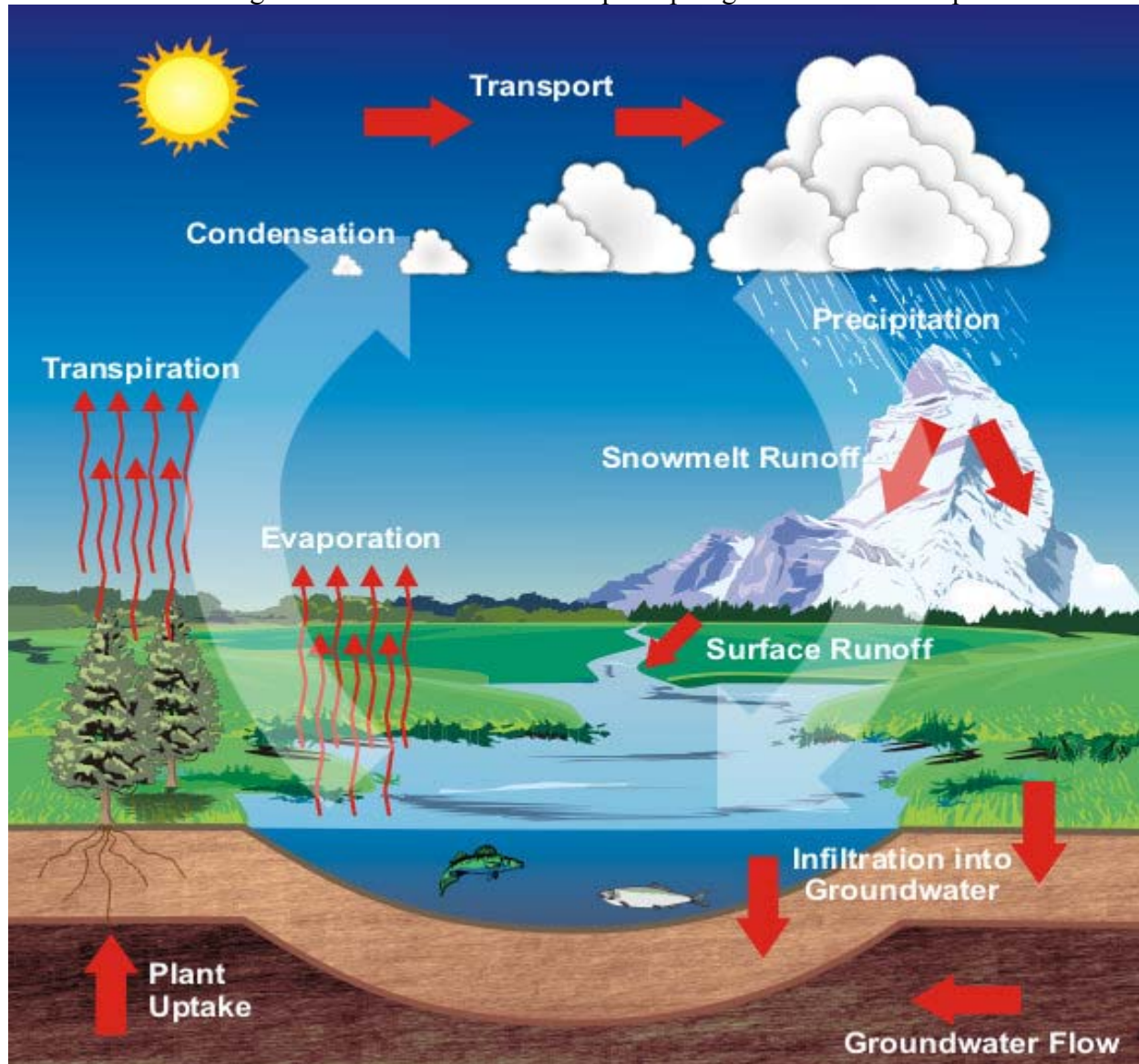


Figure 1. The Hydrologic cycle. (source: <http://www.srh.noaa.gov/jetstream/atmos/hydro.htm>).

regarding moisture and temperature transfers for processes associated with evaporation (water vapor transfer). The amount of difference between the respective meteorological parameter(s) determines the rate of change or transfer rate between the two parameter levels and the degree of demand on the resource, in this case, water or water vapor to be precise. As an example, relative humidity (RH), which represents the amount of moisture or water vapor in the air, reflects the relative measure (the level) of the air to contain additional vapor and is commonly referenced with a scale of 0 to 100 percent. As RH decreases, the atmosphere (i.e. drier air) “exerts more demand” on water vapor from available “free” water sources, such as ponds, lakes, plant surfaces

(leaves), pavements, etc. The rate of water vapor transfer is increased assuming that free water surfaces are available. This is not generally the case as limited water resources and non-optimal conditions on plants are usually encountered, particularly in drier environments.

The prevalent impacting meteorological parameters that affect irrigation water requirements are solar irradiance (commonly referred to as solar radiation) affecting temperature and wind speed, which thus affects the convective aspect of the rate of transfer of a higher energy (moister) source level to a lesser one, typically the atmosphere. In the Texas High Plains, there is not generally adequate moisture available to sustain high atmospheric humidity levels (high RH). Thus the atmosphere is at a deficit in relation to its water holding capacity, resulting in this region's general classification as a semi-arid environment. Simply stated, there are not sufficient free moisture surfaces to meet potential water holding demands of the atmosphere or even substantially increase the atmospheric moisture levels. These meteorological parameters vary throughout the day, the temporal demand period, and whether computed on a daily, hourly or smaller time scale, accumulation of these differences over that period summarize the water demand for the specified period. For general irrigation purposes, the preferred time period is on a daily basis and the parameters' diurnal fluctuations are sampled and summed to reflect the atmospheric demand and water resource requirements for the day.

Evapotranspiration Concept

Evapotranspiration (ET) is defined as a measure of the total water demand from evaporation (from the soil, standing water, and other surfaces such as stubble, rock, plants, grass, etc.) and plant transpiration into the atmosphere. Potential evapotranspiration (PET) has been commonly used in the past as a term that represents the maximum amount of water that a grass or crop would require if water was not limited and no crop stress were present. From one internet source, *"Potential evapotranspiration (PET) is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile. It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere. Evapotranspiration is said to equal potential evapotranspiration when there is ample water."* (Wikipedia, 2008). The problem with this past term of ET demand is that there was no accepted standardization as to what the short

green crop should be across the country and use of the differing reference crops did not allow appropriate comparison of calculated ET data sets between regions. This demand term has now been revised with standardization and will be addressed later.

In the past, this total water demand (ET) has also been referred to as “crop water use.” This term is outdated and has been replaced as it was commonly confused between actual crop demand, maximum ET potential, and reference ET (ET_o). A more appropriate and standardized reference ET term today is that of ET_{ref} , which is a measure relating to the specific ET demand of the atmosphere at a particular location and environment for a defined “reference crop”. A more appropriate and standardized term of crop ET is ET_c , which is a measure relating to the specific ET demand of a particular crop being grown in a particular environment. The typical short green crop (Wikipedia term) is a “reference” crop that is designated as either alfalfa or a grass, with both being well watered. Grass is the generally preferred short reference crop in arid and semi-arid areas such as the Texas High Plains principally due to the fact it is more representative of “native reference” conditions. Alfalfa in this demanding environment is considered a tall crop and requires more water resources and more maintenance. In scientific studies today, reporting is being solicited, and may be later required, with both references to allow advanced comparisons of the data sets in the future. Thus, reference ET (ET_{ref}) – rather than PET - is the preferred term describing potential water demand as measured and the reference crop is to be specified with the measurement.

Reference ET (ET_{ref}) can be accurately computed from meteorological data recorded from weather stations instrumented with properly calibrated sensors and programmed for hourly (or shorter interval) data acquisition output. Crop-specific water use by growth stage, as derived from lysimeter studies, is typically used to develop crop coefficient curves that accurately relate ET_{ref} to crop specific ET (ET_c) to be used in daily irrigation scheduling programs, water demand models and other applications. The accuracy of these ET_c values is highly dependent on parameters such as meteorological station location and representation - particularly in regards to topography, wind obstructions, buildings, soil surfaces, roadways, drainage and waterways, lakes and ponds, and cover crop influences.

Various methods of ET computation can result in differing ET values using the same weather station output data. To standardize ET computation and improve application and transferability

of ET research and crop coefficients, the ASCE Standardized Reference Evapotranspiration Equation (Allen et al., 2005) was established by a team of internationally recognized ET scientists and engineers located throughout the United States, whereby comparative computations can be made irrespective of climate area and reference crop used (note: the reference crop is still to be designated to depict whether the computed ET value is based on a tall or short reference). The effort was requested by scientific and educational communities and the Irrigation Association, who were particularly concerned about the differences in ET estimates derived from the same input data parameters. Currently it is not known how all of the respective weather networks in Texas compute ET. A statewide effort (Marek et al., 2008) is underway with the state of Texas (Texas Water Development Board) to investigate this issue and impacting factors. Furthermore, irrigation and consultant clientele have reported confusion about which computed ET values to use in various irrigation scheduling software and related tools. This confusion has hindered the adoption of ET-based irrigation scheduling in some, if not all, regions of Texas.

Since irrigation scheduling has been identified as one of the priority water conservation strategies in several Texas regional water plans and the comprehensive statewide water plan (TWDB, 2006a and 2006b), there is a specific statewide need to identify and document parameters associated with the current ET networks as well as identify and illustrate the use of a simple irrigation scheduling process using a uniform, standardized method of ET computation utilizing appropriate, available data parameters.

ET Methodologies

In the past, there have been numerous methods to estimate or compute ET with several requiring differing data input. Some of the methods used in the past were the Texas Board of Water Engineers (1960), Blaney-Criddle (1962), Jensen and Haise (1963), Penman-Monteith (Monteith, 1965) and modified Penman (Wright, 1982). Some ET methods were developed based on the limitations of data and approximations to certain data such as solar radiation and were developed to yield an average type ET value. Several of these methods are not in widespread use today because of the “average” nature of the estimations and their inability to adapt to seemingly smaller temporal ET scales which are being computed and evaluated in today’s scientific environment.

The ASCE-ET Task Committee (Allen et al., 2000) conducted a comparison of ET equations in an analysis, including the newly standardized ASCE reference ET equation, using REF-ET (Allen, 1999). REF-ET is a software program used to compare the computational values of various ET methods. Based upon selections of the ASCE designated Task Committee, 20 reference ET equations were evaluated using 49 sites from 16 states and 89 site years of data. The results indicated that variations using the differing calculations were apparent. These differences were not so great on a small time scale to cause undue concern from a daily or even cumulative basis of a week, but the sum lead to a notable difference over the course of the growing season. This has been the case experienced in a few Texas ET networks as well. Multiple interrogations from the same weather station by differing scientists and agencies resulted in differing computed daily and summed crop ET values thereby confusing producers and presenting the scenario that the group of scientists and engineers involved did not agree on a uniform method of calculation. This left the producer or irrigator with the question of which number is actually correct and which to use?

The ASCE Standardized method is the ET method recommended by the leading ET scientists and engineers today as it best reflects state of the art computation as well as accurate, representative data outputs from universal inputs. The ASCE standardized method has the advantages of providing the following according to Walter et al. (2005):

“1. A standardized calculated evaporative demand that can be used in developing transferable crop coefficients.

*2. A clear methodology for practicing engineers to use for estimating reference evapotranspiration; therefore, the $K_{cr} * ET_{rs}$ or $K_{co} * ET_{os}$ procedure will more readily be adopted by the private sector, federal, and state agencies. (The equations represent the computation of crop ET by multiplying reference ET by a crop coefficient).*

3. More universal hourly equations that will provide better comparisons between summed hourly reference ET and daily reference ET.”

New nomenclature associated with the standardized ASCE reference ET equation defines reference ET generally as ET_{ref} and with the standardized ET equation being designated as ET_{sz} . The general form of the ET_{sz} equation is as follows:

$$ET_{rs} = \frac{0.408 \Delta (R_n - G) + \gamma \frac{C_n}{\gamma + 2/3} u_2 (e_s - e_a)}{\Delta + \gamma (1 + C_d u_2)}$$

where:

ET_{sz} = standardized reference evapotranspiration,

R_n = net radiation,

G = soil heat flux,

T = mean air temperature,

u_2 = mean wind speed (at 2-m height),

e_s = saturation vapor pressure of the air,

e_a = actual vapor pressure of the air,

γ = psychrometric constant,

Δ = slope of the saturation vapor pressure-temperature relationship,

C_n = numerator constant, and

C_d = denominator constant.

Equation and term units and constants values can be found along with other applicable equation details in Allen et al. (2005).

When ET_{sz} is computed based with a well watered grass (“short”) reference, the proper reference ET term designation is ET_{os} and when the reference crop is alfalfa (“tall”), the correct reference ET term designation should be ET_{rs} . As in previous computations, crop ET_c values are to be calculated by multiplying reference ET by a crop coefficient as in the following equations:

$$ET_c = K_{co} * ET_{os} \quad \text{or} \quad ET_c = K_{cr} * ET_{rs}$$

where:

K_{co} = crop coefficient for use with ET_{os} , and

K_{cr} = crop coefficient for use with ET_{rs} .

The value of the crop coefficients (K_{co} and K_{cr}) will differ depending on which (research) reference crop they were derived from. Generally, crop coefficients are derived from lysimeter measurements and this is typically the preferred method. Because lysimeters are not available in many areas (environments, locales) to determine accurate values, crop coefficients are

sometimes estimated from selected scientific studies from other production regions. For example, crop coefficients for peanuts grown in the Texas High Plains region were estimated from such studies conducted in other parts of Texas.

Irrigation Scheduling Methods

There are several different approaches (both levels and methods) used to schedule irrigation. Some scheduling methods entail soil water levels, plant stress criteria, leaf water potential, sap flow, and canopy measurements. Some of these methods require information from sensors, imagery and advanced automated instrumentation. Other irrigation scheduling methods involve soil water balance models or the use of mechanistic models that depend on plant growth stage and water status or a combination thereof. This section is not intended to be exhaustive or comprehensive concerning the identification and total number of assessments and techniques that researchers have evaluated over the last 30 years. Nor is the intent of this publication to address any significant details of the complex scheduling models. It will, however, provide a brief overview and historical perspective to assist the reader in understanding the background of the current state of the art.

One of the earliest and simplest scheduling methods was that of a fixed time interval. Surface irrigators in the Texas High Plains typically scheduled irrigations on a fixed 7 to 10 day rotation throughout the entire production season for water sensitive crops such as corn. (Surface irrigation is also sometimes referred to as surface flow or furrow irrigation). For less sensitive crops such as grain sorghum and wheat, a 10 to 14 day interval was used. While this simple technique may have been effective in terms of meeting or exceeding ET_c , it was not very efficient or water conscious, as long application times resulted in water resources being lost through deep percolation with the leaching of nutrients from the root zone, particularly in the upper end (head) of the field. Also, runoff from the lower end of the field was common and necessary to allow adequate time for a desired depth of infiltration. The inefficiencies of surface irrigation and using this scheduling method typically resulted in larger than necessary groundwater withdrawals from the Ogallala aquifer.

As sprinkler irrigation systems began to replace surface flow methods in the 1980's, a 3½ or 7 day irrigation system schedule was typically adopted. Although sprinkler irrigation limited deep percolation and improved field distribution efficiency with less total water applied, runoff was

still an issue, particularly in the case of 7 day irrigation schedule. Research tests along with commercial development of lower pressure sprinkler nozzles later lowered energy requirements but applied irrigation water at a higher application rate than the soil could generally support. This was particularly evident on the heavier soils such as the Pullman and Sherm clay loam series prevalent throughout much of the central and northern Texas High Plains region. Through the development and utilization of furrow dikes to contain the high instantaneous application rates, runoff losses were reduced; resulting in improved water efficiency with reduced water application per unit area. Producers quickly realized that with the gains in efficiency per area of center pivots that more acreage could be irrigated resulting in increased profits. As pumpage regulations were generally not limiting at the time, adoption of more advanced irrigation scheduling methods were not perceived as warranted.

In the mid to late 1980's, irrigation researchers initiated a bulletin board system at the then Texas Agricultural Experiment Station (agency officially renamed to Texas AgriLife Research in 2008) in Amarillo/Bushland (Marek and Michels, 1986) whereby daily ET_o and crop coefficients were available for area crops and could be used in calculations regarding daily ET_c . This was the first known and documented effort towards a centralized, regional based, irrigation scheduling system for the northern Texas High Plains. During this time period using water planning models, agricultural engineers, researchers, water personnel, and policy makers were beginning to express concerns over the amount of the Ogallala groundwater withdrawals and subsequently encouraged more advanced application scheduling methods. These efforts began to be significantly established and promoted during the early 1990's following years of system based development work with irrigation scheduling.

Another method and level of irrigation scheduling is that of an allowable depletion or water deficit concept based on the root zone level of plant available water (PAW). This concept is sometimes referred to as an available water concept (AWC) method. This concept utilizes an allowable level of depletion within the soil profile (the plant's root zone) called a managed allowable depletion (MAD). Once the specified MAD level is depleted, an irrigation event is triggered or scheduled for application. The simple method of soil water level accounting with this depletion concept is known as the "checkbook" method. This is due to the fact that entries of the various inputs and depletions are entered and balanced in a simple "addition and subtraction type" format. While the basis of the technique is simple, proper estimates and

attribution of the contributing inputs such as effective rainfall and runoff can be difficult and may involve multiplicative or percentage values for application with some inputs of the method.

The next level(s) of irrigation scheduling entail sensors and readings that can be used in the automated control of the irrigation system to initiate an irrigation event typically with a predetermined duration. To date these input devices have been used in a limited fashion with center pivot systems and are currently more commonly used in drip irrigation systems where the frequency of application can be more frequent, sometimes with multiple small applications per day. These scheduling techniques are management intensive and are generally classified as complex. Following the adage of “time is money”, it is common for producers to hire additional management or crop consultants to assist in the analysis and management decisions with these intense irrigation practices. The implementation of such complex, intensively managed systems for the production of cereal grains in the northern Texas High Plains has not been generally warranted to date.

The next class of scheduling methods involves simulation models driven by a variety of real time, historical, and probability based inputs. This class of scheduling method (also commonly classified as “Hi-Tech”) involves uniquely complex remote sensing inputs and algorithms that require significant, higher level interpretations and analysis for translation to reduced values for any practical irrigation application. The remote sensing inputs are currently process intensive with acquisition and turnaround time being a limiting factor for practical irrigation scheduling. These complex models are typically beyond the scope of producers and most crop consultants in field practice but are appearing to show potential promise in improving ET assessments potentially in regional water planning efforts. In recent discussions with researchers, this class of models and methods will not displace ET networks but will complement their operation as well as temporal and spatial representation.

Listed above are the general classes of irrigation scheduling models. Further advanced irrigation models are also being developed that entail real-time assessment of parameters that account for soil moisture, water availability, production potential and in-season input plus commodity price trends. These very complex methods entail the temporal aspects of multi-source irrigation water availability, distribution grid transport, crop need allocation, and pipeline flow/pressure balances. These models also integrate current crop pricing and consider a producer’s (or multiple

operations level –e.g. co-op level) forward-contracted volumes of commodities (required to be grown), but are currently limited to higher institutional research personnel and management. While these models have generally been beyond the scope of practical irrigation use by even the most advanced irrigation groups, multi-agency efforts are currently being pursued to advocate testing of these models on selected, very large, “test pilot” farms within the central and western U.S. The primary objective of using this complex class of irrigation scheduling model is that of increased profits. Ancillary objectives are to increase overall irrigation water use efficiency and promote water resource conservation. It is not anticipated that this class of models will receive large scale distribution or adoption in the near future and may only receive practical demand with high value cropping systems.

The checkbook method:

Of the scheduling tools being promoted and in use today, the most prevalent is the simple checkbook method due to its simplistic nature and limited number of inputs required. As mentioned earlier, accuracy of the method is dependent upon the accuracy and representation of the inputs. Given the range of spatial and temporal variability that exists within and among fields and farms, the checkbook method provides producers with a practical estimate of the plant available water (PAW) and managed allowable depletion (MAD) water available within a certain soil profile.

There are numerous versions of spreadsheets and hard copy forms that have been developed and used with the checkbook method over time. A simple spreadsheet version of the checkbook method is relatively easy to create and is shown in Figure 2. In essence, this method calculates the managed allowable depletion (MAD) water available within the defined root zone of the soil profile on a daily interval. The method uses the concept of a “virtual bucket” with the amount of water remaining within that bucket representing the water available for crop growth and development. The required data inputs with this method are those of crop ET (ET_c), irrigation amount applied, rainfall, and the stored soil (root zone) water available to the plant. Refer to Figures 2 and 3 to see examples of the tabular and graphical checkbook type water accounting method. The crop ET data is acquired from an ET network on a daily basis. The other data values are provided by the producer or irrigator for a specific farm or field. The number of days to the next irrigation can be estimated by dividing the soil profile level (the amount of MAD

water left in the soil profile) by the estimated average daily crop ET rate (early in the season these values are typically low because the plant is small). Of course, as the crop begins to grow and air temperatures began to warm (e.g. – approaching summer growing season), crop ET will increase substantially and the irrigation interval will decrease accordingly. A calculation example regarding crop water needs and low system capacity is illustrated in Figure 4. Another subsequent, mid-season example will follow and illustrate a differing operational constraint with a much smaller irrigation interval requirement.

Date	Daily ET, inches	Observed Rain, inches	Eff. Rain, inches	Effective Irrigation, inches	MAD, inches	Soil Profile Level, inches	Level of MAD, %	Irrigate ? (Yes or No)
4/1/2008	0.03				5.42	3.12	58	No
4/2/2008	0.04				5.42	3.08	57	No
4/3/2008	0.05				5.42	3.03	56	No
4/4/2008	0.04				5.42	2.99	55	No
4/5/2008	0.07				5.42	2.92	54	No
4/6/2008	0.05				5.42	2.87	53	No
4/7/2008	0.05				5.42	2.82	52	No
4/8/2008	0.04				5.42	2.78	51	No
4/9/2008	0.01	0.08	0		5.42	2.77	51	No
4/10/2008	0.03				5.42	2.74	51	No
4/11/2008	0.03				5.42	2.71	50	Yes
4/12/2008	0.05			3.91	5.42	5.42	100	No
4/13/2008	0.04				5.42	5.38	99	No
4/14/2008	0.07				5.42	5.31	98	No
4/15/2008	0.1				5.42	5.21	96	No
4/16/2008	0.06				5.42	5.15	95	No
4/17/2008	0.02				5.42	5.13	95	No
4/18/2008	0.05				5.42	5.08	94	No
4/19/2008	0.06				5.42	5.02	93	No
4/20/2008	0.09				5.42	4.93	91	No
4/21/2008	0.06				5.42	4.87	90	No
4/22/2008	0.05				5.42	4.82	89	No
4/23/2008	0.04	0.01	0		5.42	4.78	88	No
4/24/2008	0.12				5.42	4.66	86	No
4/25/2008	0.09				5.42	4.57	84	No
4/26/2008	0.09				5.42	4.48	83	No
4/27/2008	0.07				5.42	4.41	81	No
4/28/2008	0.09				5.42	4.32	80	No
4/29/2008	0.09				5.42	4.23	78	No
4/30/2008	0.15				5.42	4.08	75	No

5/1/2008	0.13				5.42	3.95	73	No
5/2/2008	0.09				5.42	3.86	71	No
5/3/2008	0.08				5.42	3.78	70	No
5/4/2008	0.1				5.42	3.68	68	No
5/5/2008	0.1	0.52	0.02		5.42	3.60	66	No
5/6/2008	0.05				5.42	3.55	65	No

Figure 2. Checkbook method of irrigation scheduling data worksheet. Managed allowable depletion is set at 50% plant available water; hence when the % level of MAD drops below 50%, an irrigation application is scheduled.

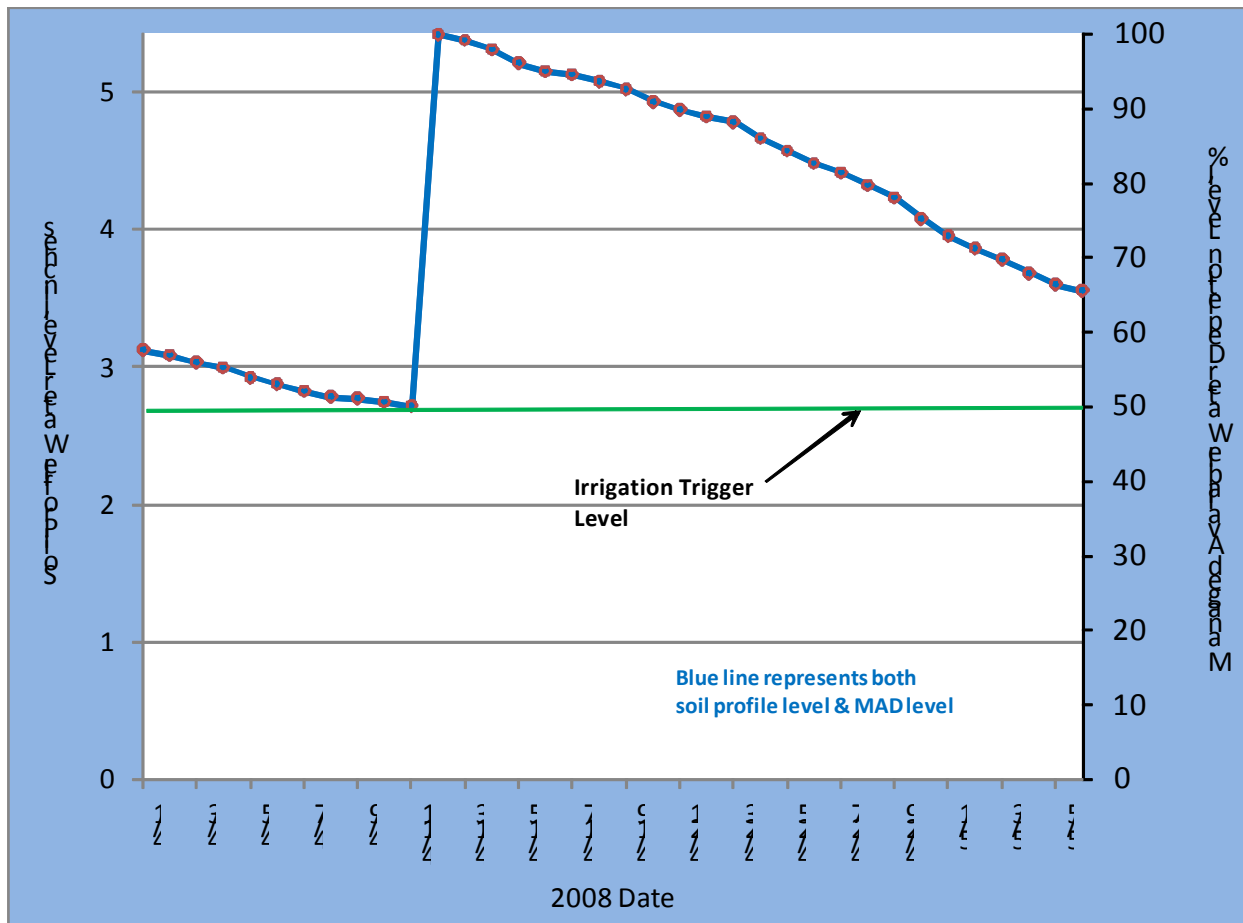


Figure 3. Graphical representation of worksheet shown in Figure 2.

Example: Given the following conditions, how long will it take to achieve the desired target soil moisture of 75% field capacity?

Estimated Root Zone Depth: 5 feet

Approximate soil water at field capacity: 1.5 inch water per ft. soil

Target soil moisture: 75% field capacity

Estimated soil moisture before irrigation: 50%

Irrigation capacity: 3 GPM/Acre (1.11 inches per week)

Irrigation efficiency: 80%

Water to be applied: 5 ft. X 1.5 in/ft X (0.75-0.50) = 1.88 inches

Adjust for irrigation application efficiency 1.88/0.8 = 2.3 inches

Time to apply 2.3 inches: 2.3 / 1.11 inches per week = 2.1 weeks

It will take just over 2 weeks to apply 2.3 inches of water at a rate of 3 GPM per acre

Figure 4. Example of irrigation scheduling calculations.

Date	Daily ET, inches	Observed Rain, inches	Eff. Rain, inches	Effective Irrigation, inches	Max. PAW, inches	Soil Profile Level, inches	% Level of PAW	Irrigate ?
6/23/2008	0.34				5.42	4.03	74	No
6/24/2008	0.36				5.42	3.67	68	No
6/25/2008	0.40				5.42	3.27	60	No
6/26/2008	0.44				5.42	2.83	52	No
6/27/2008	0.41			1.01	5.42	3.43	63	No
6/28/2008	0.30				5.42	3.13	58	No
6/29/2008	0.31				5.42	2.82	52	No
6/30/2008	0.38				5.42	2.44	45	Yes
7/1/2008	0.43	0.08	0	1.01	5.42	3.02	56	No
7/2/2008	0.45				5.42	2.57	47	Yes
7/3/2008	0.18				5.42	2.39	44	Yes
7/4/2008	0.27			1.01	5.42	3.13	58	No
7/5/2008	0.37				5.42	2.76	51	No
7/6/2008	0.40				5.42	2.36	44	Yes
7/7/2008	0.32				5.42	2.04	38	Yes
7/8/2008	0.18			1.01	5.42	2.87	53	No
7/9/2008	0.09				5.42	2.78	51	No
7/10/2008	0.23	0.75	0.25		5.42	2.80	52	No
7/11/2008	0.32			1.01	5.42	3.49	64	No
7/12/2008	0.24				5.42	3.25	60	No
7/13/2008	0.22				5.42	3.03	56	No
7/14/2008	0.30				5.42	2.73	50	No

7/15/2008	0.33	0.01	0	1.01	5.42	3.41	63	No
7/16/2008	0.29				5.42	3.12	58	No
7/17/2008	0.35				5.42	2.77	51	No
7/18/2008	0.32			1.01	5.42	3.46	64	No
7/19/2008	0.22				5.42	3.24	60	No
7/20/2008	0.37				5.42	2.87	53	No
7/21/2008	0.40				5.42	2.47	46	Yes
7/22/2008	0.38			1.01	5.42	3.10	57	No
7/23/2008	0.41	1.25	0.75		5.42	3.44	63	No
7/24/2008	0.41				5.42	3.03	56	No
7/25/2008	0.38			1.01	5.42	3.66	68	No
7/26/2008	0.37				5.42	3.29	61	No
7/27/2008	0.35	0.52	0.02		5.42	2.96	55	No
7/28/2008	0.41				5.42	2.55	47	Yes

Figure 5. Mid-season checkbook method of irrigation scheduling data worksheet.

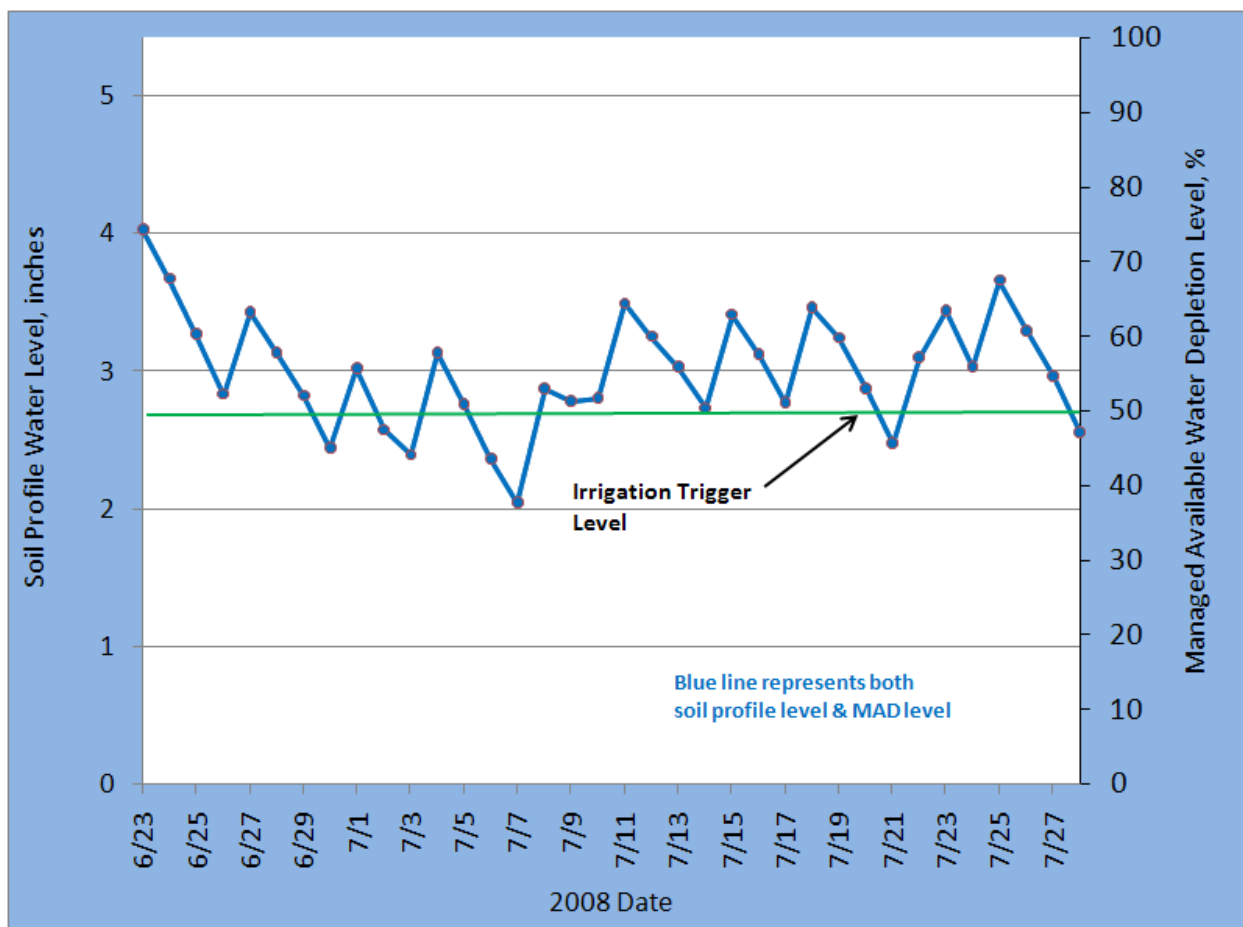


Figure 6. Mid Season graphical representation of worksheet shown in Figure 5.

In Figure 5, the irrigation interval changes with a center pivot system having less application per 3-1/2 day rotation and less capacity than from the previous example. The system is typical of a 6 gpm/ac (gross 0.32 in /day) system capacity with 90% application efficiency. In Figure 6, the frequency of irrigation to meet crop demand and maintain a targeted 50% MAD level is illustrated. In this case and many similar throughout the Texas High Plains region, the system rotation and well capacity governs the irrigation schedule and the system cannot meet the average per day crop ET demand. Thus, the crop must draw water from the soil profile beyond the 50% MAD level until such time as rainfall augments the system's irrigation capacity or crop ET demand is lowered (by crop development past peak ET demand periods). This is clearly seen in Figure 6 around the 7/6/2008 date (corn pollination period in this case). This balancing of the capacity and ET demand loads is referred to as **irrigation management** and tools such as this simple irrigation scheduling analysis highlight the importance of filling or maintaining a high level of moisture in the soil profile early in the growing season to mitigate the irrigation capacity shortfall and therefore prevent stressing the crop during these high demand periods. One such peak demand period for corn will be the pollination period. It makes little sense for a producer to meet nominal growth periods throughout the season and stress a corn crop during this most critical period in terms of yield impact and potential. Too often, producers believe that procurement of a system will "cure their irrigation woes". Advanced irrigation systems can have a dramatic impact on many aspects of an irrigated producer operations and profitability but the purchase of a system alone is only part of the solution as **irrigation management** is always required and may represent the most important and majority factor in accomplishing their productivity goals.

A mindset of some irrigated producers (particularly in the past) is that "my irrigation scheduling routine is to turn the pump on at planting and shut it off just before harvest". For the capacity limited producer, this has some old truth in it, but if critical crop periods are being unduly stressed due to significant system capacity limitations, a change in crop may be in order for those producers. Furthermore, few producers can afford to over irrigate in the "off periods" given today's energy costs and the regulatory constraint of irrigation runoff from fields is no longer allowed. For producers wanting to know the status of the soil profile and the possible replenishment potential with good irrigation scheduling and management, the checkbook is a good tool to assess crop water status. Ironically, the use of a checkbook is analogous to this

scheduling method in that, if you want to know the daily, residual water status of the profile throughout the growing season, the method will estimate it. Conversely without some type of irrigation scheduling method, it would be analogous to a producer starting the season maybe knowing how much money there was in the farm account and not looking (“checkbooking”) or balancing it (knowing where you stand financially) until at or after the season. Most financiers would declare this inappropriate when considering operational loans and projected production level returns. Thus, a producer cannot afford to not know where he/she is in terms of crop water status during the season, even if he/she has limited irrigation capacity and cannot meet the full crop ET_c needs. Most Texas High Plains irrigators have been in the position of dealing with capacity constraints for years.

Input Data Availability and temporal aspects:

Crop ET (ET_c) can be readily obtained from several consistent sources that estimate ET_c over the majority of the irrigated Texas High Plains region. These estimates are derived from the same meteorological sources and can be obtained on a daily basis from the North Plains EvapoTranspiration (NPET) network at <http://amarillo2.tamu.edu/nppet/station.htm> and the South Plains EvapoTranspiration (SPET) network at <http://lubbock.tamu.edu/irrigate/weatherdata.php> in text file format. The same ET_c information can be queried in either a “text based” or “table based” daily file format from the Texas High Plains EvapoTranspiration network site at <http://txhighplainset.tamu.edu/> under the weather data tab. The text format can then be imported into a spreadsheet for additional or other analysis by the user. (The step by step process to import a queried and downloaded text file into Microsoft Excel® is provided in Appendix A for use in other user programs or applications.). The TXHPET network site contains hourly and daily ET_c, for both grass and alfalfa referenced ET data sets. (Note: currently within the NPET, SPET and TXHPET hourly files, some of the grass referenced ET is designated as ET_{og} with the alfalfa referenced ET being designated as ET_{oa}. (e.g. – g for grass and a for alfalfa) This nomenclature was implemented before standardization of the recent ASCE method and is progressively being upgraded to the new term designations.) Access to these data sets can be obtained following the procedures outlined in the version 1.02 user manual of the TXHPET (Porter et al., 2005). The manual is also available online at: <http://txhighplainset.tamu.edu/> and clicking on the User’s manual tab.

The plant available water (PAW) values for various Texas High Plains soils can be estimated by data located from the Web at <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>. The NRCS web soil map (Figure 3) indicates that digital, online soil characterization is available for virtually all of Texas. The step-by-step process of navigating the NRCS Web site can be found in Appendix B. (Please be aware that the NRCS Web soil survey is not available at all times as designated times for upgrades and maintenance are scheduled - see <http://websoilsurvey.nrcs.usda.gov/app/Help/MaintenanceSchedule.htm>).

Personal assistance in the process of estimating PAW and managed allowable depletion (MAD) levels can additionally be obtained by contacting the following Texas AgriLIFE Extension Service personnel of Nicholas Kenny for the northern region (806-677-5662; npkenny@ag.tamu.edu) and Dr. Dana Porter for the southern region (806-746-4022; d-porter@tamu.edu).

Available Soil Survey Data

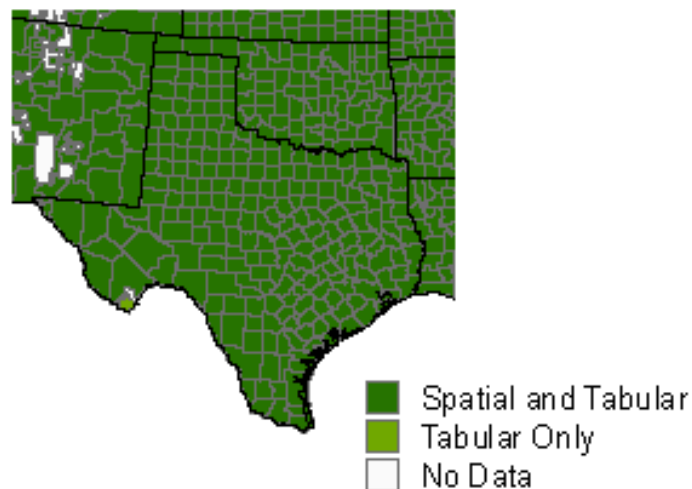


Figure 7. NRCS Web Available Soil Survey Data in Texas. (Source: <http://websoilsurvey.nrcs.usda.gov/DataAvailability/SoilDataAvailabilityMap.pdf>).

Generally, the managed allowable depletion (MAD) of the PAW, if not specified, is estimated to be 50% of the soils water holding capacity. This value varies for different soil types. For clay loam soils, the MAD corresponds to about 50% of the PAW value. For corn or similar stress sensitive crops, the MAD should be estimated at about 50% (or less) of the PAW value. Less water sensitive (or drought tolerant) crops can be allowed to deplete (the MAD) to a level of up to 70% of the PAW. Allowing the crop plants (and delaying irrigation) to deplete the available moisture beyond this level can be risky as the crop approaches the wilting point status of the crop. System capacity will also impact a producer's ability to replenish the profile and should be factored in to the scheduling scenario and the allowable MAD level at differing growth stage periods of crop development. As can be envisioned, the user is not "locked" into having one operational MAD per crop per season, particularly if the stress tolerance and overall production impacts are known with the particular crop. However, the process of knowing and implementing this detailed knowledge again reflects the concept that a well prepared and analyzed **irrigation management** plan will lead to the best efficient production scenario.

The last input variable that is required with the checkbook method is that of rainfall or, more appropriately, effective rainfall. There is not a universally accepted method to determine rainfall effectiveness, but an easy estimation method currently being evaluated by selected Texas High Plains researchers involved in irrigation scheduling is that of omitting single rainfall events less than $\frac{1}{2}$ inch. This does not mean that these small precipitation events are discounted from influencing irrigation demand, but rather that their overall influence is best summarized in the reduction in the next day's ET_c value (through the networks' ET calculations). This threshold rainfall amount is discounted based on research field observations that approximately $\frac{1}{2}$ inch of rain is required before any water is effectively added to the soil profile and counted as plant available water (PAW). Regarding large or intensive rainfall events, the amount of effective rainfall is relatively subjective and would require using a nomograph (a set of complex computations represented in graphical format) to compute effective rainfall per event and is beyond the scope of this publication. It should be recognized that the maximum amount of effective rainfall that can be attributed to a soil profile within a single rainfall event is limited to the voids (space) available in the soil at the time of the event. The effective amount of rainfall that can be stored ranges between the soil's available water holding capacity and the field capacity level of the soil profile. The residual amount of rain beyond this soil holding limit is

attributed to runoff unless the irrigated area is terraced or otherwise bordered and allowed to pond, in which case, the water is then considered as percolation through the profile and counted as deep percolation below the root zone. Either way, the soil profile can only hold a given amount of water which can be accessed by the crop.

Due judgment should be exercised as to where rainfall values are obtained from for individual field or farm irrigation scheduling. Due to the high spatial variability of most rainfall events, data commonly reported by ET networks, school net sites, county offices, TV and radio stations, the National Weather Service (NWS), National Atmospheric and Atmospheric Administration (NOAA), newspapers and airports seldom represent actual rainfall received on the field site of interest. The best procedure is to have a field site rain gage or multiple rain gages at several field sites to adequately represent field based rainfall amounts. Again, the accuracy of an irrigation scheduling methods is only as good as the inputs.

Irrigation Scheduling Using ET

The checkbook irrigation scheduler (Figure 3) can have a depletion trigger that represents a user designated MAD level. The user is encouraged to review the suggested allowable depletion level related to the crop being produced and irrigate accordingly (see Allen, 1998 or contact the extension personnel mentioned earlier). For a well watered crop such as corn, the suggested MAD level has been set at 50 % in research trails (Marek and Cox, 2008). A less sensitive or drought tolerant crop may be permitted to reach a lower soil moisture level (higher management allowed depletion (MAD)- e.g. lower value) status before irrigating. A producer's target production goals, as well as irrigation capacity and allowable pumping level, should be taken into consideration when making these irrigation event triggering decisions.

Caution should be exercised with some heavy soils in that irrigation limitations (such as experienced in the Texas High Plains as the lower zones of profile water extraction by roots cannot be replenished in-season from irrigation event observations and research experience (Marek and Cox, 2008.) Furthermore, post season ripping of the soil profile with heavy tillage equipment in field practice is generally required for deep profile water replenishment when follow-up crops are considered (known as double cropping). Additionally, late season upper soil profile dry down is a management concern to avoid excessive mechanical compaction by harvest

combines and grain transport equipment. Thus, late season plant water and irrigations should be managed to extract lower profile water in lieu of upper profile irrigations.

When using the checkbook method, a soil's actual field moisture condition should be monitored throughout the season and can be easily assessed by observing its feel and appearance. A soil probe, auger, or spade may be used to extract a small soil sample within each foot of root zone depth. The sample is gently squeezed manually in the palm of a hand to determine whether the soil will form a ball or cast, and whether it leaves a film of water and/or soil in the hand. Pressing a portion of the sample between the thumb and forefinger allows one to observe whether the soil will form a ribbon. Results of the sample should be compared with guidelines defined and illustrated in "Estimating Soil Moisture by Feel and Appearance" by the USDA-NRCS (1998).

Conclusions

Crop water requirements are crop-specific, and they vary with weather and growth stage. Irrigation scheduling and adequate irrigation water management is especially important for critical periods of crop development and profitable production. Knowledge of the soil profile characteristics should be assessed and verified to optimize irrigation scheduling and management taking into account the crop's effective rooting depth, the soil moisture storage capacity, and field-specific conditions (shallow soils, caliche layers, etc.). In the use of irrigation scheduling, soil moisture monitoring, evapotranspiration information, and/or plant indicators can be used to fine-tune water applications to meet crop needs and have profitable production.

Irrigation scheduling methods have advantages and limitations. They vary in cost, accuracy, ease of use, and applicability to local conditions (soils, moisture ranges, etc.) Most require verification for accurate measurement to a specific field or farm. Proficiency of use and in interpreting information irrigation scheduling results in practice results with experience and understanding under given production operations and field conditions.

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http://www.twdb.state.tx.us/publications/reports/State_Water_Plan/2007/2007StateWaterPlan/Chapter%202_Regional%20A%20final_112906.pdf

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Appendices

Appendix A

How to Import Text File Format into Microsoft Excel® 2003 Format for Additional User Based Analysis

The TXHPET text file data output format offers a convenient way to download weather data in a “generic” file that can be easily imported into other applications, such as word processing (for reports, for instance) or spreadsheet programs for further data processing and analysis. This appendix describes step-by-step instructions for accessing data from the Texas High Plains ET Network database at <http://txhighplainset.tamu.edu>, selecting (left clicking with a mouse) the text file format, and importing the data into Microsoft Excel® in a form for further analysis. (The buttons or tabs on the user pages of the web site and menu items are highlighted in this document with a highlighted yellow background).

From the main page of the Texas High Plains ET Network (Figure A-1), select the **Weather Data**, and then select either **Daily Data** or **Hourly Data** (Figure A-2).

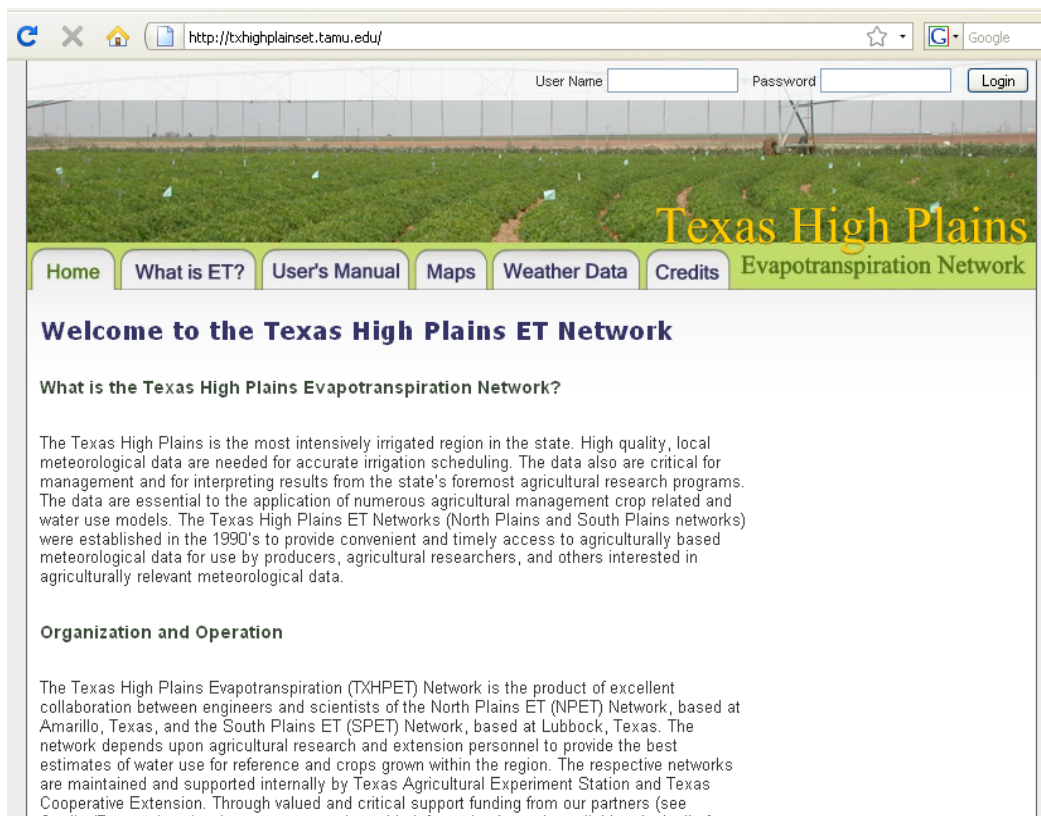


Figure A-1. Texas High Plains Evapotranspiration Network Main Page
<http://txhighplainset.tamu.edu/>

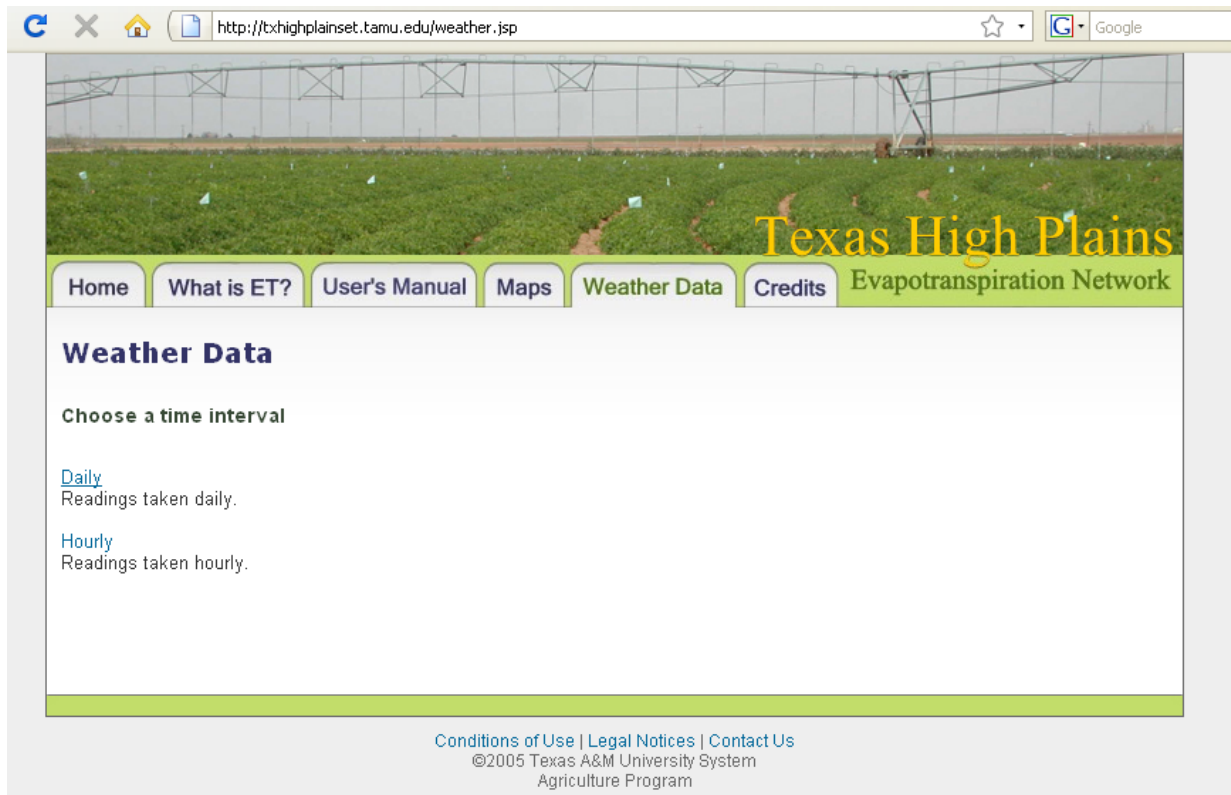


Figure A-2. Texas High Plains Evapotranspiration Network Weather Data tab opens the weather data query page from which the user can select to query Daily or Hourly data sets.

The data query is accomplished by using pull-down menus (Figure A-3). Start by selecting one or more weather stations of interest, using the **Add** button to add each station selection to the list. Use the Select Information pull-down menu to select data items, using the **Add** button to add each selection to the desired data list. Similarly, select the data date range (**start** and **end** dates) and **times** (if hourly data is selected). Choose **English** or **Metric** units, and choose the data format (**data table**, **text file**, **graph**, or **advanced graphics**). Then hit the **Submit** button. The graphical data presentation options are very convenient for online data presentation of the results. The data table format is easily imported in to a spreadsheet through the use of the “copy/paste” function, but for long data sets, this can be tedious, since it must be accomplished on a page-by-page basis. The text file format generally is the most convenient way to download relatively long data sets.

Texas High Plains Evapotranspiration Network

Home | What is ET? | User's Manual | Maps | Weather Data | Credits

Daily Weather Data

Select a Location

Select a location from the following list and click the Add button. You may add more than one location. If you wish to remove a location simply click the remove link located next to the location.

Location List: Bushland (ARS)

Added Locations: Bushland (ARS) [remove](#)

Select Information

Select a group or individual item of information from the following list and click the Add button. You may add more than one item of information at a time. If you wish to remove an item simply click the remove link located next to the item.

Information List: ---- Individual Items ----

Added Information: Average Air Temperature [remove](#)
Full Season Corn ET - Planted April 15 [remove](#)
North Plains Cotton ET - Planted June 1 [remove](#)

Time Range

Complete the following time range by setting a start date and an end date. Be sure to enter a valid year.

Start Date: Date April 15, 2006

End Date: Date October 15, 2006

Units

Select the units of measurement.

Units: English

Output Method

Select an output method for your data.

Output Method: Data Table
 Text File
 Graph
 Advanced Graph (next page for options)

Figure A-3. Weather data query using pull-down menus.

When the database search is completed, an option to download the data is presented. Simply click on the underlined text, “[Click Here to Download](#)” (Figure A-4). A file download pop-up box as to whether to **Open**, **Save** or **Cancel**. Either **Save** the data.txt file to the desired computer directory or **Open** the file on screen. If the file is opened on screen, the data will be shown on screen in the default text file format shown in the Microsoft Notepad® view as in Figure A-5.

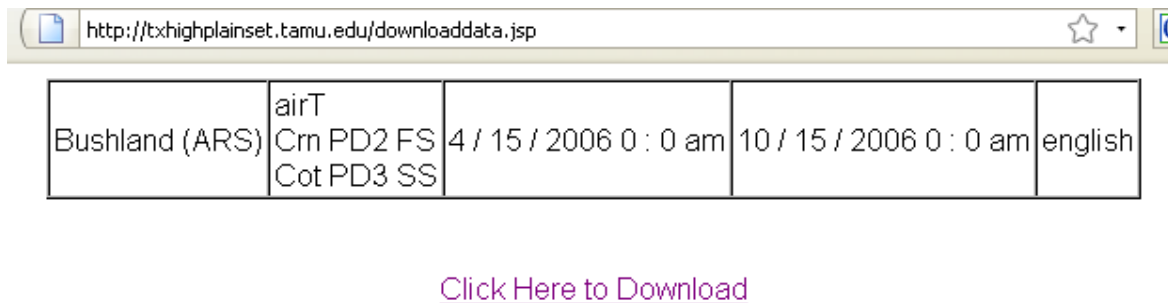


Figure A-4. TXHPET data screen presented when database search is completed.

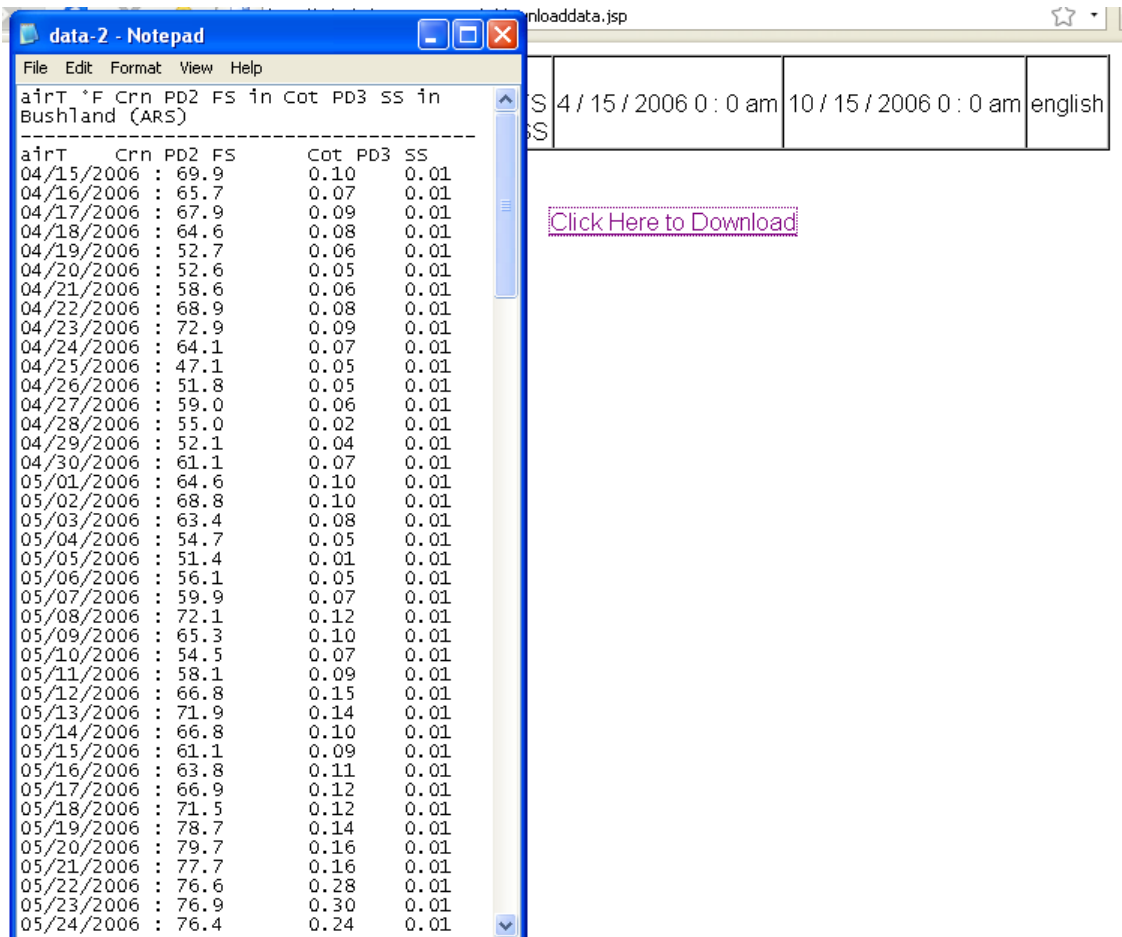


Figure A-5. TXHPET “text file” data format shown imported in the Microsoft Notepad® application.

Right click on the notepad sheet on screen or go to **Edit** on the menu bar, and scroll down to **Select All**. Click “**Select All**” (Figure A-6). Then use “Control C” (press the CTRL key and the C key together) or right click, scroll down and click on “**Copy**” (Figure A-7). This places the selected data into your computer’s temporary memory (on your computer’s clipboard), indicated as such when the selected data are shaded.

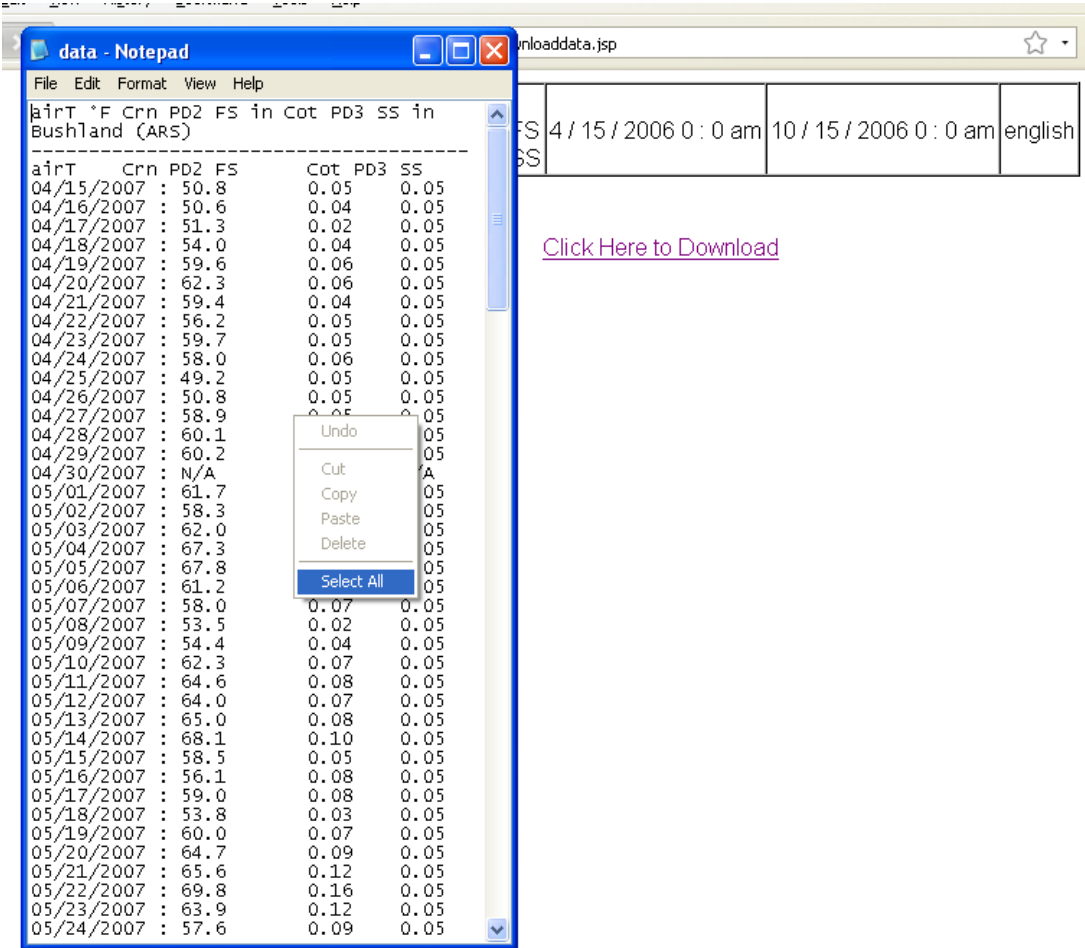


Figure A-6. Process of data selection involves a right click and scroll down the menu to Select All.

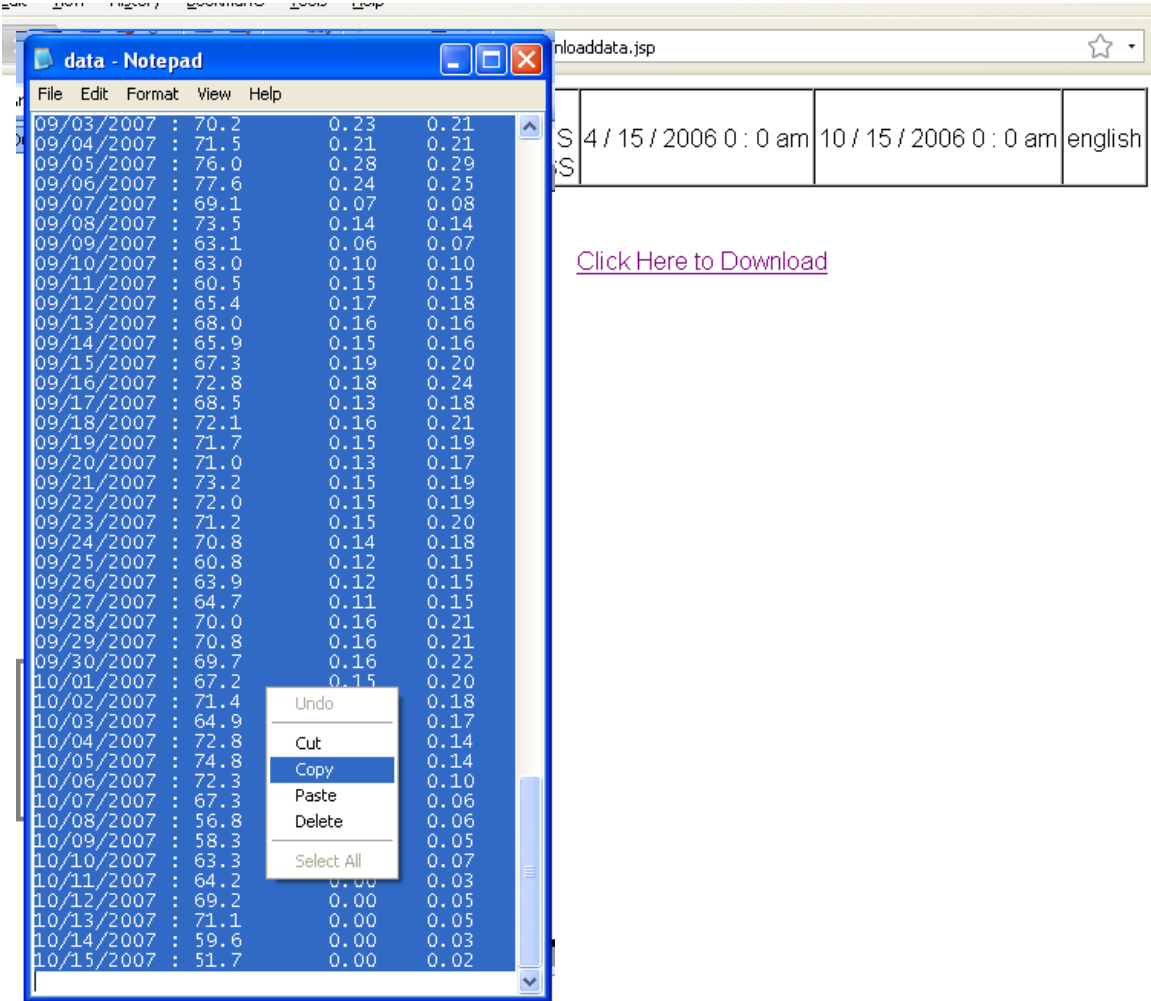


Figure A-7. Copy selected data by scrolling down and clicking on Copy, or simply use the “control C” macro application to place the data on the “clipboard”.

Open the target software application. Figure A-8 shows an open blank Microsoft Excel® 2003 worksheet. Select a target cell in the target worksheet and **paste** the copied text format data into the spreadsheet, using the pull-down options under the Edit tab (Figure A-9), or use the Control V built-in macro function.

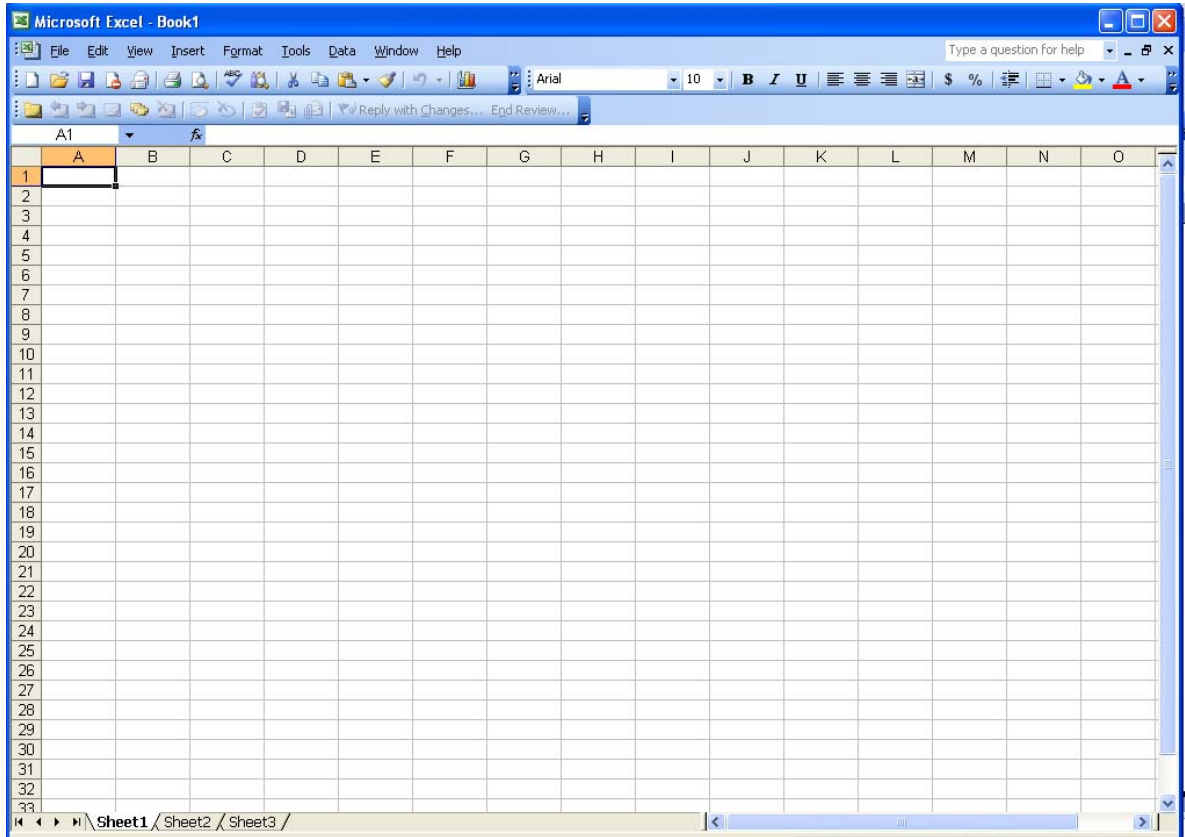


Figure A-8. Open the target software application. (Microsoft Excel® 2003 is the target application shown).

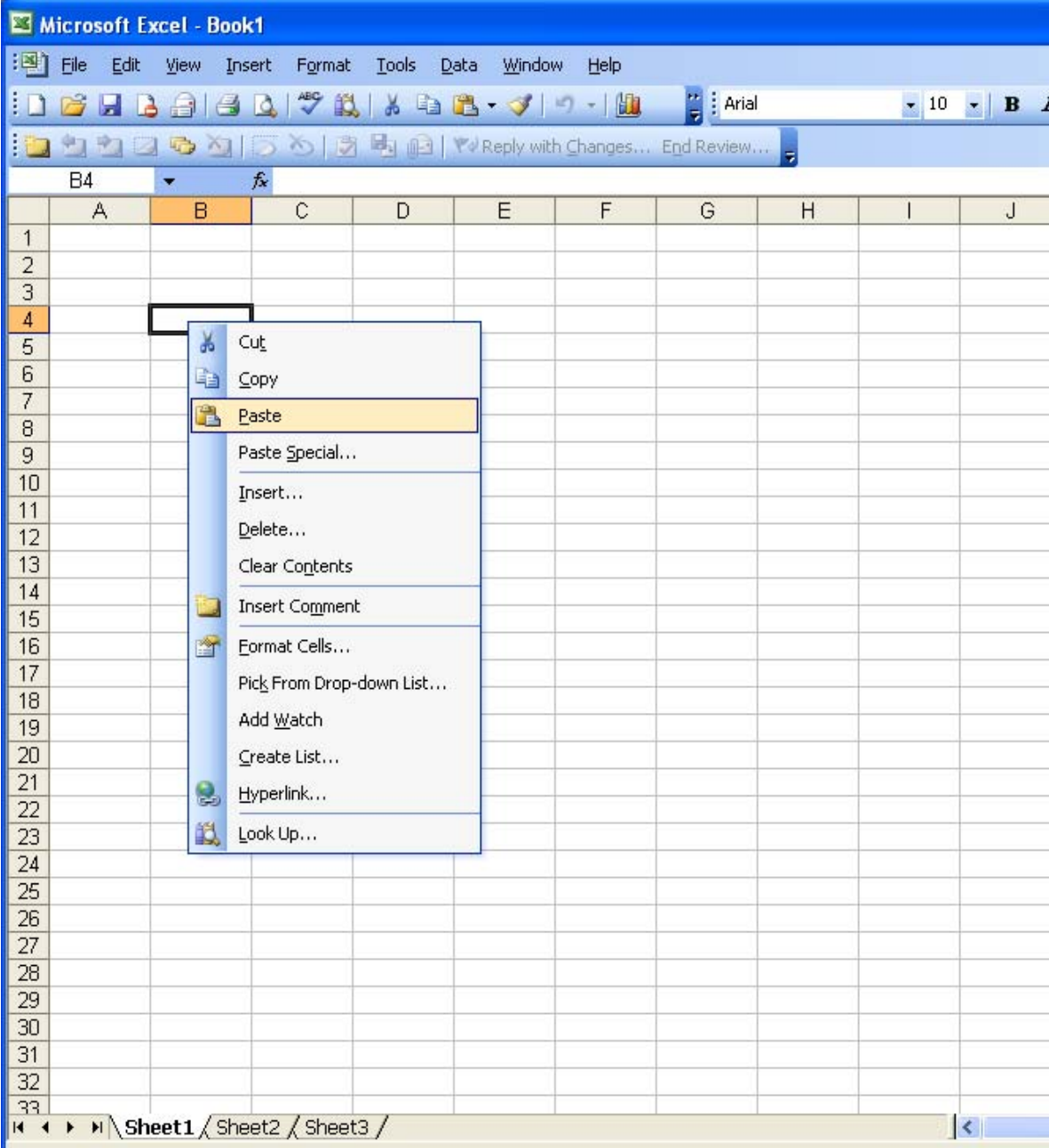


Figure A-9. Pasting copied data into the Excel spreadsheet, sheet 1.

The copy/pasted data will appear in the spreadsheet (Figure A-10). If two columns of data appear in one combined column as in the example in Figure A-10, insert a column to the right of that column (Figure A-11) by highlighting the column immediately to the right of the combined column and using the **Insert** tab on the Excel toolbar as shown. Scroll down to Column under the Insert tab. The newly inserted column will appear as in the example in Figure A-12.

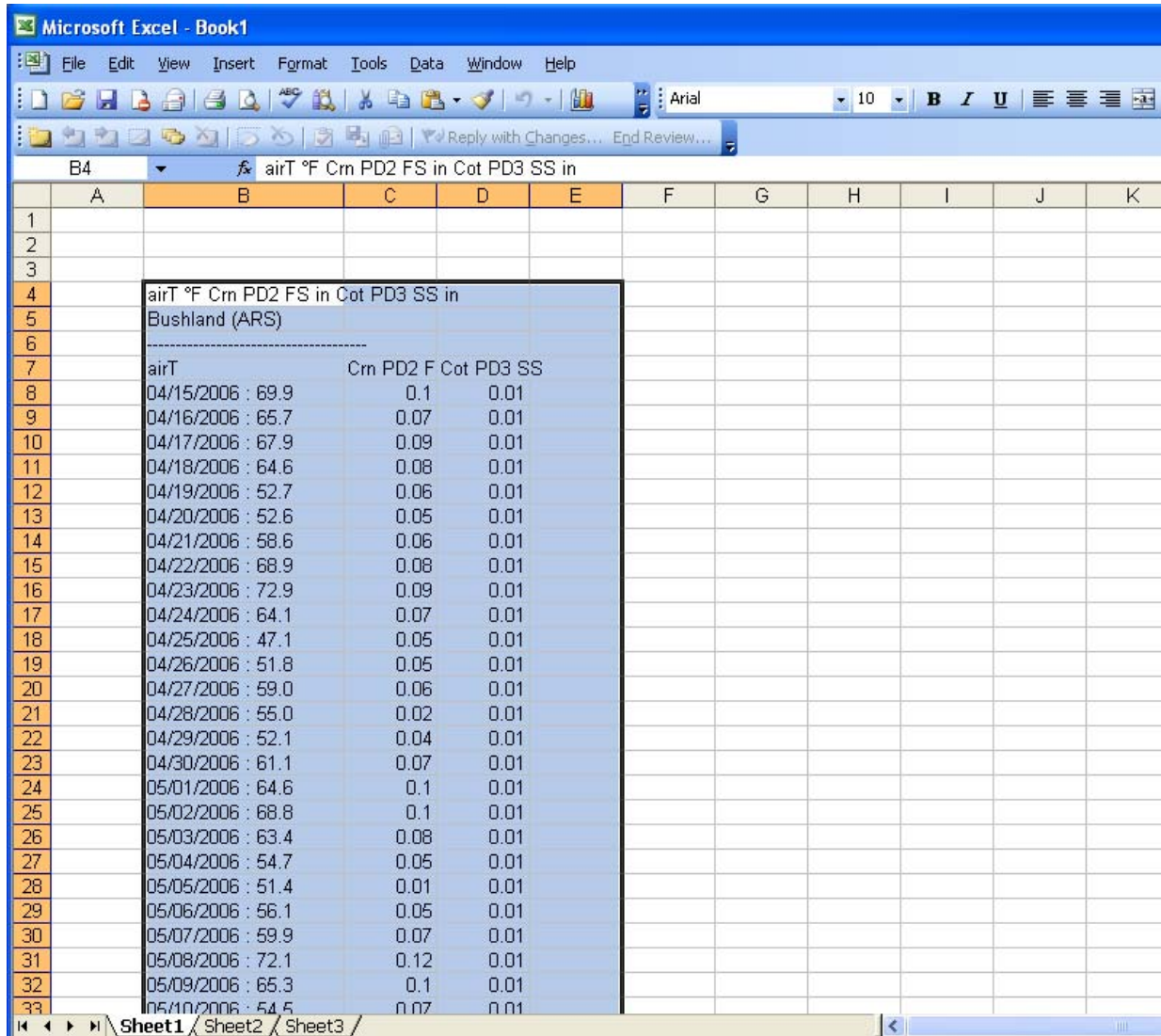


Figure A-10. Data are copied onto the Excel worksheet. If two data columns are combined in one column (as in Column B in this example), the columns can be separated as described below.

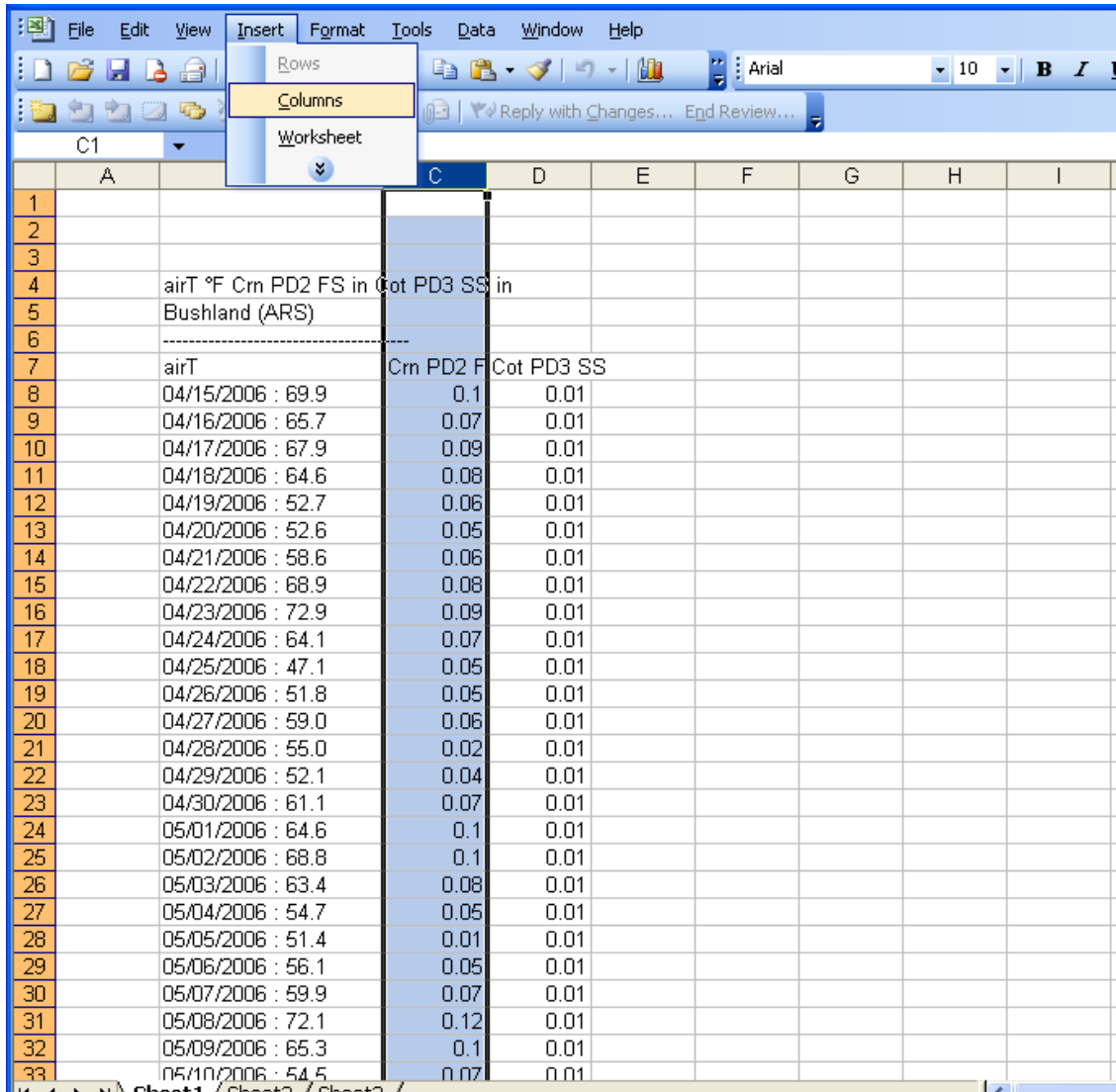


Figure A-11. Highlight the target location of the inserted column. Scroll down to select “Column” under the Insert tab on the Excel toolbar.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4		airT °F Crm PD2 FS in	Cot PD3 SS in								
5		Bushland (ARS)									
6											
7		airT		Crm PD2 F	Cot PD3 SS						
8		04/15/2006 : 69.9		0.1	0.01						
9		04/16/2006 : 65.7		0.07	0.01						
10		04/17/2006 : 67.9		0.09	0.01						
11		04/18/2006 : 64.6		0.08	0.01						
12		04/19/2006 : 52.7		0.06	0.01						
13		04/20/2006 : 52.6		0.05	0.01						
14		04/21/2006 : 58.6		0.06	0.01						
15		04/22/2006 : 68.9		0.08	0.01						
16		04/23/2006 : 72.9		0.09	0.01						
17		04/24/2006 : 64.1		0.07	0.01						
18		04/25/2006 : 47.1		0.05	0.01						
19		04/26/2006 : 51.8		0.05	0.01						
20		04/27/2006 : 59.0		0.06	0.01						
21		04/28/2006 : 55.0		0.02	0.01						
22		04/29/2006 : 52.1		0.04	0.01						
23		04/30/2006 : 61.1		0.07	0.01						
24		05/01/2006 : 64.6		0.1	0.01						
25		05/02/2006 : 68.8		0.1	0.01						
26		05/03/2006 : 63.4		0.08	0.01						
27		05/04/2006 : 54.7		0.05	0.01						
28		05/05/2006 : 51.4		0.01	0.01						
29		05/06/2006 : 56.1		0.05	0.01						
30		05/07/2006 : 59.9		0.07	0.01						
31		05/08/2006 : 72.1		0.12	0.01						
32		05/09/2006 : 65.3		0.1	0.01						
33		05/10/2006 : 54.5		0.07	0.01						

Figure A-12. Inserted column to the right of the combined column.

To separate the combined data column, select the column to be separated, and scroll down to select the “**Text to Columns**” function under the Data tab on the toolbar (Figure A-13). The Convert Text to Columns Wizard (Figure A-14) will guide you through the process. For this example, select the **Delimited** data format, since the data are separated by a colon. Select the delimiter (Figure A-15). In this case, select “**Other**”, and fill in a colon “**:**” in the box. Click the Next button to proceed. Select a column data format as prompted by the Wizard (Figure A-16). In this example, the data will be “**General**”. Click the **Finish** button to complete the Text to Column data conversion. Finally, make any adjustments to column headings and data width, if needed and to alignment of cells as needed (Figure A-17). For example, make the column(s) wider if a series of “#####” are displayed as the width is not sufficient to display the value(s). Proceed with data summary, interpretation and analysis using the Excel spreadsheet capabilities (Figure A-18).

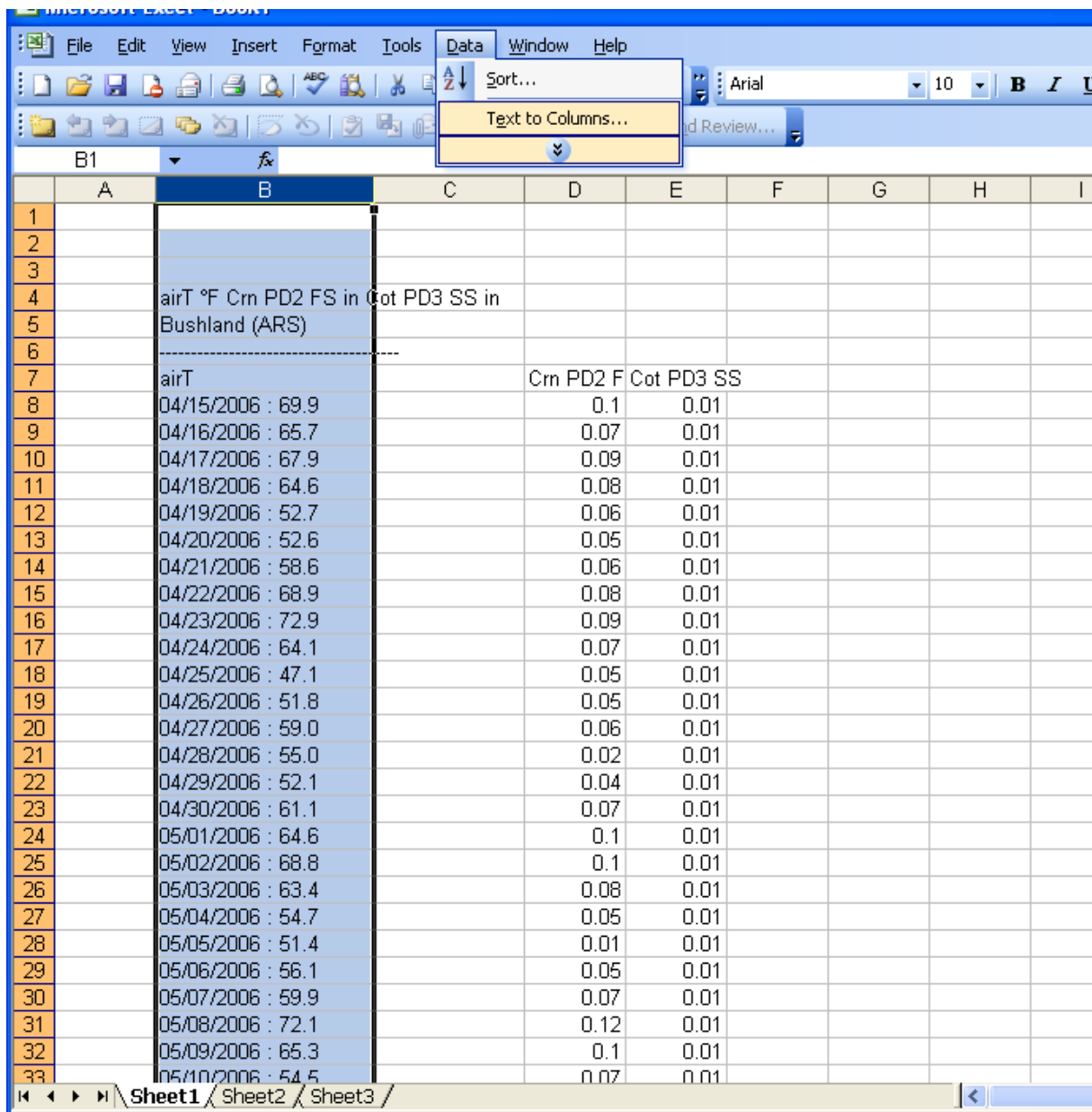


Figure A-13. Select the column to be separated; then scroll down to select the “Text to Columns” function under the Data tab on the toolbar.

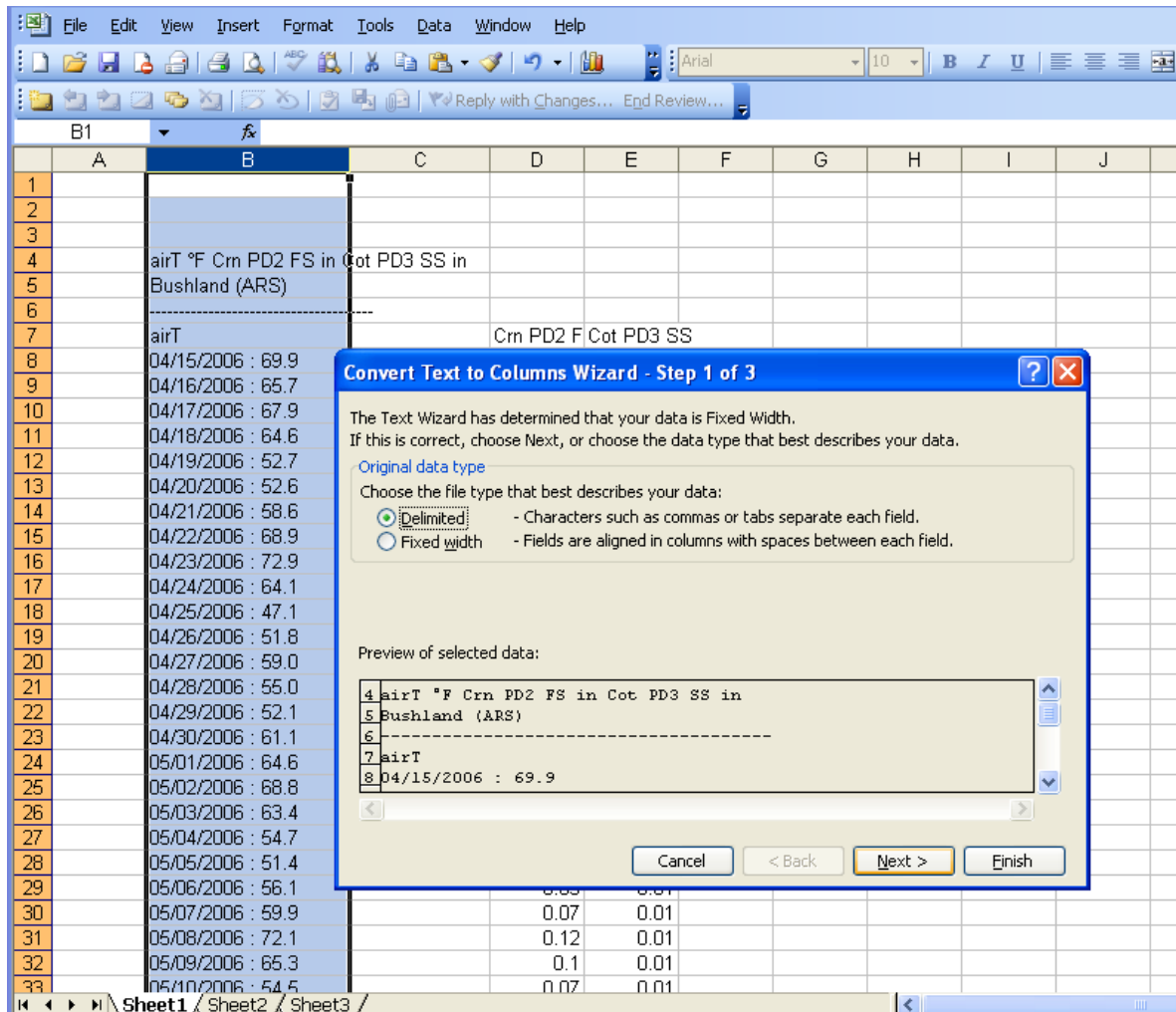


Figure A-14. The Convert Text to Columns Wizard will guide you through the data separation process. For this example, select the Delimited data format, since the data are separated by a colon.

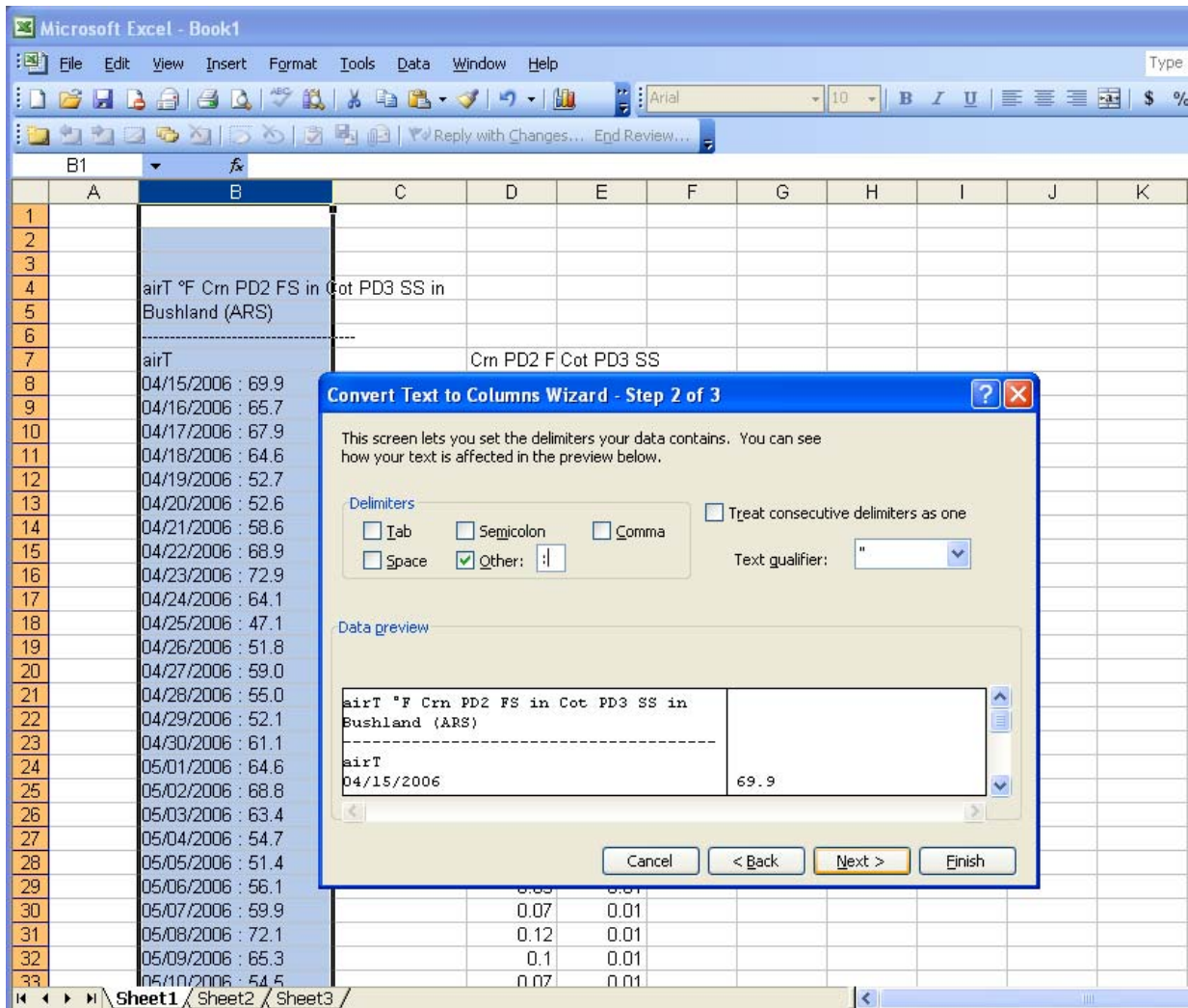


Figure A-15. Select the data “text” delimiter. In this case, select “Other”, and fill in a colon “:” in the box. Click the Next button to proceed.

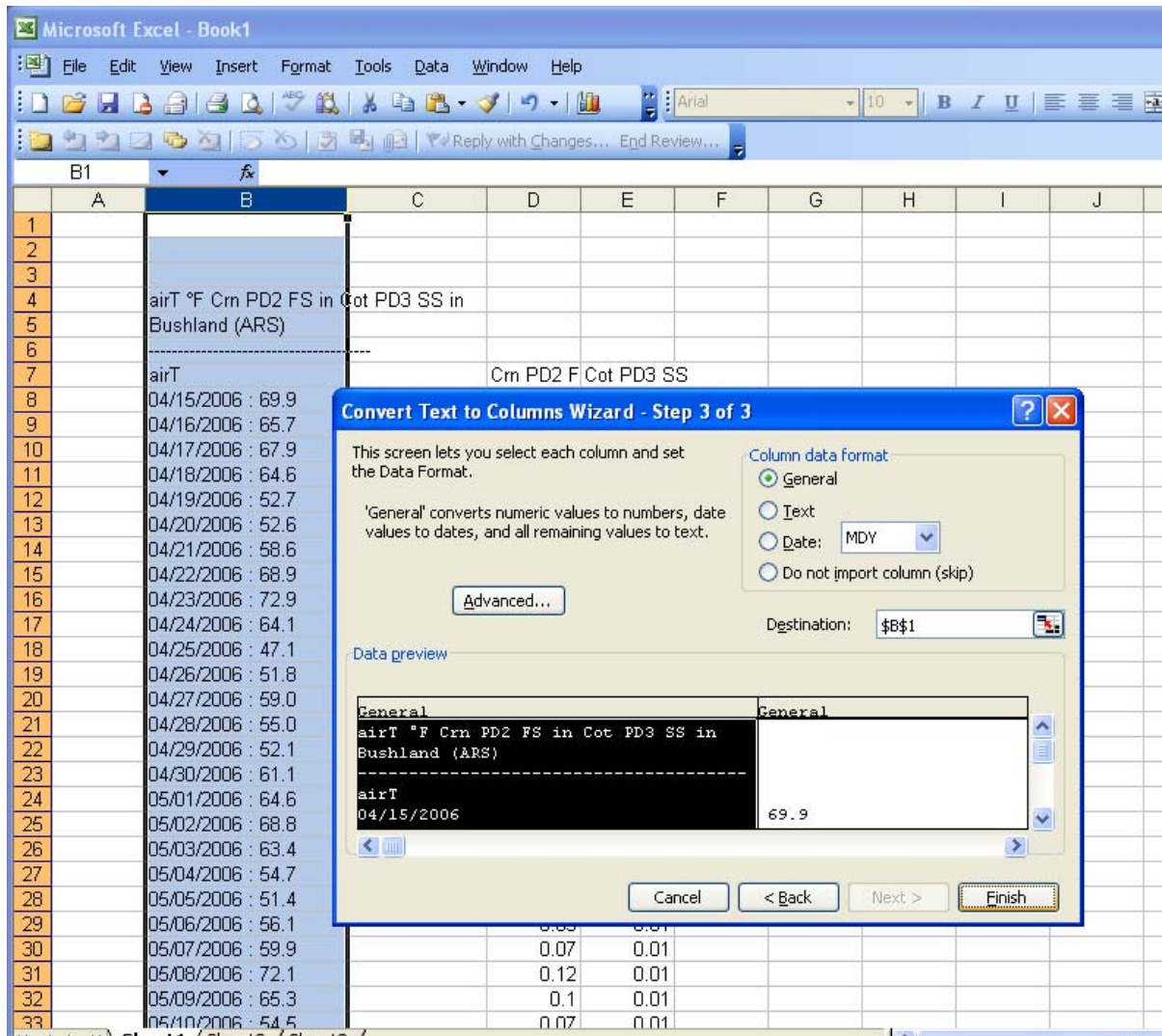


Figure A-16. Select a column data format as prompted by the Wizard. In this example, the data will be “General”. Click the Finish button to complete the Text to Column data conversion.

The screenshot shows a Microsoft Excel spreadsheet with the following data:

	A	B	C	D	E	F	G	H
1		airT °F Crn PD2 FS in Cot PD3 SS in						
2		Bushland (ARS)						
3		-----						
4			airT	Crn PD2 FS	Cot PD3 SS			
5		4/15/2006	69.9	0.1	0.01			
6		4/16/2006	65.7	0.07	0.01			
7		4/17/2006	67.9	0.09	0.01			
8		4/18/2006	64.6	0.08	0.01			
9		4/19/2006	52.7	0.06	0.01			
10		4/20/2006	52.6	0.05	0.01			
11		4/21/2006	58.6	0.06	0.01			
12		4/22/2006	68.9	0.08	0.01			
13		4/23/2006	72.9	0.09	0.01			
14		4/24/2006	64.1	0.07	0.01			
15		4/25/2006	47.1	0.05	0.01			
16		4/26/2006	51.8	0.05	0.01			
17		4/27/2006	59	0.06	0.01			
18		4/28/2006	55	0.02	0.01			
19		4/29/2006	52.1	0.04	0.01			
20		4/30/2006	61.1	0.07	0.01			
21		5/1/2006	64.6	0.1	0.01			
22		5/2/2006	68.8	0.1	0.01			
23		5/3/2006	63.4	0.08	0.01			
24		5/4/2006	54.7	0.05	0.01			
25		5/5/2006	51.4	0.01	0.01			
26		5/6/2006	56.1	0.05	0.01			
27		5/7/2006	59.9	0.07	0.01			
28		5/8/2006	72.1	0.12	0.01			
29		5/9/2006	65.3	0.1	0.01			
30		5/10/2006	54.5	0.07	0.01			
31		5/11/2006	58.1	0.09	0.01			
32		5/12/2006	66.8	0.15	0.01			
33		5/13/2006	71.9	0.14	0.01			

Figure A-17. After making necessary alignment adjustments, the data are ready for use in further spreadsheet-based analysis.

The screenshot shows an Excel spreadsheet with the following data:

	A	B	C	D	E	F	G	H	I
1		airT °F Crn PD2 FS in Cot PD3 SS in							
2		Bushland (ARS)							
3									
4			airT	Crn PD2 FS	Cot PD3 SS				
5			Air Temperature	Corn ET	Cotton ET				
6		4/15/2006	69.9	0.1	0.01				
7		4/16/2006	65.7	0.07	0.01				
8		4/17/2006	67.9	0.09	0.01				
9		4/18/2006	64.6	0.08	0.01				
10		4/19/2006	52.7	0.06	0.01				
11		4/20/2006	52.6	0.05	0.01				
12		4/21/2006	58.6	0.06	0.01				
13		4/22/2006	68.9	0.08	0.01				
14		4/23/2006	72.9	0.09	0.01				
15		4/24/2006	64.1	0.07	0.01				
16		4/25/2006	47.1	0.05	0.01				
17		4/26/2006	51.8	0.05	0.01				
18		4/27/2006	59	0.06	0.01				
19		4/28/2006	55	0.02	0.01				
20		4/29/2006	52.1	0.04	0.01				
21		4/30/2006	61.1	0.07	0.01				
22		5/1/2006	64.6	0.1	0.01				
23		5/2/2006	68.8	0.1	0.01				
24		5/3/2006	63.4	0.08	0.01				
25		5/4/2006	54.7	0.05	0.01				
26		5/5/2006	51.4	0.01	0.01				
27		5/6/2006	56.1	0.05	0.01				
28		5/7/2006	59.9	0.07	0.01				
29		5/8/2006	72.1	0.12	0.01				
30		5/9/2006	65.3	0.1	0.01				
31		5/10/2006	54.5	0.07	0.01				
32		5/11/2006	58.1	0.09	0.01				
33		5/12/2006	66.8	0.15	0.01				

Figure A-18. In this example, column titles have been changed to a name to be used in the user's analysis.

Appendix B

Navigation and Computation of Plant Available Water (PAW) and Management Allowable Depletion (MAD) for a Crop Soil Profile

Effective use of an ET-based irrigation scheduling method requires some knowledge of soil moisture characteristics, including soil moisture storage capacity, effective root zone, Plant Available Water, and Management Allowable Depletion. Soil moisture characteristic information is readily available through the United States Department of Agriculture – Natural Resources Conservation Service. Previously published in hardcopy format by the agency (formerly named the USDA-Soil Conservation Service, “SCS”) the Soil Surveys were available - by county - through the county SCS office. These surveys have been updated, converted to electronic format, and made available online through the USDA-NRCS Web Soil Survey website: <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm> (Figure B-1). The following information details the navigation and calculation process associated with the web site.

The screenshot shows the main page of the USDA-NRCS Web Soil Survey. At the top, there is a banner with the USDA logo and the text 'Web Soil Survey'. Below this is a navigation bar with links for 'Home', 'About Soils', 'Help', and 'Contact Us'. The main content area is divided into several sections. On the left, there is a 'Search' box with a 'Go' button and a 'Browse by Subject' menu. The central part of the page features a large green button labeled 'START WSS' and a 'Welcome to Web Soil Survey (WSS)' section. This section includes a photograph of people in a field and text explaining that the Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. To the right of the main content, there are three boxes: 'I Want To...', 'Announcements/Events', and 'I Want Help With...'. The 'I Want To...' box lists several options, including 'Start Web Soil Survey (WSS)', 'Know the requirements for running Web Soil Survey', 'Know whether Web Soil Survey works in my web browser', 'Know the Web Soil Survey hours of operation', and 'Find what areas of the U.S. have soil data'. The 'Announcements/Events' box mentions 'Web Soil Survey 2.1 has been released! View description of new features.' The 'I Want Help With...' box lists 'How to use Web Soil Survey', 'How to use Web Soil Survey Online Help', 'Known Problems and Workarounds', 'Frequently Asked Questions', and 'Citing Web Soil Survey as a source of soils data'. Below the 'Welcome' section, there is a 'Three Basic Steps' section, with the first step being 'Define', which includes a screenshot of the 'Area of Interest (AOI)' tab and a description: 'Use the Area of Interest tab to define your area of interest.'

Figure B-1. The USDA-NRCS Web Soil Survey Main Page (<http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>).

To enter the NRCS Web Soil Survey, click on the green **Start WSS** button on the main page (Figure B-1). The **Area of Interest** tab can be selected on the map by address, state and county, latitude and longitude, or by “zooming in” using the tools on the Area of Interest Interactive Map (Figure B-2). Pull-down menus and toolbars on the site are used for navigation, from locating and selecting an Area of Interest (field or farm, for instance) to selecting and accessing soil data (Figures B-2 through B-6).

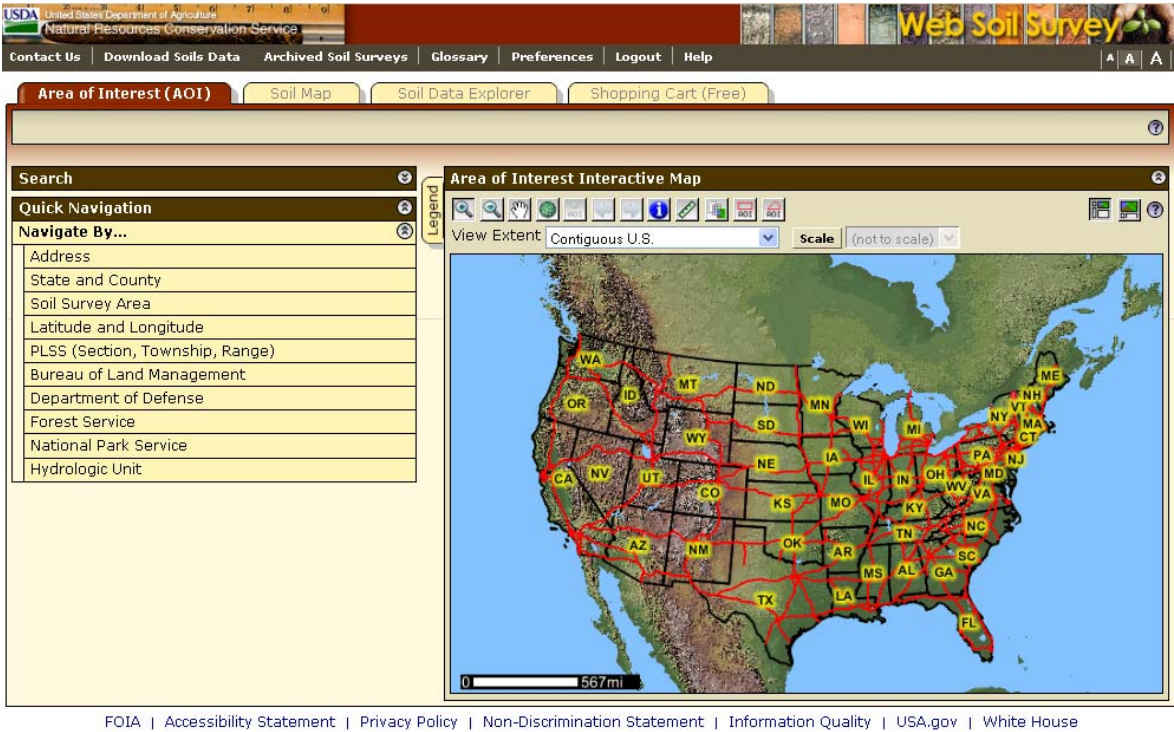


Figure B-2. Web Soil Survey Area of Interest Interactive Map. Note the navigation menu on the left and the toolbar above the map. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

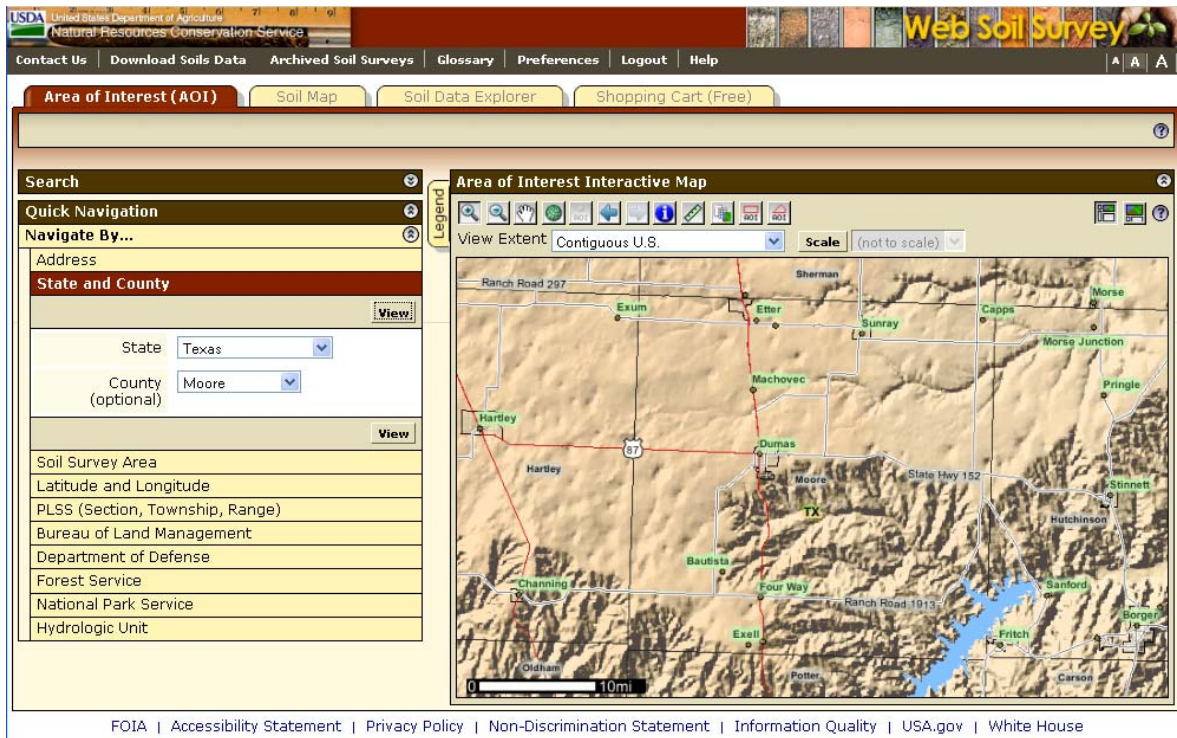


Figure B-3. Pull-down menus can be used to locate a given state and county on the Area of Interest Interactive Map. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

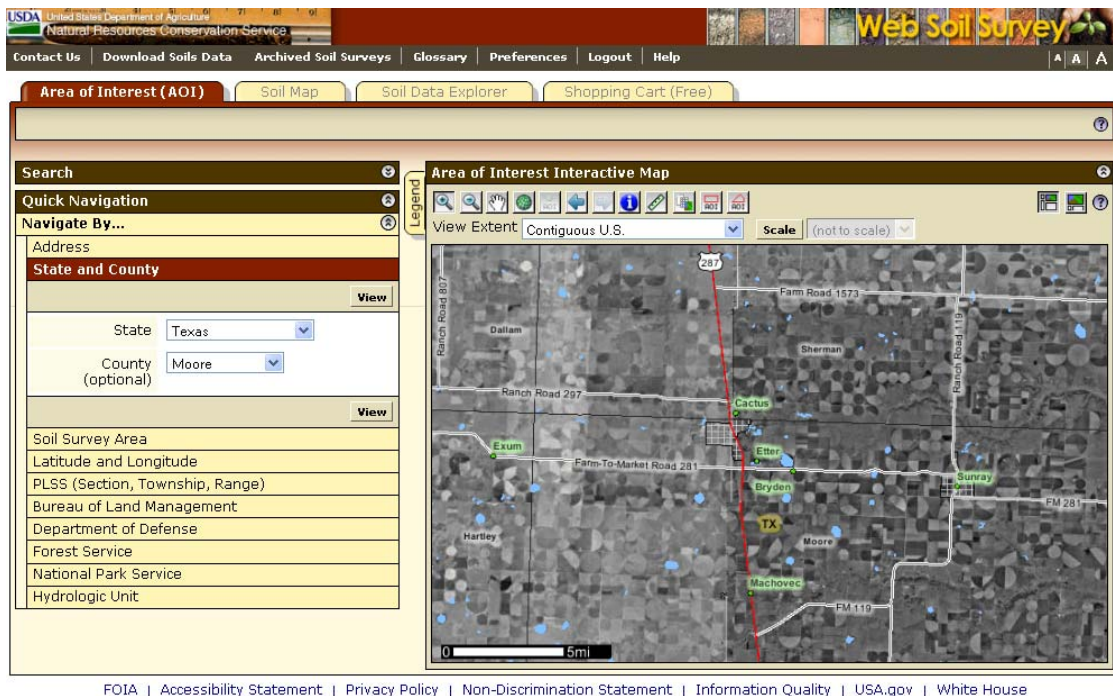


Figure B-4. The “zoom in” function on the Area of Interest Interactive Map toolbar makes it easy to locate a specific site on the map. Note that towns and roads are labeled for ease of locating an area of interest. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

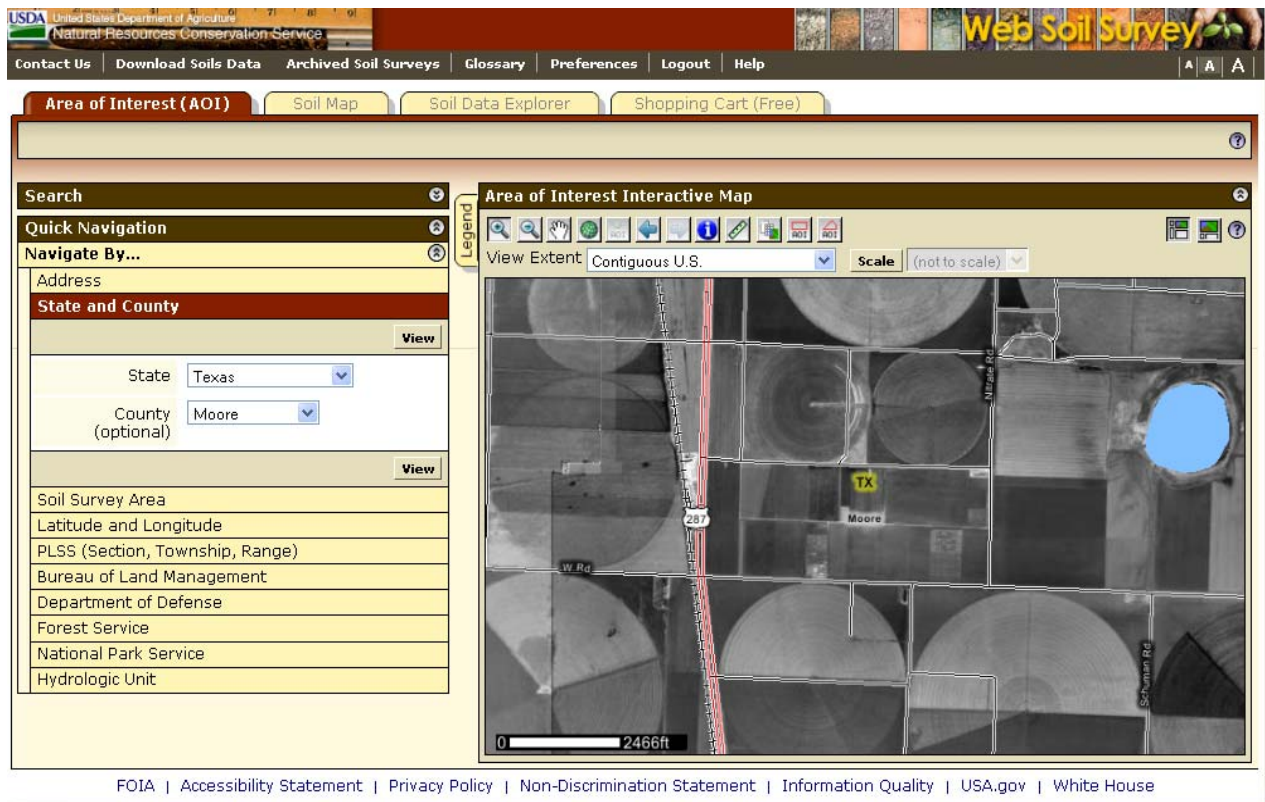


Figure B-5. Users can “zoom in” on the Area of Interest Interactive Map, locating specific fields, roads, and geographic features. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

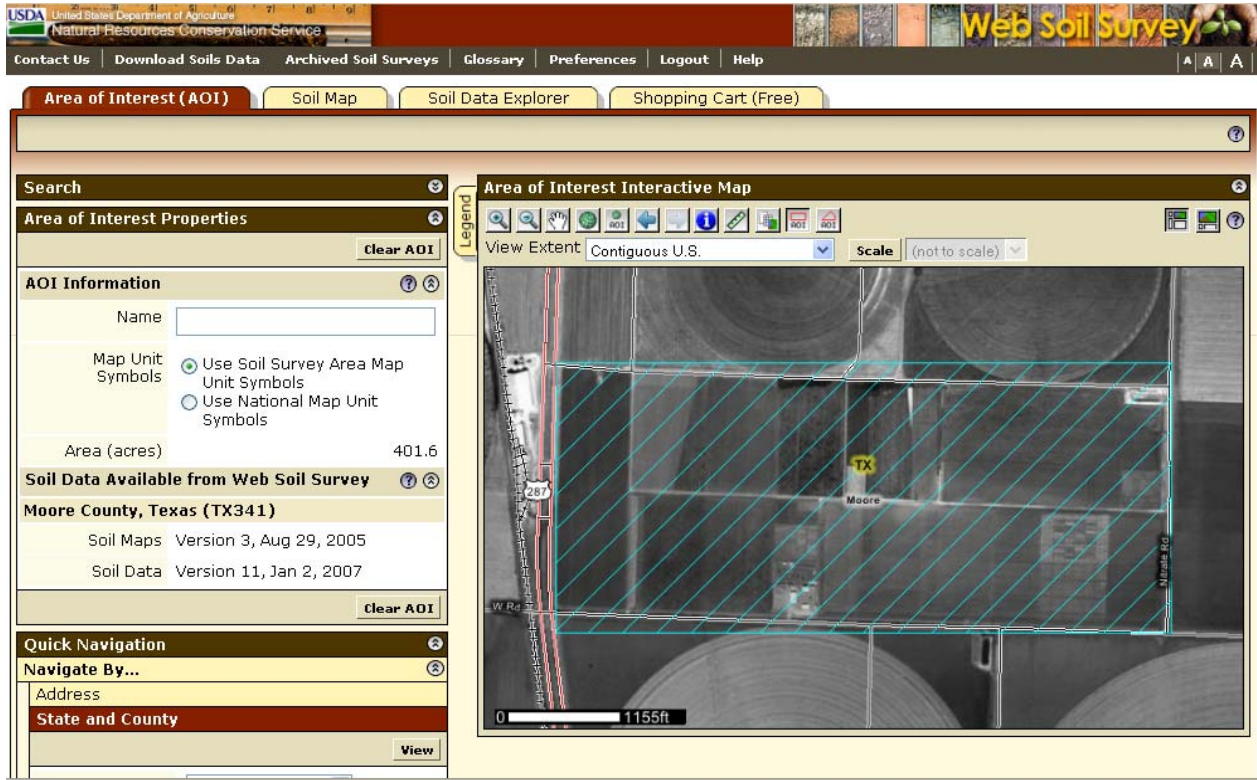


Figure B-6. The Area of Interest is selected by clicking on one of two AOI buttons on the Area of Interest Interactive Map toolbar, then clicking and dragging on the map. The selected Area of Interest will be outlined and shaded. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

After the Area of Interest is selected, tabs are used to access Soil Map or Soil Data Explorer applications (Figure B-7). The **Soil Map** feature superimposes the soil survey map over the Area of Interest. The table at the left lists soils within the selected area, and indicates percent of the area represented by each soil (Figure B-7). The Soil Data Explorer tab provides access soil-specific information, including **Soil Properties and Qualities** (Figure B-8). Information and qualities available for the soils are listed in the table to the left. Soil water characteristics are listed under Soil Physical Properties. Soil physical properties (including soil moisture characteristics) are also available under the Soil Reports tab under the Soil Data Explorer (Figure B-9).

Search

Map Unit Legend

Moore County, Texas (TX341)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
ShA	Sherm silty clay loam, 0 to 1 percent slopes	393.2	98.8%
SuA	Sunray loam, 0 to 1 percent slopes	4.8	1.2%
Totals for Area of Interest		398.0	100.0%

Soil Map

Scale (not to scale)

Warning: Soil Map may not be valid at this scale.

FOIA | Accessibility Statement | Privacy Policy | Non-Discrimination Statement | Information Quality | USA.gov | White House

Figure B-7. The Soil Map feature superimposes the soil survey map over the Area of Interest. The table at the left lists soils within the selected area, and indicates percent of the area represented by each soil. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

USDA United States Department of Agriculture
Natural Resources Conservation Service

Contact Us | Download Soils Data | Archived Soil Surveys | Glossary | Preferences | Logout | Help

Area of Interest (AOI) | Soil Map | **Soil Data Explorer** | Shopping Cart (Free)

View Soil Information By Use: All Uses [v] Printable Version Add to Shopping Cart

Intro to Soils | Suitabilities and Limitations for Use | **Soil Properties and Qualities** | Ecological Site Assessment | Soil Reports

Search

Properties and Qualities Ratings

Open All Close All

Soil Chemical Properties ? ?

Soil Erosion Factors ? ?

Soil Physical Properties ? ?

Available Water Capacity

Available Water Supply, 0 to 100 cm

Available Water Supply, 0 to 150 cm

Available Water Supply, 0 to 25 cm

Available Water Supply, 0 to 50 cm

Bulk Density, 15 Bar

Bulk Density, One-Tenth Bar

Bulk Density, One-Third Bar

Linear Extensibility

Liquid Limit

Organic Matter

Percent Clay

Percent Sand

Percent Silt

Plasticity Index

Soil Map

Scale (not to scale)

0 1175ft

Figure B-8. The Soil Data Explorer tab provides access soil-specific information, including Soil Properties and Qualities. Information and qualities available for the soils are listed in the table to the left. Soil water characteristics are listed under Soil Physical Properties. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>)

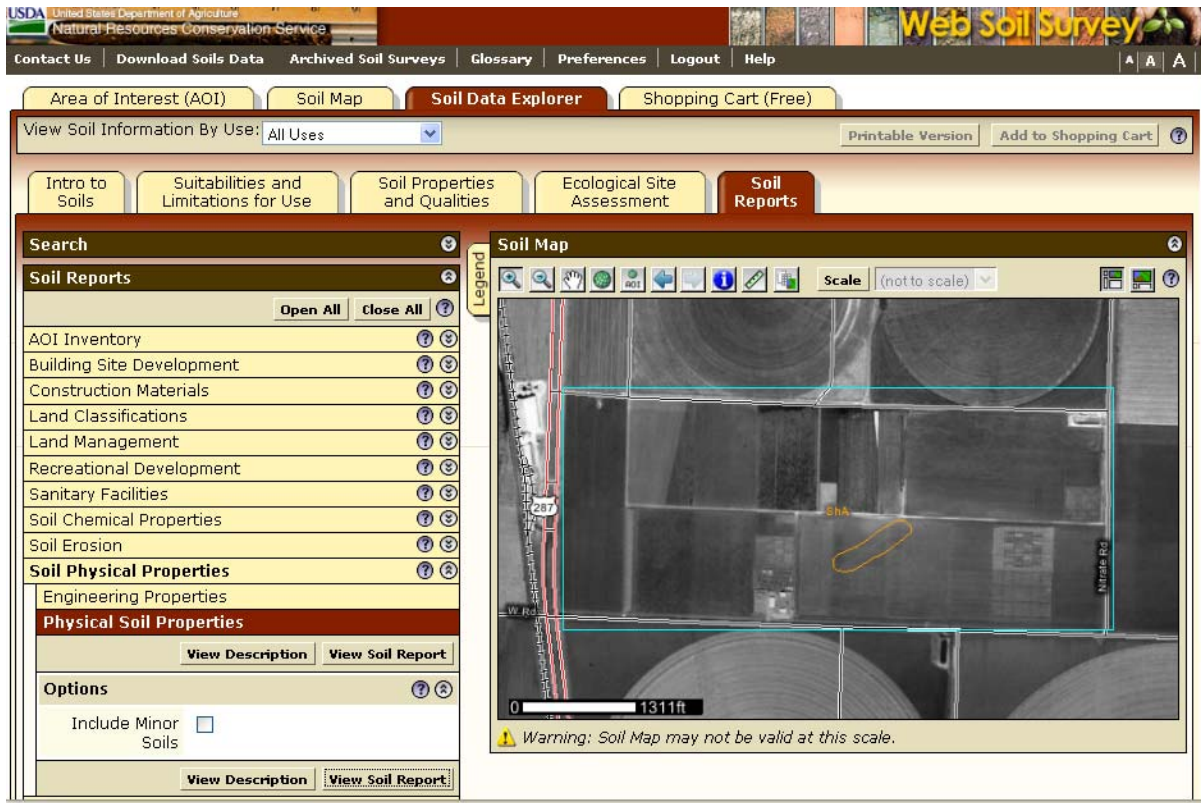


Figure B-9. Soil physical properties (including soil moisture characteristics) are also available under the Soil Reports tab under the Soil Data Explorer. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>)

Users familiar with the SCS Soil Survey publications will recognize the tables included in the Soil Report (Figure B-10). New users will find the descriptions of soil physical properties helpful (Figure B-11). Key items of interest for soil moisture management are the soil name, depths and textures of the soil layers, bulk density (needed for converting gravimetric soil moisture estimates to volumetric soil moisture), saturated hydraulic conductivity (describing the rate at which water moves through the soil under saturated conditions), and Available Water Capacity (plant available water). Hydraulic conductivity provides an indication of the relative ease at which water enters the soil, affecting runoff of irrigation and rainfall.

Report – Physical Soil Properties														
Moore County, Texas														
Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensibility	Organic matter	Erosion factors			Wind erodibility group	Wind erodibility index
										Kw	Kf	T		
	In	Pct	Pct	Pct	g/cc	micro m/sec	In/In	Pct	Pct					
ShA—Sherm silty clay loam, 0 to 1 percent slopes														
Sherm	0-6	—	—	27-40	1.25-1.40	0.42-1.40	0.16-0.20	3.0-5.9	1.0-3.0	.37	.37	5	7	38
	6-50	—	—	40-55	1.35-1.50	0.42-1.40	0.13-0.18	6.0-8.9	0.1-1.0	.37	.37			
	50-72	—	—	35-55	1.35-1.50	0.42-1.40	0.10-0.17	3.0-5.9	0.1-0.5	.37	.37			
SuA—Sunray loam, 0 to 1 percent slopes														
Sunray	0-12	—	—	15-30	1.35-1.50	4.00-14.00	0.15-0.20	0.0-2.9	1.0-3.0	.32	.32	5	4L	86
	12-22	—	—	20-35	1.40-1.55	4.00-14.00	0.14-0.19	3.0-5.9	0.5-1.0	.32	.32			
	22-60	—	—	20-35	1.40-1.55	4.00-14.00	0.10-0.18	3.0-5.9	0.1-0.5	.32	.32			

Description – Physical Soil Properties
<p>Physical Soil Properties</p> <p>This table shows estimates of some physical characteristics and features that affect soil behavior. These estimates are given for the layers of each soil in the survey area. The estimates are based on field observations and on test data for these and similar soils.</p> <p><i>Depth</i> to the upper and lower boundaries of each layer is indicated.</p> <p>Particle size is the effective diameter of a soil particle as measured by sedimentation, sieving, or micrometric methods. Particle sizes are expressed as classes with specific effective diameter class limits. The broad classes are sand, silt, and clay, ranging from the larger to the smaller.</p>

Figure B-10. Soil Physical Properties - texture, bulk density, saturated hydraulic conductivity, Available Water Capacity, and other information – are available for each soil within the Area of Interest. A description is available to explain the soil properties. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>)

Description — Physical Soil Properties
<p>Physical Soil Properties</p> <p>This table shows estimates of some physical characteristics and features that affect soil behavior. These estimates are given for the layers of each soil in the survey area. The estimates are based on field observations and on test data for these and similar soils.</p> <p><i>Depth</i> to the upper and lower boundaries of each layer is indicated.</p> <p>Particle size is the effective diameter of a soil particle as measured by sedimentation, sieving, or micrometric methods. Particle sizes are expressed as classes with specific effective diameter class limits. The broad classes are sand, silt, and clay, ranging from the larger to the smaller.</p> <p><i>Sand</i> as a soil separate consists of mineral soil particles that are 0.05 millimeter to 2 millimeters in diameter. In this table, the estimated sand content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.</p> <p><i>Silt</i> as a soil separate consists of mineral soil particles that are 0.002 to 0.05 millimeter in diameter. In this table, the estimated silt content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.</p> <p><i>Clay</i> as a soil separate consists of mineral soil particles that are less than 0.002 millimeter in diameter. In this table, the estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.</p> <p>The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification.</p> <p>The amount and kind of clay affect the fertility and physical condition of the soil and the ability of the soil to adsorb cations and to retain moisture. They influence shrink-swell potential, saturated hydraulic conductivity (<i>K_{sat}</i>), plasticity, the ease of soil dispersion, and other soil properties. The amount and kind of clay in a soil also affect tillage and earthmoving operations.</p> <p><i>Moist bulk density</i> is the weight of soil (oven-dry) per unit volume. Volume is measured when the soil is at field moisture capacity, that is, the moisture content at 1/3- or 1/10-bar (33kPa or 10kPa) moisture tension. Weight is determined after the soil is dried at 105 degrees C. In the table, the estimated moist bulk density of each soil horizon is expressed in grams per cubic centimeter of soil material that is less than 2 millimeters in diameter. Bulk density data are used to compute linear extensibility, shrink-swell potential, available water capacity, total pore space, and other soil properties. The moist bulk density of a soil indicates the pore space available for water and roots. Depending on soil texture, a bulk density of more than 1.4 can restrict water storage and root penetration. Moist bulk density is influenced by texture, kind of clay, content of organic matter, and soil structure.</p> <p><i>Saturated hydraulic conductivity (K_{sat})</i> refers to the ease with which pores in a saturated soil transmit water. The estimates in the table are expressed in terms of micrometers per second. They are based on soil characteristics observed in the field, particularly structure, porosity, and texture. Saturated hydraulic conductivity (<i>K_{sat}</i>) is considered in the design of soil drainage systems and septic tank absorption fields.</p> <p><i>Available water capacity</i> refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in inches of water per inch of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems. Available water capacity is not an estimate of the quantity of water actually available to plants at any given time.</p> <p><i>Linear extensibility</i> refers to the change in length of an unconfined clod as moisture content is decreased from a moist to a dry state. It is an expression of the volume change between the water content of the clod at 1/3- or 1/10-bar tension (33kPa or 10kPa tension) and oven dryness. The volume change is reported in the table as percent change for the whole soil. The amount and type of clay minerals in the soil influence volume change.</p> <p>Linear extensibility is used to determine the shrink-swell potential of soils. The shrink-swell potential is low if the soil has a linear extensibility of less than 3 percent; moderate if 3 to 6 percent; high if 6 to 9 percent; and very high if more than 9 percent. If the linear extensibility is more than 3, shrinking and swelling can cause damage to buildings, roads, and other structures and to plant roots. Special design commonly is needed.</p>

Figure B-11. Descriptions of the Physical Soil Properties explain the properties and indicate applications of the information. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

Available Soil Water storage capacity can also be accessed in composite format (0-25 cm, 0-50 cm, 0-100 cm, 0-150 cm) or by a user-specified soil depth range (Figures B-12 and B-13) using the pull-down menu on the left under the **Soil Properties and Qualities** tab. Figures B-14 and B-15 illustrate the process for accessing the data for user-specified depths.

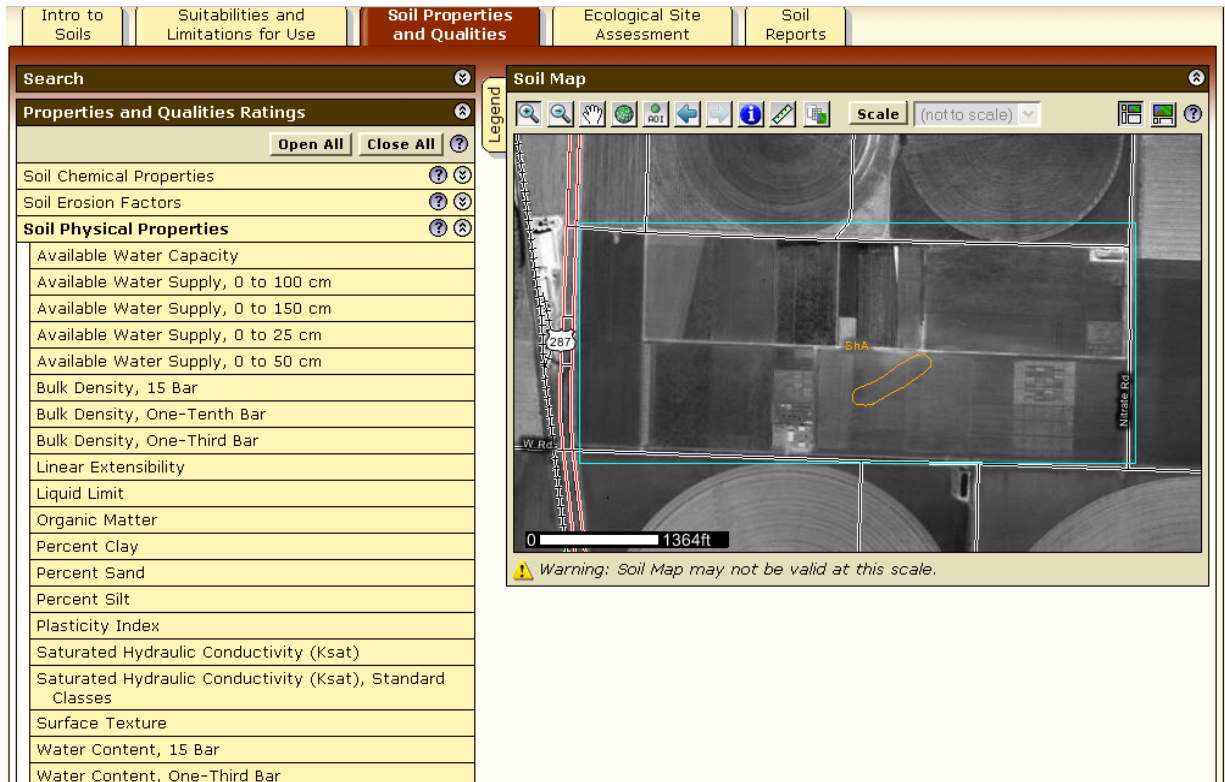


Figure B-12. Available Water Capacity (Plant Available Water) ratings can be accessed as composites by depth (0-50 cm or 0-10 cm for instance). (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>)

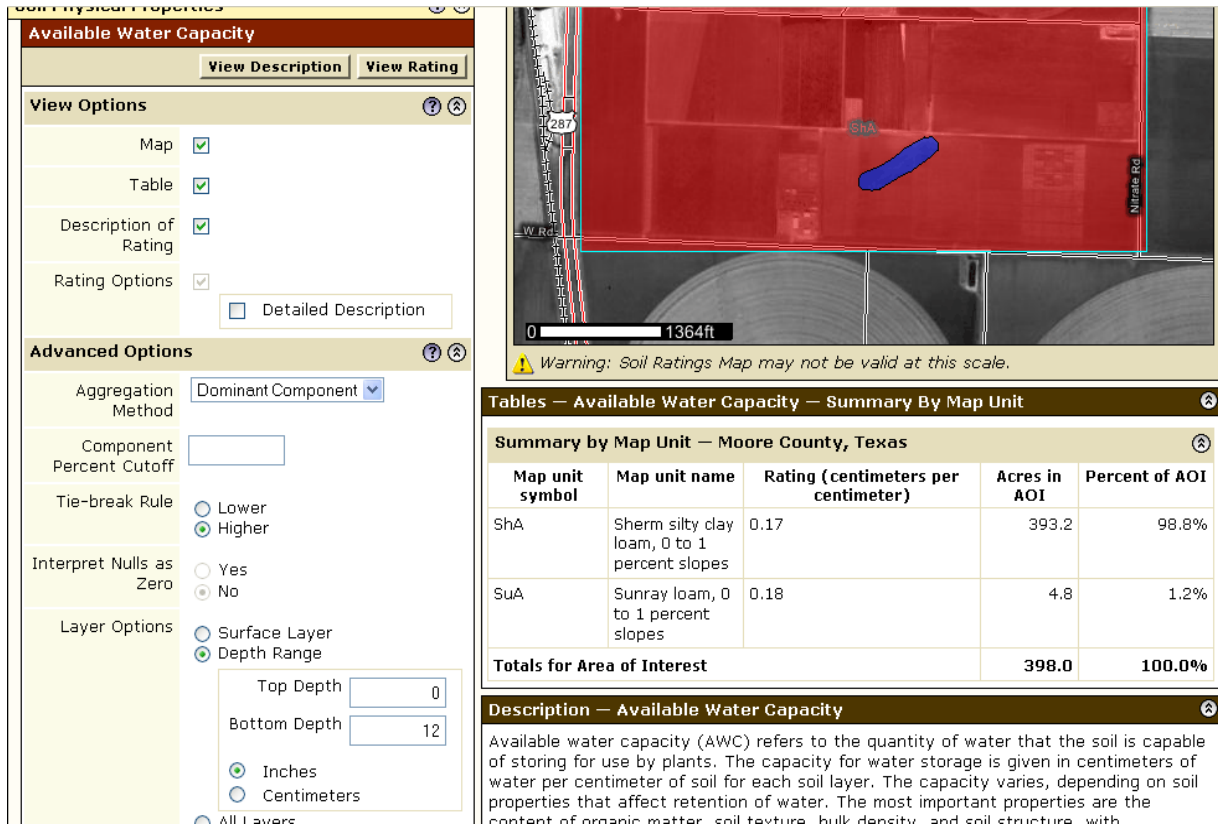


Figure B-13. The pull-down menu on the left allows the user to specify depth of interest, summary formats, etc. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>)

Advanced Options

Aggregation Method: Dominant Component

Component Percent Cutoff: []

Tie-break Rule: Lower, Higher

Interpret Nulls as Zero: Yes, No

Layer Options: Surface Layer, Depth Range

Top Depth: [0]

Bottom Depth: [12]

Inches, Centimeters, All Layers

Tables — Available Water Capacity — Summary By Map Unit

Summary by Map Unit — Moore County, Texas

Map unit symbol	Map unit name	Rating (centimeters per centimeter)	Acres in AOI	Percent of AOI
ShA	Sherm silty clay loam, 0 to 1 percent slopes	0.16	393.2	98.8%
SuA	Sunray loam, 0 to 1 percent slopes	0.15	4.8	1.2%
Totals for Area of Interest			398.0	100.0%

Description — Available Water Capacity

Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in centimeters of water per centimeter of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems. It is not an estimate of the quantity of water actually available to plants at any given time.

Available water supply (AWS) is computed as AWC times the thickness of the soil. For example, if AWC is 0.15 cm/cm, the available water supply for 25 centimeters of soil would be 0.15 x 25, or 3.75 centimeters of water.

For each soil layer, AWC is recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

View Description **View Rating**

- Available Water Supply, 0 to 100 cm
- Available Water Supply, 0 to 150 cm
- Available Water Supply, 0 to 25 cm
- Available Water Supply, 0 to 50 cm
- Bulk Density, 15 Bar
- Bulk Density, One-Tenth Bar
- Bulk Density, One-Third Bar
- Linear Extensibility

Figure B-14. Under Available Water Capacity, the user may specify depths. In this example the Available Water Capacity Rating is queried for the top foot of soil (0-12 inches). AWC is rated in centimeters water per centimeter soil depth (= inches water per inch of soil depth) (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

Rating Options Detailed Description

Advanced Options

Aggregation Method: Dominant Component

Component Percent Cutoff:

Tie-break Rule: Lower Higher

Interpret Nulls as Zero: Yes No

Layer Options: Surface Layer Depth Range

Top Depth:
Bottom Depth:

Inches Centimeters

All Layers

Available Water Supply, 0 to 100 cm

Available Water Supply, 0 to 150 cm

Available Water Supply, 0 to 25 cm

Available Water Supply, 0 to 50 cm

Bulk Density, 15 Bar

Bulk Density, One-Tenth Bar

Bulk Density, One-Third Bar

Linear Extensibility

Tables — Available Water Capacity — Summary By Map Unit

Summary by Map Unit — Moore County, Texas

Map unit symbol	Map unit name	Rating (centimeters per centimeter)	Acres in AOI	Percent of AOI
ShA	Sherm silty clay loam, 0 to 1 percent slopes	0.16	393.2	98.8%
SuA	Sunray loam, 0 to 1 percent slopes	0.17	4.8	1.2%
Totals for Area of Interest			398.0	100.0%

Description — Available Water Capacity

Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in centimeters of water per centimeter of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems. It is not an estimate of the quantity of water actually available to plants at any given time.

Available water supply (AWS) is computed as AWC times the thickness of the soil. For example, if AWC is 0.15 cm/cm, the available water supply for 25 centimeters of soil would be 0.15 x 25, or 3.75 centimeters of water.

For each soil layer, AWC is recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

Rating Options — Available Water Capacity

Figure B-15. Available Water Capacity Rating is queried for the second foot of soil (12-24 inches). (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>)

Available water capacity (plant available water) is the water held between field capacity (maximum water that can be stored after gravitational drainage) and permanent wilting point (point beyond which roots cannot extract water effectively). The maximum water that is available to a crop is estimated by the available water capacity (plant available water) for the effective root zone depth. For most crops the effective root zone can be as deep as 5 or 6 feet, although the crop will extract most of its water requirement from the top 2-3 feet of soil.

For example, the Sherm silty clay soil described in Figure B-16 will hold 0.16 – 0.20 inches water per inch of soil in the top 6 inches of depth, and 0.13 – 0.18 inches of water per inch of soil for 6-50 inch depth. We can use these values to estimate water holding capacity of this soil (Table 1).

Report — Physical Soil Properties												
Moore County, Texas												
Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensibility	Organic matter	Erosion factors		
										Kw	Kf	T
	<i>In</i>	<i>Pct</i>	<i>Pct</i>	<i>Pct</i>	<i>g/cc</i>	<i>micro m/sec</i>	<i>In/In</i>	<i>Pct</i>	<i>Pct</i>			
ShA—Sherm silty clay loam, 0 to 1 percent slopes												
Sherm	0-6	—	—	27-40	1.25-1.40	0.42-1.40	0.16-0.20	3.0-5.9	1.0-3.0	.37	.37	5
	6-50	—	—	40-55	1.35-1.50	0.42-1.40	0.13-0.18	6.0-8.9	0.1-1.0	.37	.37	
	50-72	—	—	35-55	1.35-1.50	0.42-1.40	0.10-0.17	3.0-5.9	0.1-0.5	.37	.37	
SuA—Sunray loam, 0 to 1 percent slopes												
Sunray	0-12	—	—	15-30	1.35-1.50	4.00-14.00	0.15-0.20	0.0-2.9	1.0-3.0	.32	.32	5
	12-22	—	—	20-35	1.40-1.55	4.00-14.00	0.14-0.19	3.0-5.9	0.5-1.0	.32	.32	
	22-60	—	—	20-35	1.40-1.55	4.00-14.00	0.10-0.18	3.0-5.9	0.1-0.5	.32	.32	

Description — Physical Soil Properties

Figure B-16. Soil properties are listed for each layer of each soil. (Source: United States Department of Agriculture Natural Resources Conservation Service <http://websoilsurvey.nrcs.usda.gov/>).

Table 1. Using Available Water Capacity and effective root zone depth to estimate plant available water storage capacity of Sherm silty clay soil.

Depth (inches from surface)	Available Water Capacity (in/in)	Soil water storage capacity in layer (in. water)	Approx. Soil water storage in 1 ft soil	Approx. Soil water storage in 2 ft soil	Approx. Soil water storage in 3 ft soil	Approx. Soil water storage in 4 ft soil
0 -6	0.16 – 0.20 (ave. 0.18)	0.96 – 1.2 (ave. 1.1)	(1.1 + 6 X 0.155)*	(1.1 + 18 X 0.155)	(1.1 + 30 X 0.155)	(1.1 + 42 X 0.155)
6 – 50	0.13 – 0.18 (ave. 0.155)	5.72 – 7.92 (ave. 6.8)	2.0	3.9	5.8	7.6

* There is an estimated 1.1 inches of available water storage in the top 6 inches of this soil. In the second six inches there are approx. 6 inches soil X 0.155 inch water/inch soil = 0.93 inches water. Hence the total estimated water storage capacity in the top foot of soil is 1.1 + 0.93 = 2.0 inches water.

As soil moisture is removed from the root zone through gravity, evaporation and transpiration, increasing energy is required for the plant to extract additional water. Also, as water is removed from the shallower portion of the root zone, more energy is required for roots to remove deeper soil moisture (assuming there are active feeder roots in the deeper soil). As the soil is dried from field capacity toward the permanent wilting point, the potential for drought stress in the crop is increased. To avoid drought stress, irrigation managers often select a Management Allowable Depletion (MAD) to “trigger” an irrigation application. For many crops this MAD is approximately 50% of Available Water Content (Plant Available Water). For the soil in the example above, a crop with a 4-ft deep effective root zone has a plant available water holding capacity of approximately 7.6 inches (with a range of 6.4 to 8.8 inches). If a 50% MAD is used to trigger an irrigation application, irrigation would be applied when no more than 3.8 inches (7.6 inches X 50% = 3.8 inches) of water were removed through evapotranspiration.

As the above are approximations to the estimation of PAW and MAD, verification should be made by field assessments to assure that the conditions estimated are appropriate for a producers’ actual field characteristics. One simple method to use is the NRCS moisture level “feel method”. A visual guide of estimating with the feel method is available on line at

http://www.nm.nrcs.usda.gov/technical/handbooks/iwm/NM_IWM_Field_Manual/Section05-IrrigationWaterManagement/IWM10b.doc and is shown in Figure B-17 below.

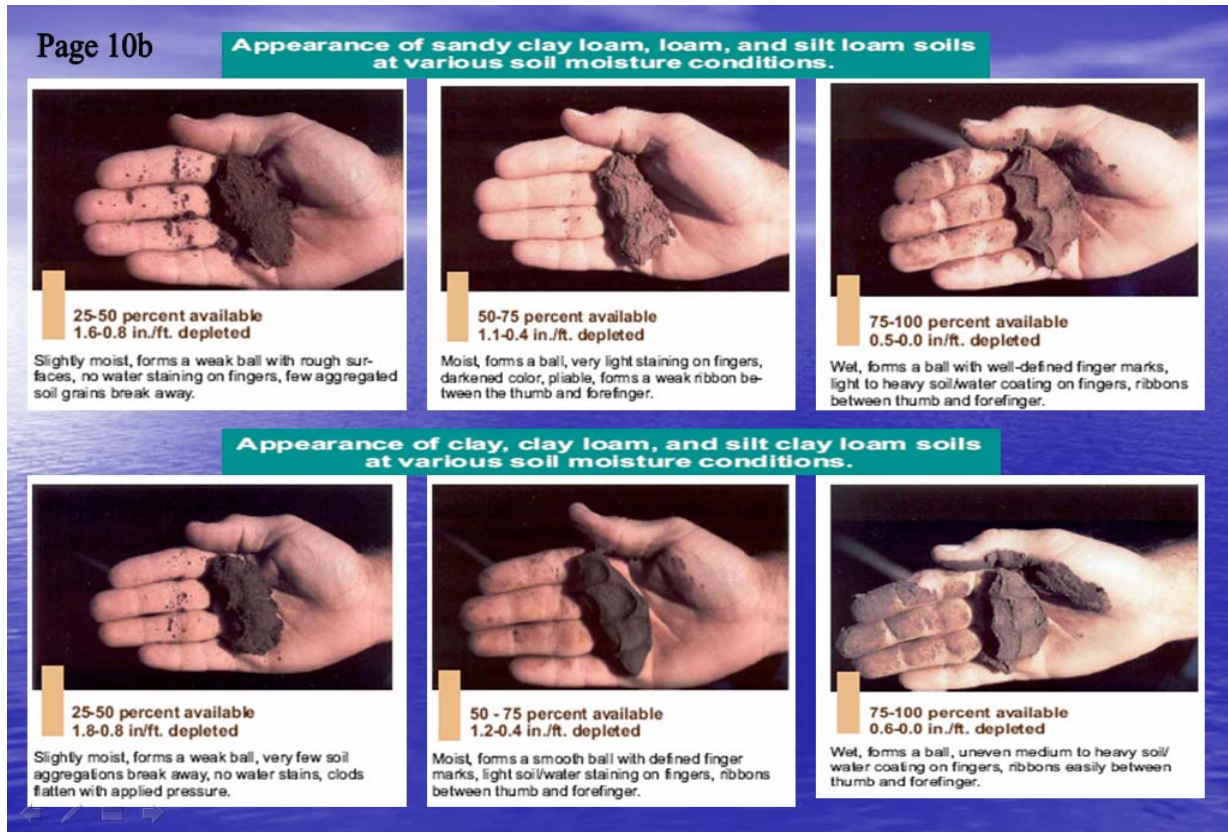


Figure B-17. Appearance guide of differing soil moisture contents using the feel method. (Source: USDA-NRCS, April 1988, Estimating Soil Moisture by Feel and Appearance, <ftp://ftp-fc.sc.gov.usda.gov/MT/www/technical/soilmoist.pdf>).

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AGRILIFE RESPONSES TO REVIEWER COMMENTS

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Reviewer Comments for Draft Final Report for Contract No. 0603580596 Texas Water Development Board

TWDB Comment	AgriLife Response
1. <i>Cover page</i> Need to acknowledge the contributing partners in the proper light.	Corrected – added “Funded by” prior to Texas Water Development Board and added TWDB and TWRI logos Completed
2. Include <u>definitions</u> of some important terms and also a list of <u>acronyms</u> .	Definitions to important terms were added. Completed
3. Add a map showing the Edwards aquifer with the overlying study areas.	Edwards aquifer map added from Edwards Aquifer Authority. Completed
4. “...irrigation practices may provide water savings and <u>associated benefits</u> .” Elaborate on benefits as it pertains to profitability.	While researchers recognize that growers focus on profits from crops, an economic study of profitability was not conducted in this project.
5. There is a typo in the second paragraph, last sentence, “Though this project the accuracy...” should read “Through this project...”	Corrected – added “r” Completed
6. “Improved irrigation strategies were realized and newly developed crop coefficients helped increase water savings for growers in the region.”	Information revised Completed
Specify which crop coefficients were developed in PIN II; there is only a table including coefficients on onions. Were there coefficients developed in PIN II for artichokes or any other crops?	Crop coefficients specified and tables added for PIN II crop coefficients. Completed
Need discussions on how new crop coefficients were developed as a part of PIN II.	Statement added elaborating on crop coefficient development. Completed
7. Outreach, presentations, workshops, publications, and brochure: Provide more details and more importantly their impacts.	More details provided. Completed
8. “...crops that were also evaluated in these studies include <u>watermelon</u> , onions, <u>cabbage</u> , and <u>peppers</u> .” There is no data presented on these crops; only artichoke and onion	Data on watermelon, cabbage and peppers were added in Chapter 2. Completed
9. Table 1-2. December 2007 yield data missing for half of the farmers’ fields.	Missing data was inputted. Completed
10. <u>kPa</u> is not included in the abbreviations/acronym list.	kPa added to acronym list Completed

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11. <i>Table 1-3</i> Inconsistent format	Incorrect table – deleted. Completed
12. “...wheat field (yield data not yet available)...” 2007 yield data should be included in final report.	Text and wheat graph removed. It was not supposed to be included. Completed
13. <i>Figure 1-5 A-C</i>	(Revised to Figure 1-5 A-B)
Different unit of measurement used here, <u>centibars</u> .	Added statement explaining why centibars is used. Completed
Centibars should be included in the definitions list, if this is used instead of –kPa.	Centibars has been added to the acronym/definition list. Completed
Font size for charts should be increased so the label is legible	Graphs made larger. Completed
14. Use one measurement system instead of conversions made “when possible.”	All units of measurement have been converted from metric to English units. Completed
15. Include <u>FAO</u> in the acronym list.	FAO added to list Completed
16. There are two page 25’s.	Page numbers corrected. Completed
17. Charts here (pages 25-28 in draft) measure temperature and rainfall in Celsius and Millimeters, whereas later it is in Fahrenheit and Inches.	All metric measurements were converted to English units. These graphs now read degrees Fahrenheit and inches. Completed
18. ANOVA and SPSS need to be added to the acronym & terms.	Added to list Completed
19. Insert space between “table” & “1-7”	Space added; number changed (Chapter 2) Completed
20. Add SSC to the acronym list. Elaborate on the statistical analysis tools utilized.	SSC added to list. Statistical analysis elaborated on. Completed
21. “...growers would have...additional 4 inches to 5 inches of unnecessary water.” Perception or reality?	Revised statements to explain; reality. Completed
22. <i>Table 1-10</i>	Revised. Completed
Does not fit within the page margins	Fit to margins. Completed
Inconsistent format with previous & following Tables	This table was not meant to be consistent as it shows different data than other tables.
What does “on-target” water savings mean?	Added “on-target” explanation. Completed
English units here, while the rest of the section is in Metric units	Metric units were all converted to English units. Completed
What year is this data from?	Year added. Completed
23. <i>Table 1-11</i> Does not fit within the page margins	Resized to fit within the margins. Completed
24. Figure 1-9: Resize or stack graphs (one above the other) to fit within margins.	Revised graph and fits within the margins. Completed
25. Add SE to the abbreviations list.	Added to the list.

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	Completed
26. Figure 1-10: Resize or stack graphs (one above the other) to fit within margins; or, split into 2 separate figures for each year.	Stacked to fit within the margins. Completed
27. Define SPAD	Completed
28. Add SSC, SSCy & UAN to the acronym/definitions list, as well as Brix.	Added to the list. Completed
29. Add ABA to the acronym list.	Completed
30. As “Region A” is referred to here, should include a map showing the regional water planning groups & include a brief description for the reader.	Map and description added. Completed
31. “...which is anticipated to be in some degree of physiological development error; however, research data prior to this and the prior PIN I study is not adequately available to adjust the values...” Simplify this statement.	Revised statement; simplified. Completed
32. Fahrenheit used here, whereas in the previous chapter Celsius measure is used.	All units changed to English. Completed
33. Briefly elaborate on SAM. How and why were the coefficients adjusted in the stage adjusted model?	Brief description added. Completed
34. Add ET _{co} to the abbreviations/definitions list.	Added to the list. Completed
35. Add ET _{os} to the abbreviations/definitions list.	Added to the list. Completed
36. Appendix does not include, as mentioned, the user’s manual of the ET networks. Is this available on-line, as well? If so, give Web address.	User’s manual now included as Appendix B. Web site address added. Completed
37. Also, elaborate on the TXHPET user manual series & where reader can obtain more information.	Described in more detail. Completed
38. “...an economic analysis was made for each scenario to determine profitability...” Include the results of this analysis with examples from participating producers’ farms presented in PIN I & PIN II workshops.	A description of the 2006 Summer Crop Growers’ Portfolio Workshop was given, however, this was conducted under PIN I, prior to PIN II beginning. Completed
39. Add NRCS to the acronym list.	Added to list. Completed
40. Figure 3-1 uses tons per hectare, whereas the following tables use bushels per acre. This can be confusing to readers	Revised figures and information. All in English units.

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accustomed to the English system.	Completed
41. Add EPIC, RUSLE, and RUSLE2 to the acronym/definitions lists and include brief discussion of the use of these models.	Acronyms and definitions added to the list. Completed
42. Add Irrig-Aid to definitions list & include brief discussion of its use; also include the web address to this “Web-based tool.”	Definition and brief description added to the list. Completed
43. Add TAIA to the acronym list.	Completed
44. Add WinEPIC with discussion of difference of this model from EPIC.	Brief discussion added to the list. Completed
45. Sentence “...without in-depth knowledge of the site conditions and <u>peculiarities</u> ” Please elaborate on this open-ended/inconclusive statement	Sentence deleted. Completed
46. “Historical weather data was used in the simulations.” Include this, side-by-side, for comparison with actual weather data.	Statement revised. Completed
47. The y-axis scales should match for Figure 3-2 A&B and C&D.	These scales are different due to the differing amounts of irrigation applied each year. Irrigation scenarios were only carried out until a yields leveled off. Completed
48. Please include a table or figure showing 2005 & 2006 rainfall and temperature data for reference to the statement – “...differences can be attributed to differences in rainfall, temperature, and past levels.”	This statement was removed during the editing process. Therefore, this information was not included. Completed
49. “These differences can be attributed to differences in rainfall,” Rainfall is not included in this analysis?	Statement taken out. Completed
50. “...reducing irrigation on the corn would have resulted in...yield decreases, and therefore, would result in a <u>possible reduction of profit.</u> ” Need economic analysis to make this conclusion. What is the break-even yield? At what point do pumping costs surpass the profits from higher yields? There is a point of diminishing returns with regards to profits and production, in other words, maximum yield potential does not necessarily equate to production level at which maximum profit potential is	Statement revised. Completed

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achieved.	
51. "...it is suspected that some of the data is not completely accurate." Need to verify and correct suspect data, time was not an issue.	Revised. Completed
52. Need to verify the irrigation amounts and yields from Lamon's corn crop.	Verified and information revised. Completed
53. <i>Conclusion section of Chapter 3</i> "It provided <u>potential water savings</u> as well as <u>potential profit increases...</u> " Has this project done enough to convince producers to change behaviors?	This was not set out in the scope of work, therefore this information was not officially gathered. However, growers who have used the PIN tools have realized they are saving water.
54. "(these) tools...provide valuable information to producers, which enable them to make more educated decisions in regards to irrigation application timing and irrigation distribution among crops <u>resulting in increased water savings as well as increased overall profits.</u> " Show results and describe impacts.	Results and impacts were described. Completed
55. <i>Conclusion section of Chapter 3</i> "It enabled the producer to determine the <u>most profitable irrigation distribution...</u> The tool also provided a <u>profit analysis report...</u> " Where can the reader find this tool and elaborate on the specifics of this tool. Give an example of the profit analysis report & most profitable irrigation distribution adopted by producers in this project.	Tool web site is listed and specifics were elaborated on. The profit analysis report is dependent on each producer's individual scenarios. There is not any one specific irrigation distribution that was more profitable over another because it varied from grower to grower. Completed
56. "(these) tools...provide valuable information to producers, which enable them to make more educated decisions in regards to irrigation application timing and irrigation distribution among crops <u>resulting in increased water savings as well as increased overall profits.</u> " Show results and describe impacts.	Results and impacts (water savings) are already described in the Accomplishment section of the Executive Summary. Completed
57. <i>PIN brochure</i> Specify references or Web address	References and Web address added. Completed
58. <i>Educational Outreach</i> List in chronological order with month, day and year	Table developed to list events in chronological order. Completed
59. <i>Acknowledgements</i> Include TWDB in this section as the	Revised acknowledgements and added additional contributors and agency.

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funding agency.	Completed
60. <i>Appendix</i> (Producer Data) pages are blank. If Intentionally left blank, explain; otherwise, data should be included here.	These pages were accidentally left blank. This has been corrected. Completed