Title: Comparison of Grain Sorghum and Corn Productivity under Limited Irrigation with Subsurface Drip

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Ph.D.		
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Total	4	

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Publications:

Abstracts:

1. Gatlin, J., and J.G. Warren. 2014. Comparison of grain sorghum and corn productivity under limited irrigation with subsurface drip. *In* ASA-CSSA and SSSA abstracts. Available online at: https://scisoc.confex.com/scisoc/2014am/webprogram/Paper86030.html

Thesis:

1. Gatlin, Jordan. 2015. Corn and Sorghum yield response to limited irrigation supplied by sub-surface drip. MS Thesis. Department of Plant and Soil Sciences, Collage of Agricultural Sciences and Natural Resources, Oklahoma State University, Stillwater, OK, 40p

Extension Presentations:

1. Warren, J., D. Sims, and C. Murley. 2015. Alternative planting strategies for sub-surface drip. Presented at the Fall Crops Tour. Goodwell, OK. 21 Aug.
2. Warren, J. 2015. Economics of Irrigated Corn vs. Grain Sorghum. Presented at the Winter Crops Clinic. Goodwell, OK. 10 Apr.
3. Gatlin, J., and J. Warren. 2014. Subsurface Drip Technology & Research. Fall Crops Tour. Goodwell, OK 13 Aug.
4. Warren, J. 2014. Subsurface Drip Irrigation. Sorghum Tour. Goodwell, OK 25 July.

Grant Proposals Written:

1. Schipanski, M., J. Warren, et al. 2015. Sustaining Agriculture through Adaptive Management Resilient to a Declining Ogallala Aquifer and Changing Climate. Submitted to AFRI Coordinated Agricultural Project Program for $10,000,000. Pending.

Agronomic Report

INTRODUCTION

The Ogallala aquifer is a vital resource for the entire economy of the Oklahoma Panhandle. Agricultural irrigation is the primary use of water in the region overlaying the Ogallala aquifer, representing 86% of water used (OWRB, 2012). This water is used to produce a variety of crops, however much of the irrigation water is used for the production of corn grain. In fact, the 2007 National Agricultural Statistic Survey shows that approximately 84,000 acres of corn were irrigated, producing approximately 18.4 million bushels of corn to be fed at regional animal production facilities (NASS, 2007). Recent production estimates show that corn production in the region has increased to as high as 26.8 million bushels in 2010 (NASS, 2010). Additional value, for the State of Oklahoma and the broader Southern High Plains Region, is added to this corn as a component of feed for cattle and hogs produced in the region.

The loss of pumping capacity resulting from drawdown of the Ogallala aquifer and/or future restrictions on withdrawal for irrigation poses a significant risk to the future of irrigated crop production and the animal production systems in the region which depend on this local source of grain. Numerous studies have been published in the past 20 years showing that the water levels in this aquifer are declining. For example, the USGS found that water levels declined by as much as 100 ft under Texas County, OK between the 1940s and 1990s. The report went on to suggest that if withdrawal continued at the same rate as in 1996, the water level would decrease by an additional 20-25 ft under Texas County, OK by 2020 (Luckey, et al. 2000).

The effects of these aquifer drawdowns are being felt by an increasing number of crop producers in the Panhandle region. Specifically, irrigation well pumping capacities are declining to levels insufficient to irrigate corn for optimum yields. Historically, various strategies have been used to overcome these declines in well pumping capacity. First, the drilling of additional wells can maintain production potential. Another option is to decrease irrigated acreage by using a smaller portion of the center pivot or combine wells to increase the capacity on a specific field. The cost of drilling a new well combined with the uncertainty of its pumping capacity has made this option less attractive to many producers. Combining wells or otherwise decreasing the acreage irrigated per well will allow for effective use of available water for corn production but in time will cause a net decrease in the feed grain production capacity of the region. This will have a negative impact on the regional animal production complex and the overall economy of the Oklahoma panhandle because of reduced availability of local feed grain.

The producers are now left with very serious decisions about water use and management. One proven technology to increase water use efficiency is subsurface drip irrigation. Subsurface drip irrigation delivers water at low pressure through plastic tape buried below ground. This eliminates evaporative water losses during application thereby resulting in 100% application efficiency. This is a significant improvement in the efficiency of water application when compared to common pivot irrigation systems that apply water at 70 to 90% efficiency. Water use efficiency is additionally improved by the fact that in a subsurface drip system, the soil surface is dry, which allows for improved infiltration of precipitation. The dry soil surface also minimizes evaporative water loss, which further improves efficiency. Interception of irrigation water by the crop canopy is nonexistent in a drip irrigation system, resulting in additional improvements in water use efficiency.

Various research projects have demonstrated the utility of subsurface drip irrigation to improve water use efficiency for crops in the U.S. High Plains. Lamm and Trooien (2003) summarized 10 years of research in Kansas and concluded that irrigation water use for corn can be reduced by 35-55% using subsurface drip irrigation compared to commonly used irrigation systems in the region. The pool of knowledge demonstrating the efficiency of drip irrigation negates the need for further comparison of drip to center pivot irrigation. This project does not seek to do so, but rather this project will be utilized to demonstrate drip irrigation and to develop local knowledge in the successful utilization of this irrigation practice.

Irrigated grain producers also have the option of growing alternative crops with lower water requirements than corn. Grain sorghum provides an ideal alternative crop. It is well adapted to the region and can serve as a replacement for corn in the animal production systems in the region. Historically, grain sorghum has not been competitive with corn as a component of animal feed due to the perception of lower feed quality and milling characteristics. However, modern sorghum varieties have equivalent feed quality characteristics to corn and feed mills are becoming more accepting of sorghum as a feed ingredient. This along with the use of grain sorghum as a feedstock for ethanol production has caused sorghum prices (currently $4.44/bushel) to be competitive with corn prices ($4.44/bushel). This makes sorghum an ideal alternative to corn for irrigation in the Panhandle.

Irrigated grain sorghum has not been given the attention that corn has received due to the historic popularity and profitability of corn. Therefore, irrigation requirements for sorghum have yet to be fully evaluated in the Panhandle region of Oklahoma. Previous research clearly shows that sorghum can be produced with dramatically less irrigation water than corn. For example, the NRCS irrigation guide (NRCS, 2010) suggests that at Goodwell, OK, optimum production of corn requires 20 inches of supplemental water, while grain sorghum only requires 15.5 inches. A preliminary report by Rees and Anderson (2010) confirmed the lower water requirements of sorghum by showing that evapotranspiration (ET) by sorghum was 30% less than that of corn in south central Nebraska. A study conducted at Garden City, KS showed that maximum sorghum yields of 120 bushels/acre could be achieved with an average of 4 inches of irrigation water. In comparison, maximum corn yields of 205 bushels required 12 inches of irrigation (Klocke and Curri, 2009). Additionally, average yields in Oklahoma State University sorghum variety trials conducted in the Oklahoma Panhandle between 2009-2012 were 150 bushels/acre with an average annual irrigation rate of 9.4 inches/acre. In contrast, corn yields in variety trials conducted in the Panhandle produced an average of 190 bushels/acre with an average irrigation rate of 22 inches of water/acre. These data demonstrate the lower water requirement for grain sorghum in the growing environment presented in the Panhandle region of Oklahoma. Similar data collected in the Southern High Plains of Texas near Lubbock on producer's fields were combined with economic analysis to show that grain sorghum yields of 115 bushels/acre produced more value/inch of water ($31.4/inch) than corn yields of 214 bushels/acre which provided a value of $27.6/inch of water. In this research, the sorghum received an average of 7.9 inches compared to 17.4 inches of water for the corn. It should be noted that corn was more profitable/acre ($479/acre) than sorghum ($248/acre) (Texas Alliance for Water Conservation, 2011). Of course, as water becomes more scarce, returns per unit of water will become a more important driver of the decision making process.

Despite this limited data, there has not yet been a comprehensive economic analysis of irrigated sorghum that encompasses both profitability and risk at a wide range of irrigation application rates. This study is expected to show that producers who follow long-term profit maximization principles in the choice of crops, irrigation water use, and equipment selection will be able to gain more grain production and greater discounted profits from current water supplies than producers who choose maximization of immediate profits.

Commercially available irrigation scheduling technologies provide opportunity to improve irrigation water use efficiency by providing producers with science based recommendations for daily irrigation requirements. Technologies which estimate water requirements based on estimates of evapotranspiration, combined with short-term weather forecasts, provide the most promise for the region. These tools use meteorological data to estimate evapotranspiration and irrigation rates scheduled to replace the daily loss of water from the soil system. The proposed project will evaluate one such scheduling tool as well as provide valuable water use data for high yielding sorghum that will be useful in improving the accuracy of such technologies for irrigated sorghum.

The **OBJECTIVES** of this project are to compare the yield potential and water use efficiency of sorghum and corn under limited irrigation with subsurface drip. This data will serve to validate estimates used in the economic analysis to evaluate the profitability of irrigated grain sorghum and its risk relative to that of corn production under limited water availability.

The funding of this project will also be used to demonstrate a number of technologies proven to improve water use efficiency of irrigated crop production. Specifically, this project will demonstrate the use of subsurface drip irrigation and a commercially available irrigation scheduling product. This will increase the knowledge levels of producers in the region and improve the adoption of these technologies.

METHODOLOGIES

Irrigation system and plot layout

This research utilized the subsurface drip irrigation system located at the Oklahoma Panhandle Research and Extension center. This system provided 48 individually plumbed experimental units that could be irrigated independently. These plots are 15.24 m long and 4.57 m wide. The drip tapes are located at a depth of 0.35 m below the soil surface and 1.52 m apart such that one tape irrigates two crop rows spaced 0.76 m apart. The plots are six rows wide (4.6 m), which means there are three tapes located in each plot, and 15.3 m long. The emitters on the tape are located every 0.30 m and were set to emit 4.5 L/min each. This resulted in a target application rate of 4mm/ha/hour. Flow meters with analog totalizers were installed during the 2013 growing season on each plot to assess instantaneous flow and to monitor cumulative irrigation applied to each plot during the growing season.

Experimental Design

The experimental design is a randomized complete block with split plot design. Main plots were crop (corn or sorghum), and subplots were irrigation rate. The four sorghum treatments and the four corn treatments simulated application rates achievable with well pumping capacities shown in Table 1 when applied to a 50.6 ha center pivot. The sorghum treatments included all pumping capacities included in the table except for the 3028 L min^{-1} because this rate exceeds water requirements for sorghum. The corn treatments included all pumping capacities listed except for the 379 L min^{-1} rate because this is well below the required water for irrigated corn. In 2013 the target irrigation depth was 38.1 mm per irrigation event which resulted in return intervals and application rates shown in Table 1.

Table 1: 2013 Irrigation Treatments.

Treatment		Well Capacity	Application per Interval	Minimum Irrigation Interval	Application Rate
Corn	Sorghum	L $min^{-1}ha^{-1}$	mm	days	L $min^{-1}ha^{-1}$
C1	--	3028	38.1	4.24	60
C2	S1	2271	38.1	5.66	45
C3	S2	1514	38.1	8.49	30
C4	S3	757	38.1	16.94	15
--	S4	379	38.1	29.02	7.5

Treatments are meant to simulate a center pivot system irrigating a 50.6 ha circle with specific well pumping capacities.

In 2014, the target irrigation depth was 25.4 mm per irrigation event which resulted in return intervals and application rates shown in Table 2.

Table 2: 2014 Irrigation Treatments.

Treatment		Well Capacity	Application per Interval	Minimum Irrigation Interval	Application Rate
Corn	Sorghum	L $min^{-1}ha^{-1}$	mm	days	L $min^{-1}ha^{-1}$
C1	--	3028	25.4	2.9	60
C2	S1	2271	25.4	3.7	45
C3	S2	1514	25.4	5.9	30
C4	S3	757	25.4	11.8	15
--	S4	379	25.4	23.1	7.5

Treatments are meant to simulate a center pivot system irrigating a 50.6 ha circle with specific well pumping capacities.

Crop Management

Prior to planting corn and sorghum in 2013 and 2014, plots were fertilized using a strip-till fertilizer applicator. Corn plots received 225 kg N ha^{-1} as liquid UAN (28-0-0) and sorghum plots received 140 kg N ha^{-1} as liquid UAN (28-0-0). Strip tillage was conducted April 5, 2013 and April 15th, 2014. At planting, 19 L of 10-34-0 liquid fertilizer were applied as starter fertilizer. In 2013, corn was planted on April 15th and sorghum was planted June 17th. Inaccurate row placement of the corn rows relative to the drip tape caused unacceptable distribution of water to the corn rows in the April planting; therefore this crop was terminated and corn was replanted on June 4th. In 2014, corn was planted on April 16th and sorghum was planted June 3rd. In each year, dry conditions in April (Table 3) presented stand establishment challenges. Specifically, the strip tillage appeared to reduce capillary movement of water from the drip tape to the corn crop row. Therefore, in order to initiate emergence the corn rows were hand watered. In 2013, the June planted corn did not require hand watering, nor did the sorghum in either year.

Table 3: In-Season Rainfall, Goodwell, OK (mm)

			Month				Total
Year	April	May	June	July	August	September	
2013	8	4	49	26	103	50	240
2014	12	87	95	74	25	41	334

Corn hybrids utilized in both years were Pioneer 1768AMX, planted at 81,500 seeds ha^{-1} on treatments receiving 60 and 45 LPM ha^{-1}, and Pioneer 1151YXR4, planted at 43,200 seeds ha^{-1} on treatments receiving 30 and 15 LPM ha^{-1}. Sorghum hybrids used were Pioneer 84G62, planted at 154,400 seeds ha^{-1} for treatments receiving 45 and 30 LPM ha^{-1}, and DeKalb 3707, planted at 74,100 seeds per ha^{-1} on treatments receiving 15 and 7.5 LPM ha^{-1}. The practice of planting shorter season hybrids on the treatments with lower well capacities is common in this region. The earlier maturing varieties are better suited to limited irrigation systems because they do not require as much water throughout the season as the longer full season varieties. They also are planted at lower populations than the full-season hybrids to ensure better plant survival with limited water. Using these different planting populations also allows the data to be more realistic when utilized for future economic analyses evaluating economic returns from the range of irrigation treatments imposed in this study. In 2013, corn was harvested on October 16th and sorghum was harvested on October 24th with a small plot combine. In 2014, corn was harvested on October 8th and sorghum was harvested on October 15th. The center two rows from each plot were harvested to determine plot weight, test weight and moisture with a harvest master weighing system. Yields presented were corrected to 15.5% moisture for corn and 14% moisture for grain sorghum and 25 kg test weight.

<u>Soil Sampling</u>

Soil cores (4.4 cm diameter) were collected on June 11, 2013 prior to planting of sorghum. The cores were also collected from the corn plots on this date after the second planting. These cores were taken to a target depth of 2.4 m or resistance with a tractor-mounted hydraulic probe. One core per plot was collected in October 2013 post-harvest to assess residual soil moisture to the target depth of 2.4 m. Due to dry subsurface conditions, this target depth was not attainable in all plots, and so the target depth was adjusted to 1.2 m.

In 2014, soil cores were taken from the corn plots on May 7 and from the sorghum plots on June 4 with a hydraulic probe to determine soil water content. One core per plot was collected October 22, 2014 to assess residual soil moisture post-harvest to a target depth of 1.2 m. One core per plot was collected and cut into 0.3 m sections before being weighed, dried at 100°C for 24 hours, and then weighed again to determine gravimetric water content and bulk density. These values were used to determine volumetric water content of the soil. This was then used to calculate the depth of water per depth of soil ($m\ m^{-1}$).

Irrigation Management

In 2013, approximately 76 mm of pre-season irrigation was applied to the corn plots prior to the first planting. Between the first planting and the collection of soil samples on June 11th an additional 100 mm was applied to the corn plots in an effort to germinate the first planting. During this time 38 mm was applied to the sorghum plots. The in-season irrigation was initiated on June 15th for the corn plots and June 28th for the sorghum plots as advised by the Aquaplanner program.

In 2014, 81 mm of irrigation was applied prior to planting the corn and collection of initial soil samples. However, no pre-plant irrigation was applied to the sorghum plots because 85 mm of rainfall was received during the 2 weeks prior to sorghum planting. In season irrigation initiated on May 9th for the corn crop and on June 24th for the sorghum crop.

After initiation, irrigation was applied to treatments at the frequencies presented in Tables 1 and 2. When rainfall was experienced irrigation was postponed if the Aquaplanner program calculated that the soil profile was at or near field capacity.

An irrigation log was maintained which consisted of irrigation duration and volume of water applied to each plot. Water volumes were measured with flow meters attached to the valves on each of the 32 plots to confirm actual flow applied to each plot. This flow meter data was collected throughout the growing season. This flow meter data allowed for the discovery of leaks and incorrect flow rates within the system, and so application times were adjusted accordingly. It was found that in 2013, flow rates were estimated incorrectly, and so the target application of 38.1 mm per event was not realized; instead, the application per event was closer to 22.9 mm. This discrepancy was caused by a difference in the instantaneous flow and the time weighted average flow which was caused by reduced flow during filter flush events. The flows were corrected in 2014 by reducing the frequency of filter flush events and by using the average flow instead of instantaneous flow rate to schedule irrigation event duration such that actual applications were much closer to the target application of 25.4 mm per application event in 2014.

Water Balance

The fallowing water balance equation (Eq. 1) adapted from Kanemasu, et al (1983) was used in this study

Eq 1 $$SM_c = SM_{ini} + I_{eff} + P_{eff} - D - RO - E - T$$

Where:

SM_c current soil moisture content
SM_{ini} initial soil moisture content
I_{eff} effective irrigation
P_{eff} effective precipitation
D drainage from the root zone
RO runoff
E evaporation
T transpiration

The soil texture and bulk density as measured on soil samples collection in April and June of 2013, were input into the ROSETTA software program to estimate hydraulic parameters of water held at field capacity (FC, -33 kPa) and permanent wilting point (PWP, -1500 kPa). A soil water characteristic curve (SWC) was used to describe the amount of water retained in a soil at a given matric potential (Tuller et al, 2003). The curve can be constructed using a known volumetric water content (θ) of a soil and relating it to the matric potential, as shown in eq. 2 (van Genuchten, 1980).

Eq. 2

$$\frac{\theta - \theta r}{\theta s - \theta r} = \frac{1}{[1-(-\alpha \times MP)^{n}]^{m}}$$

Where:

θ water content
θ_r residual water content
θ_s saturated water content
α
n parameters dependent on the matric potential
m
MP matric potential

The pedotransfer functions utilized in the Rosetta software allow users to input limited physical data such as texture to provide estimates for hydraulic parameters (Schaap et al, 2001). The values given by the Rosetta software using the van Genuchten Eq. 2 allow for SMC curves to be extrapolated, calculating the θ_v at various matric potentials. The water contents at the matric potentials of FC and PWP can be used to calculate how much water can be stored in the profile, and how much of that water is plant available water (PAW).

Initial and Ending Soil Moisture Collection

The volumetric water content calculated from the soil cores collected prior to planting was used to determine SM_{ini} for each treatment. These pre-plant soil moisture values were used as the starting point of the water balance, and the postharvest data was used to validate the water budget ending soil moisture.

Rainfall Data Collection

Precipitation data was collected from the Mesonet (2015) and it was not adjusted, due to the fact that there was no hourly rainfall data available. Also, the crop coefficient (Kcmid) of 1.2 used for the middle of the growing season was selected to account for increased evaporation due to interception. This meant that an efficiency of 100% was assumed to achieve the P_{eff} factor for the water balance.

Irrigation Data Collection

As previously mentioned, irrigation data was collected using flowmeters on each plot. Irrigation data was modified, to assume an efficiency of 95% for SDI (Lamm,) to achieve the I_{eff} value for the water balance.

Calculation of RO and D

Runoff was assumed to be zero, because of the lack of hourly rainfall data needed to determine if its intensity was in excess of infiltration rate. Furthermore, due to the low average seasonal rainfall at this location and the dry nears surface soil conditions presented by the use of subsurface drip irrigation, it was assumed that runoff would be negligible. Drainage was assumed to occur under saturated conditions, when the profile moisture content exceeded FC.

Calculation of ETc

Crop ET (ET_c) was calculated from a reference ET (ET_o) using the single-crop coefficient method outlined in FAO-56 (eq. 3).

Eq.3 $$ET_c = ET_o + K_c$$

Where:

ET_c crop evapotranspiration
ET_o reference evapotranspiration
K_c crop coefficient

This equation adjusts the ET_o based on the crop coefficient (K_c), and the reference ET (ET_o). The K_c can be derived using a single-crop coefficient or a dual-crop coefficient. The single-crop method is recommended for irrigation planning, design, and management utilizing basic irrigation schedules, through computing a daily water balance using the ET_c .In the single-crop coefficient, the calculations are much simpler, because they combine crop transpiration and soil evaporation into one Kc coefficient. This gives only time-averaged effects of ETc (FAO-56).

The ET_o comes from the Penman-Monteith (ASCE-PM) equation from ASCE Manual 70 (Jensen et al, 1990) for calculating a standardized reference ET, or ET_{sz} (eq.4). According to the Task Committee on Standardization of Reference Evapotranspiration, the equation for ET_{sz} uses meteorological data and characteristics of a defined vegetative surface to create a standard reference for calculating ET_c (2005). This defined vegetative surface is defined as "a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 m of the same vegetation" (ASCE, 2005). The short crop used for reference (ET_{os}) is clipped cool-season grass, and the tall crop reference (ET_{rs}) used is alfalfa. For the this study the following equation was used in combination with data from the Mesonet to calculate the ET_{rs},

Eq. 4 $$ET_{sz} = \frac{0.408\ \Delta(R_n\text{-}G) + \Upsilon(C_n/T+273)u_2(e_s\text{-}e_a)}{\Delta + \Upsilon(1 + C_d u_2)}$$

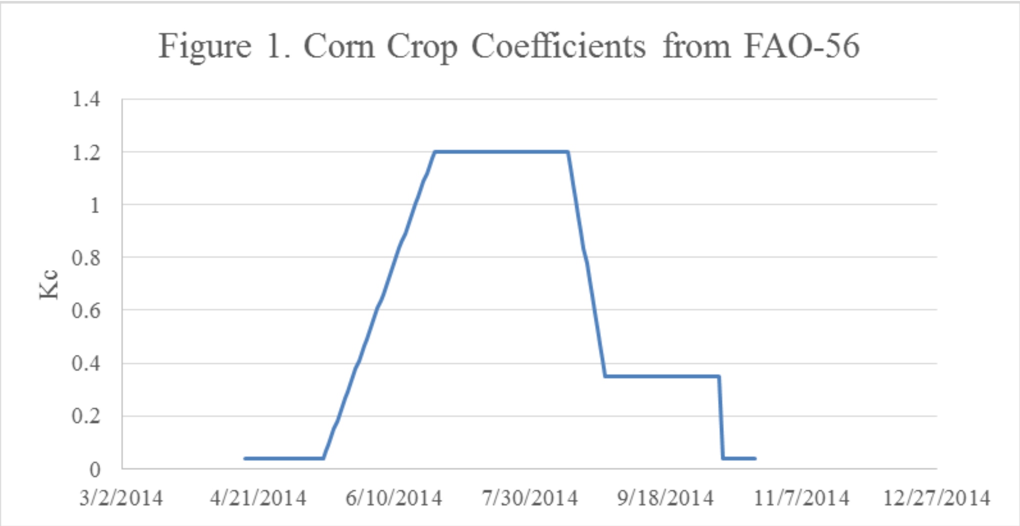
Where:

ET_{sz} standardized reference crop evapotranspiration for short (Et_{os}) or tall (Et_{rs}) surfaces (mm d^{-1} for daily time steps or mm h^{-1} for hourly time steps)
R_n calculated net radiation at the crop surface ($MJm^{-2}d^{-1}$ for daily time steps or $MJm^{-1}h^{-1}$ for hourly time steps)

G soil heat flux density at the soil surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps)
T mean daily or hourly air temperature at 1.5 to 2.5-m height (°C)
u_2 mean daily or hourly wind speed at 2-m height (m s^{-1})
e_s saturation vapor pressure at 1.5 to 2.5-m height (kPa), calculated for daily time steps as the average of saturation vapor pressure at maximum and minimum air temperature
e_a mean actual vapor pressure at 1.5 to 2.5-m height (kPa)
Δ slope of the saturation vapor pressure-temperature curve (kPa °C^{-1})
ϒ psychrometric constant (kPa °C^{-1})
C_n numerator constant that changes with reference type and calculation time step (K mm s3 Mg^{-1} d^{-1} or K mm s^3 Mg^{-1} h^{-1})
C_d denominator constant that changes with reference type and calculation time step (s m^{-1})

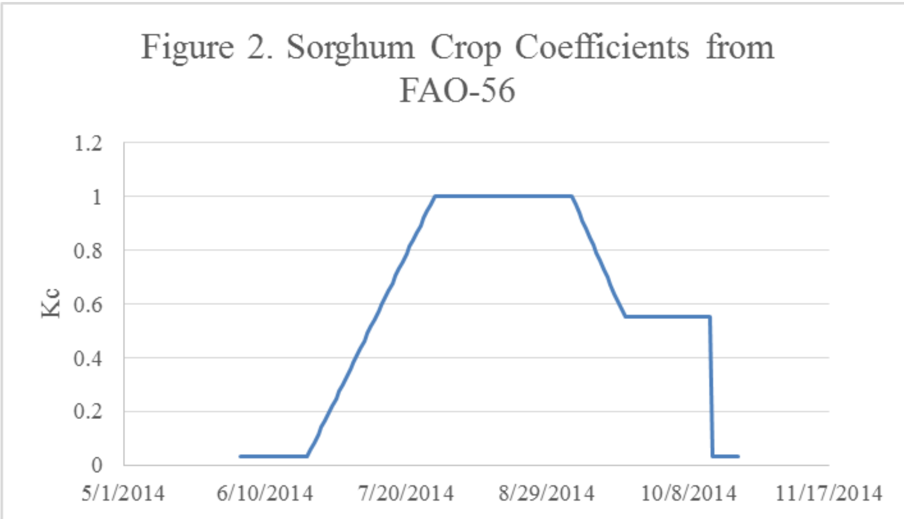
Corn Crop Coefficients

For this study, the crop coefficient was found using the single-crop coefficient method from FAO-56. The K_{cini} was adjusted for wetting, using the average rainfall events during the 30-day period after the 2014 planting date from 2011-2014. This meant that during the initial period, the K_c was very low, only 0.0325. The K_{cmid} used was 1.2. A linear increase was used to determine the K_c during the K_{cdev} stage. For corn, a 15-day period was used for the decline from the K_{cmid} of 1.2 to the K_{cend} of 0.35. After harvest in October, the K_c drops back to 0.0325.



Sorghum Crop Coefficients

For sorghum, the Kcini was determined using the rainfall data from 2011-2014 using the average rainfall for the 30-day period following a June 4 planting. The Kcmid was selected from Table 12 and was 1. The Kcend was 0.55, and the curve decreased linearly over a fifteen-day period just as with the corn. The Kcend remained 0.55 until harvest, and then it was assumed to return to 0.0375.



RESULTS:

<u>Yield and Irrigation Data</u>

In 2013, corn yields were maximized at 11173 kg ha^{-1}, reached in the highest irrigation treatment (60 LPM ha^{-1}). There were 32.8 cm of water applied to this treatment. There were no significant differences in corn yield between the 60, 45, and 30 LPM ha^{-1} treatments. Sorghum yields were maximized in the highest irrigation treatment (45 LPM ha^{-1}), with 9478 kg ha^{-1} produced with 25.9 cm irrigation water applied. Furthermore there were no differences in sorghum yields among the irrigation capacity treatments 45, 30, and 15 LPM ha^{-1}. Comparison of corn and sorghum yields found that at the 45, 30, and 15 LPM ha^{-1} irrigation capacities the corn and sorghum yields were not significantly different. In fact, sorghum yields produced with the 15 LPM ha^{-1} treatment were not significantly different from the corn yields produced with 30 LPM ha^{-1}.

As is generally observed, water use efficiency increased with decreasing irrigation water applied in 2013. The with in a irrigation treatment water use efficiency was significantly higher for sorghum compared to corn only in the 15 LPM ha^{-1} treatment.

In 2014, Grain yields were again maximized when corn was irrigated at the 60 LPM ha-1 irrigation capacity. However these yields were not significantly greater than those achieved with 45 LPM ha-1. At the 45 LPM ha-1 irrigation capacity sorghum yields were significantly lower than corn yields. At irrigation capacities below this level there were no differences between corn and sorghum. However, it must be noted that corn yields were numerically higher than sorghum yields at each irrigation capacity treatment.

Because of lower irrigation water application to sorghum under each irrigation capacity treatment, the water use efficiency was higher for sorghum than for corn. In fact, it was significantly higher at the 30, and 15 LPM ha-1 treatments. this is similar to previous research suggesting that irrigation water use efficiency for sorghum is higher than for corn.

Table 4. In season Irrigation applied, resulting yield and irrigation water use efficiency (WUE_{irr}) in 2013

Irrigation Capacity	Irrigation		Yield		Irrigation WUE	
	Corn	**Sorghum**	**Corn**	**Sorghum**	**Corn**	**Sorghum**
LPM† ha^{-1}	-----------cm----------		----------Kg ha^{-1}---------		--------Kg ha^{-1} cm^{-1}-------	
60	32.8		11173a‡		341e	
45	29.0	25.9	10482ab	9478bc	362e	366e
30	21.8	19.6	9980abc	8787cd	457cd	449cd
15	15.5	14.7	7532d	8599cd	486c	584b
7.5		9.9		7218d		729a

†LPM, liters per minute

‡ Means followed by the same letter are not statistically different. Corn and sorghum data were analyzed together to allow comparison between species.

Table 5. In season Irrigation applied, resulting yield and irrigation water use efficiency (WUE_{irr}) in 2014

Irrigation Capacity	Irrigation		Yield		Irrigation WUE	
	Corn	**Sorghum**	**Corn**	**Sorghum**	**Corn**	**Sorghum**
LPM† ha^{-1}	-----------cm----------		----------Kg ha^{-1}---------		--------Kg ha^{-1} cm^{-1}------	
60	55.1		12123a		194d	
45	45.0	33.8	11496ab	9365c	224d	273cd
30	37.3	30.0	10046bc	8789cd	218d	352b
15	22.1	18.5	6985de	5806e	213d	331bc
7.5		13.5		6446e		629a

†LPM, liters per minute

‡ Means followed by the same letter are not statistically different. Corn and sorghum data were analyzed together to allow comparison between species.

Water Use Efficiency

Tables 4 and 5 present the irrigation water use efficiency (WUE_{irr}), which does not take into account any other source of water besides irrigation. The WUE_{irr} is simply yield divided by in-season irrigation water applied, without taking into account precipitation or soil water used by the crop during the season. This number served to provide a comparison between not only treatments within each crop, but also between the two crops. When other variables are taken into account using the water balance, which accounts for all water that moves into and out of the system, the total water use efficiency (WUE_{total}) can be estimated.

Table 6 shows the pre-plant and post-harvest soil profile moisture content to a depth of 120 cm. Data shows that soil water use ranged from as high as 17 cm for treatment C2 in 2013 to as little as 2 cm for the same treatment in 2014. The elevated soil water use for the corn treatments in 2013 was result of the inadvertent under irrigation of the corn treatments in 2014 due to a error in estimating flow rates. This also explains the similarities in irrigation water use efficiency between corn and sorghum presented in table 4.

Table 6. Total cm of water in the top 120 cm of the profile averaged across reps for each treatment.

Treatment	2013 Soil Moisture		In-Season Soil Water Use	2014 Soil Moisture		In-Season Soil Water Use
	Pre-plant	Post harvest		Pre-plant	Post-harvest	
	---cm--					
C1	46	31	15	39	36	3
C2	46	29	17	37	35	2
C3	44	29	16	40	33	8
C4	44	30	15	39	32	7
S1	42	33	12	38	34	4
S2	40	36	4	34	30	4
S3	42	35	7	35	29	6
S4	42	38	4	35	25	10

†Means followed by the same letter are not statistically different.

Table 7 shows the total water use and water use efficiency for each crop in 2013 and 2014. This presentation of data demonstrates that the water use efficiency of sorghum is higher than that found for corn at each irrigation treatment. This is in agreement with prior research presented above. This suggests that sorghum with produce more grain per cm of water at all irrigation capacities evaluated in this study.

Table 7: The total water used (irrigation, rainfall, and soil water) during the 2013 and 2014 crop years and the resulting water use efficiency for corn and sorghum.

Irrigation Capacity	------Total Water Used-------				---------Water Use Efficiency------			
	------2013------		------2014------		------2013------		------2014------	
	Corn	Sorghum	Corn	Sorghum	Corn	Sorghum	Corn	Sorghum
LPM† ha^{-1}	----------------------cm---------------------				----------------Kg ha^{-1} cm^{-1} --------------			
60	76		95		146		128	
45	75	66	84	65	141	143	137	145
30	66	52	82	61	151	169	123	144
15	59	50	66	52	128	171	106	113
7.5		42		51		170		128

Water Balance

The water balance was initiated at the time of initial soil sample collection. The effective irrigation (I_{eff}), the effective precipitation (P_{eff}) were added to this value on a daily time step. The Crop ET (Etc) was subtracted from this value on a daily time step. When the soil water content to a depth of 120 cm was found to be able field capacity the difference between the current soil water content and field capacity was assumed to be equal to drainage for that day and was subtracted from the soil water. The resulting cumulative values for these variables for the 2014 crop year are presented in table 8 for each corn treatment and table 9 for each sorghum. The measured post-harvest soil moisture (Sm_{final}) is also presented for comparison to the estimated to allow for assessment of the accuracy of the the water balance. The measured value was generally 2cm larger than the estimated value in the corn treatments. In contrast, the measure value for the sorghum was 6.5 cm greater than the estimate in the S1 treatment but 0.3 cm less than the estimated value for S4. This suggests that at fully irrigated conditions our estimate of ETc was in excess of the true ET. This suggests that the ETc estimated by the aquaplanner program (Table 10) may have been closer than that used in our water balance. These findings certainly tell us that that the crop coefficicients provided by the FOA are in sufficient to provide accurate estimates of ETc from a fully irrigated sorghum crop. The similarities between the estimated and measured ETc for the S4 treatment were likely achieved despite the apparently flawed crop coefficients because of the stress coefficients prevented the estimated soil water content from approaching the permanent wilting point of the soil profile which was 23.4 cm. Prior the submission of the final report efforts will be made to find alternative crop coefficients for sorghum in an effort to improve these ET estimates. Given the similarities between the estimated and measured final soil moisture in the corn water balance we it appears that the coefficients used in this water balance were generally accurate. This is not surprising given the extent of research conducted on corn with provides improved estimates of these coefficients from the FAO.

Table 8: Individual components of the Water Balance for each Corn treatment in 2014

							Sm_{final}	
Treatment	Sm_{ini}	I_{eff}	P_{eff}	D	RO	Etc	Estimate	Measured
	----------	----------	----------	----------	cm	----------	----------	----------
C1	39	55	37	4.5	0	93	34	36
C2	37	45	37	1.8	0	84	33	35
C3	40	37	37	7.2	0	77	30	33
C4	39	22	37	4.1	0	63	30	32

Table 9: Individual components of the Water Balance for each sorghum treatment in 2014.

Treatment	Sm_{ini}	I_{eff}	P_{eff}	D	RO	Etc	Sm_{final} Estimate	Measured
	---------------------------------------cm---------------------------------------							
S1	38	34	27	6.3	0	65	28	34
S2	34	30	27	2.3	0	61	28	30
S3	35	19	27	3.5	0	51	26	29
S4	35	14	27	3.4	0	47	25	25

Table 10: ETc from the Aquaplanner, mesonet, and FAO

	Cumulative Etc (cm)		
Treatment	Aquaplanner	Mesonet	FAO
Corn	--	105.4	--
C1	89.9	--	92.7
C2	87.9	--	83.8
C3	68.8	--	77.5
C4	62.7		63.3
Sorghum	--	57.90	--
S1	56.3	--	64.8
S2	55.5	--	61.0
S3	47.1	--	51.3
S4	41.4	--	47.0

SUMMARY:

Corn provides the yield potential to allow for the maximization of grain production at irrigation capacities equal to or greater than 45 LPM ha^{-1}. At the remaining irrigation capacities corn and sorghum yields were similar, suggesting that this is the irrigation capacity where it becomes advantageous to grow sorghum instead of corn due to the lower production costs. Furthermore, the water use efficiency was higher for sorghum at irrigation well capacities less than 45 LPM ha^{-1}. This shows that the production of sorghum will result in more grain produced per L of water.

Assessment of the water budgets shows that the 3 different estimates of ETc were within 15% of each other. Specifically, under full irrigation conditions, the mesonet estimate was 15 cm greater than the aquaplanner estimate and the FAO estimate was 3 cm greater than the aquaplanner. In contrast, FAO estimate for sorghum was 8.5 cm greater than the aquaplanner estimate and the mesonet estimate was only 1.6 cm greater. The soil water budget for corn using the FAO ETc estimate showed good agreement between measured and estimated final soil moisture. In each treatment the measured profile moisture was greater than the estimated value, and the greatest difference was in the C3 treatment where the measured value was 3 cm greater than the estimate. The sorghum water budget analysis again showed that the measure values were equal to or greater than estimates with the greatest differences observed in the S1 treatment. This data suggests that our water budget is either over estimating losses such as ET, drainage or underestimate water inputs such as effective rainfall or irrigation. The water balance assumed an irrigation efficiency of 95% and a rainfall efficiency of 100%. Therefore, it is more likely that drainage or ET were over estimated. Future efforts will focus on these estimates. The ET estimates used in this study were based on empirical data collected from surface irrigation and may in fact work well for center pivot irrigation scheduling. However, they are likely over estimating ET from drip irrigation because of reduced canopy and residue interception as well as reduced soil surface wetting when using drip irrigation compared to sprinkler irrigation. Finally, the weather data used to calculate the reference ET was not collected from within the corn field but rather in an adjacent grass field; therefore the atmospheric conditions such as humidity are not accurately representing the irrigated crop. This must be corrected for through adjustments of the reference ET values.

This work has highlighted the improved water use efficiency of irrigated sorghum as compared to corn and that sorghum can be a viable alternative as well capacity declines. Furthermore, the water balance data suggests that current irrigation scheduling tools based on water budgets consistently under estimate soil water availability for subsurface drip irrigation.

Works Cited

Carreira, R.I. (2004) Economic Study of Alternative Best Management Practices for Swine Effluent Application to Corn in a Semiarid Climate, Ph.D. Dissertation, Edmond Low Library, Oklahoma State University.

Carreira, R.I., A.L. Stoecker, F.M. Epplin, J.A. Hattey, and M.A. Kizer, (2006) Subsurface Drip Irrigation Verus Center-Pivot Sprinkler for Applying Swine Effluent to Corn. Journal of Agriculture and Applied Economics. Vol. 38(3), PP 645-648.

Harris, T.R. and H.P. Mapp. 1988. A Stochastic Dominance Comparison of Water-Conserving Irrigation Strategies. Amer. J. Agricultural Economics, 68:298-305.

Klocke, N, and R. S. Curri. 2009. Corn and Grain Sorghum Production with Limited Irrigation. In the Southwest Research-Extension Center, Field Day 2009 Report. pgs 35-38. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS. Available online at: http://www.ksre.k-state.edu/library/crpsl2/SRP1014.pdf. Verified on Oct. 24, 2011.

Lamm, F.R., D.M. O'Brien, D.H. Rogers, and T.J. Dumler. 2012. Comparison of SDI and Center Pivot Sprinkler Economics. Proceedings of the 2012 Irrigation Association Technical

Conference, Orlando, Florida, Nov. 2-6. Available from the Irrigation Association, Falls Church, VA

Lamm, F.R., and T.P. Tooien. 2003. Subsurface drip irrigation for corn production: a review of 10 years of research in Kansas. Irrigation Science. 22: 195-200.

Luckey, R.R., N.L.Osborn, M.F. Beker, and W. J. Andrews. 2000. Water Flow in the High Plains Aquifer in Northwestern Oklahoma. USGS Fact Sheet 081-00.

NASS. 2007. Census of Agriculture: Oklahoma. State and County Data. Volume 1. Geographic Area Series. Part 36. Available online at: http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Oklahoma/ Verified on Oct. 8, 2012.

NASS. 2010. Oklahoma Corn County Estimates. Available online at: http://www.nass.usda.gov/Statistics_by_State/Oklahoma/Publications/County_Estimates/2011/ok_corn_county_estimates_2011.pdf Verified on Oct. 8, 2012.

NRCS. 2010. National Engineering Handbook - Part 652, National Irrigation Guide and Oklahoma Supplements. Available online at: http://www.ok.nrcs.usda.gov/technical/Manuals/ig.html. Verified on Oct. 01, 2012.

OWRB 2012. Oklahoma Comprehensive Water Plan, Panhandle Watershed Planning Region Report. Available online at: https://www.owrb.ok.gov/supply/ocwp/pdf_ocwp/WaterPlanUpdate/regionalreports/OCWP_Panhandle_Region_Report.pdf Verified on Oct. 8, 2012

Prescott, E.C. (1972) The multi-period control problem under uncertainity, Econometrica, vol 72, 1972

Rees, J., and D. Anderson 2009. Comparison of Crop Water Consumptive Use of Sorghum, Corn, and Soybeans. Annual Report, available online at: http://water.unl.edu/c/document_library/get_file?folderId=1242079&name=DLFE-14668.pdf. Verified on Oct. 08, 2012.

Sick, G.A. (1986) A Certainty-Equivalent Approach to Capital Budgeting, *Financial Management* Vol. 15, pp 23-32

Stoecker, A.L., A. Siedman, and G.S. Lloyd. 1985. A Linear Dynamic Programming Approach to Irrigation System Management with Depleting Groundwater. Management Science, 31(4)422-434.

Texas Alliance for Water Conservation. 2011. When Water Determines your Success. Observed Cotton, Grain Sorghum and Grain Corn Fields in the Texas High Plains, 2005-2011. Available online at: http://www.depts.ttu.edu/tawc/documents/Water_determines%20success.pdf Verified on Oct. 08, 2012.

Economic Modeling of Irrigated Corn vs. Grain Sorghum Using Center Pivot or Subsurface Drip Systems

Final Report to OWRRI at Oklahoma State University

August 31, 2015

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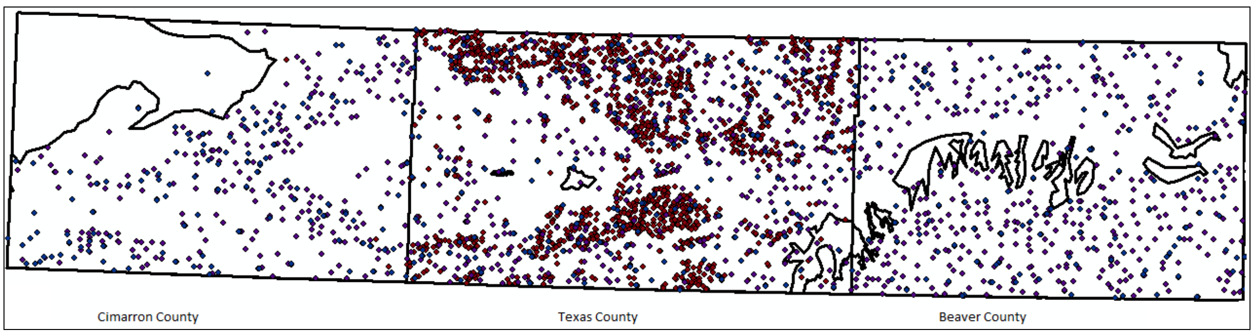
Economic Modeling of Irrigated Corn vs. Grain Sorghum Using Center Pivot or Subsurface Drip Systems

Introduction

The study area concerns the Ogallala Aquifer that underlies parts of Cimarron, Texas, and Beaver counties in the Oklahoma Panhandle. This area is intensively irrigated and there has been state and national concern over the fate of the Ogallala or Great Plains Aquifer (USGS). Figure 1 below shows the three county study area with the underlying Ogallala Aquifer and the location of wells in Cimarron, Texas, and Beaver counties.



Source: Geospatial Data Gateway and USGS website

Figure 1. Cimarron, Texas, and Beaver County Study Area with Wells and an Outline of the Ogallala Aquifer under the Oklahoma Panhandle

Both the USGS and the Oklahoma Department of Water Resources conduct measurements on water tables in wells. The USGS began publishing an annual series of water levels in wells in the High Plains Aquifer (Ogallala) across Colorado, Kansas, Nebraska, Oklahoma, Texas, and Wyoming in 1994. A simple average of the water levels measured in Beaver, Cimarron, and Texas counties is shown in Figure 2 below. The graph shows the trend is downward with considerable variation between years. A simple trend analysis shows the following water table declines in Beaver, Cimarron, and Texas counties were;

Beaver, County: 92.7 + 2.59 Yr, $r^2 = .68$,
Cimarron, County: 180.7 + 0.94 Yr, $r^2 = .28$, and
Texas, County: 178.4 + 1.87 Yr, $r^2 = .65$

The trend analysis shows that while the depth to the static water table was smaller in Beaver County, they have a greater rate of decline (2.59 feet per year) than do the deeper wells in Texas and Cimarron counties. The year to year variability is due in part to weather and in part to the fact that the location of all wells sampled changes from year to year.

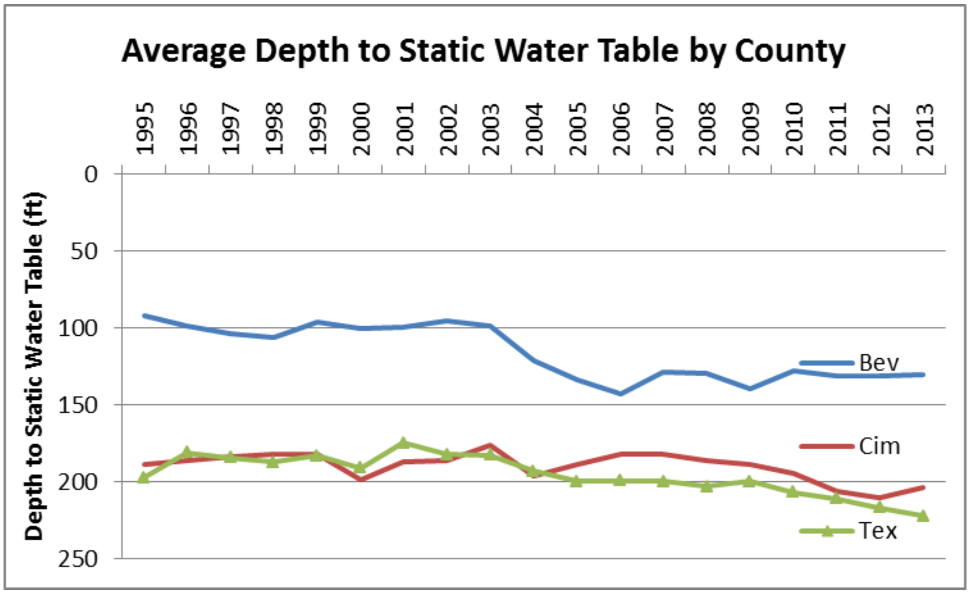


Figure 2. Average Depth to the Static Water Table in Wells in Beaver, Cimarron, Texas Counties from 1994 through 2013 as reported by the USGS.

Tex Co 178.4 + 1.87 Yr, R^2 = .65, Cim. Co. 180.7 + 0.94 Yr, R^2 = .28
Bev. Co. 92.7 + 2.59 Yr, R^2 = .68

A longer trend from 1950 would show greater declines in the level of the Ogallala in the Oklahoma Panhandle. The recharge rate to the aquifer in the Panhandle is dependent upon percolation of limited rainfall and has been estimated to be between 0.25 and 0.5 inches per year (Guru, 2000).

Luckey and others suggested that if withdrawal continued at the same rate as in 1996, the water level would decrease by an additional 20-25 feet under the Oklahoma Panhandle by 2020 (Luckey, et al. 2000). USGS found that water levels declined by as much as 100 feet under the Oklahoma Panhandle between the 1940s and the 1990s.

A primary problem for producers in the Oklahoma Panhandle is depleting ground water and ravaging droughts. The source of the irrigation water in Oklahoma Panhandle is the Ogallala aquifer. In Oklahoma, irrigation accounts for 86% of the withdrawal from the Ogallala aquifer (OWRB, 2012). It is in a state of disequilibrium, as the natural recharge to the aquifer is much less than the annual withdrawals. The continued decline in the water table causes the cost of pumping to increase. By 1989, Lacewell and Lee noted the cost of pumping irrigation water had increased from $5.98 per acre-foot in 1969 to $63.96 per acre-foot in 1988 for sprinkler irrigation (Lacewell and Lee, 1989). In response, many producers in the panhandle adopted advanced irrigation systems such as Pivot Systems and low energy precision application (LEPA) systems.

The panhandle's saturated stratum has relatively low permeability, which is the ultimate reason for the rapid water table decline. The Ogallala aquifer is an unconfined aquifer, under normal conditions in an unconfined aquifer the water percolation from the land surface is expected to freely join the saturated zone. However, due to poor permeability in the Ogallala aquifer and clay-soil characteristics the recharge rate is negligible or none. The recharge rate has been estimated to be between 0.25 to 0.5 inches per year (Guru, 2000).

Study Objectives

The overall objective of the economic portion of this study was to determine comparative advantages of irrigated corn relative to sorghum and the comparative advantages of center pivot irrigations systems relative to subsurface drip irrigation to aid producers to gain the maximum value from their remaining groundwater reserves. More specifically the objectives are to compare,

a. Long-term values and aquifer life with center pivot irrigated corn.
b. Long-term values and aquifer life with subsurface drip irrigated corn.
c. Long-terms values and aquifer life with center pivot irrigated grain sorghum.
d. Long-term values and aquifer life with subsurface drip irrigated grain sorghum.

Study Methods

The remaining ground water reserve could last from a few years to more than 50 years. The weather in the Oklahoma Panhandle is also highly variable. The analysis required estimates of crop yields and water use under a wide range of weather conditions. Actual observed and measured data relating to crop yields and water use are available for only limited periods of time. In addition future weather patterns are uncertain. Data sets reflecting alternative climate change values for the regions like the Oklahoma Panhandle are just becoming available. The approach followed was to use the EPIC (Environmental Policy Impact Calculator) simulation model to generate yields using a 50 year historical weather set for Goodwell, Oklahoma.

Construction of a 50 year daily weather set for Goodwell, Oklahoma

EPIC can utilize daily weather variables such as minimum temperature, maximum temperature, precipitation, relative humidity, solar radiation, and wind speed. EPIC will operate on daily precipitation, minimum daily temperature and maximum daily temperature. In this case, the remaining values are simulated. It was assumed a better data set could be obtained by using as much actual available weather data as possible from the area.

Two daily weather data sets were constructed for Goodwell, Oklahoma. A twenty-one year data set was constructed for the period from 1/1/1994 – 11/30/2014. This data set was based on the Oklahoma MESONET data for Goodwell, Oklahoma which can provide all of the variables listed above. Unfortunately the MESONET temperature values were not reported until February of 1997. In addition, there were many missing values for the remaining variables. Missing values were estimated by multiple regressions from the surrounding weather stations and MESONET stations with MESONET data from Hooker (in Texas County) and Boise City (in Cimarron County).

Construction of the 50 year daily weather file was more problematic. During the 50 year period from 1/1/1965 to 11/30/2014 there were many changes in weather stations and in the data collected. Variables like relative humidity, wind speed, were only reported by larger federal weather stations like Dodge City and Garden City Kansas, Amarillo, Texas, and from the airport at Liberal, Kansas. Solar Radiation data were not available outside the 1994-2014 period from the MESONET sites. Completion of the data set for the individual weather variables was done on a case by case basis.

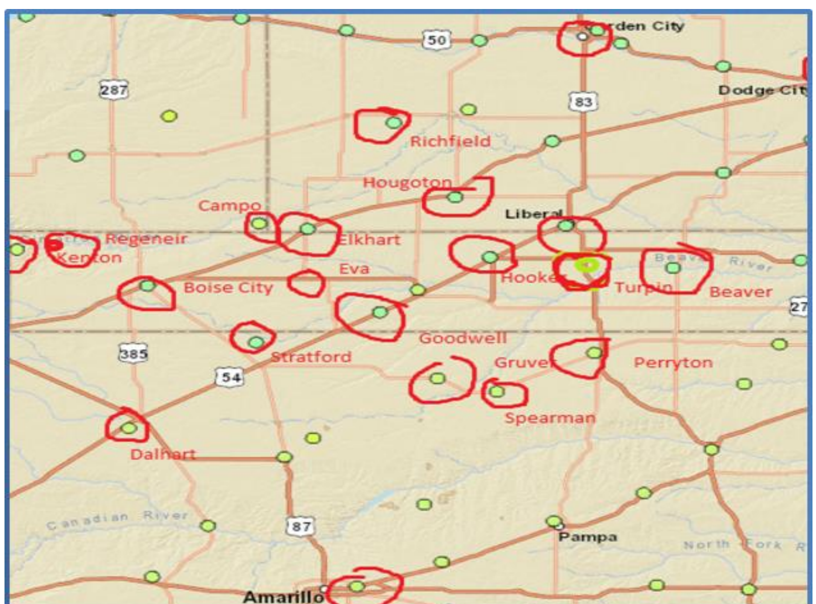


Figure 3. Locations of sites around Goodwell where Weather Variables were Obtained to Estimate Missing Goodwell Values

A common approach is to use inverse distance weighting of values from surrounding reporting sites to fill in data gaps. However this approach only uses the information in the weather values on a given day and does not use any statistically estimated relationships between sites where all data are present. A multiple regression was used in this study. Figure 3 above shows the locations of sites around Goodwell, Oklahoma where one or more weather values are reported. In order to estimate a missing temperature value for Goodwell, temperature values were obtained from Hooker, and Boise City in Oklahoma, and Liberal and Elkhart in Kansas, and Amarillo, and Perryton Texas. An OLS regression of the reported Goodwell temperature was regressed against the reported daily values (independent variables) as follows;

$$GW_t = a\ Hk_t + b\ BC_t + e\ Li_t + d\ Ek_t + ePy_t + f\ Am_t,$$

where the respective variables GW, Hk, BC, Li, Ek, Py andAm represent observations form Goodwell, Hooker, Boise City, Liberal, Perryton and Amarillo respectivelyThe estimated regression was then used to predict missing Goodwell temperature values. The limitation of the process is that the reported weather series from other locations also contain data gaps. If one of the independent sites has a missing value on the same day as Goodwell, then the regression cannot be used to estimate the Goodwell temperature. This problem was solved by estimating additional regression equations by omitting one of the independent variable. In some cases it was necessary to omit more than two variables. The equations were then ranked in order of decreasing r-square values. On days where the equation with all independent variables could not be used because one or more of the independent weather values was missing, the next best equation with no missing values was used. The estimation and predictions were carried out using SAS 9.1. SAS will not make a prediction on days when the values for one or more of the independent variables are missing.

Minimum Daily Temperature:

Goodwell was the dependent variable. The independent variables were Hooker, Boise City, Elkhart, Gruver, and Stratford. The estimated regression equations were,

$$GWm_t = -.54 + .057\,Hk_t + .279\,Elk_t + .242\,BC_t + .184\,Gru_t + .254\,Str_t, \quad r^2 = .96$$
$$GWm_t = .003 + .292\,Elk_t + .247\,BC_t + .196\,Gru_t + .280\,Str_t, \quad r^2 = .96$$
$$GWmt = .033 + .086 Hk_t + .266 BC_t + .266\,Gru_t + .318\,Str_t, \quad r^2 = .96$$
$$GWmt = -.154 + .044\,Hk_t + .389 Elk_t + .244 Gru_t + .329\,Str, \quad r^2 = .96$$
$$GWmt = .047 + .070 Hk_t + .336 Elk_t + .286 BC_t + .326\,Str_t, \quad r^2 = .96$$
$$GWmt = -.193 + .107 Hk_t + .324 Elk_t + .310 BC_t + .273 Gru_t, \quad r^2 = .96$$

All coefficients were significant at the 10 percent level or better.

Maximum Daily Temperature:

The stations used as independent variables in the estimation of missing Goodwell maximum daily temperature values were the same as above for the minimum temperature. The estimated equations were,

$$GWmx_t = -.043 + .383 Hk_t + .021\,Elk_t + .096\,BC_t + .017\,Gru_t + .487\,Str_t, \quad r^2 = .95$$
$$GWmx_t = -.319 + ,111\,Elk_t + ,130\,BC_t + .208\,Gru_t + ,567\,Str_t, \quad r^2 = .94$$
$$GWmx_t = -.066 + ,393\,Hk_t + .100\,BC_t + .015\,Gru_t + .496\,Str_t, \quad r^2 = .95$$
$$GWmx_t = .142 + 396\,Hk_t + .060\,Elk_t + .037 Gru_t{}^* + .504\,Str_t, \quad r^2 = .95$$
$$GWmx_t = -.026 + .392\,Hk_t + .025\,Elk_t + .099\,BC_t + .489\,Str_t, \quad r^2 = .95$$
$$GWmx_t = .720 + .403\,Hk_t + .336\,Elk_t + .033\,BC_t + .185\,Gru_t, \quad r^2 = .90$$

Unless indicated (*) all coefficients are significant at the 10% level or better.

Precipitation:

Daily precipitation was the hardest variable to estimate because of the unevenness of the rainfall over the High Plains area. The stations used as independent and dependent variables are listed below. Thirty-minute rainfall was reported by the Goodwell station for some of the dates. On some days when the daily total was missing, and there were two or more periods of 15 minute rainfall reported, an estimate for the day's rainfall, based on the reported 15 minute rainfall and the time of year, during the missing period could be made. However, there were still

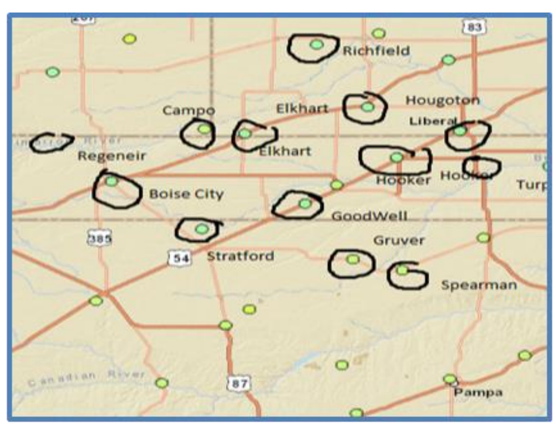


Figure 4. Location of Daily Rainfall Values used in the Regression Equations

many gaps in the precipitation values from the independent sites used in the regression. The approach was to collect all reported daily rainfall values between 1965 and the present from locations as near Goodwell as possible. Data were used from the stations circled on the map in Figure 3. The estimated regression equations were,

$GWp_t = .352\ Str_t + .110\ Elk_t + .071 Gru_t + .198\ Eva_t - .030\ Hug + .112 Spr + .062\ Rch + .09 DwtWrn_t^*$, r2 = .59
$GWp_t = .189 Str_t + .051\ Elk_t + .100\ Gru_t + .095 Eva_t + .030 Hug + .030 Spr + .029\ Rch + .371 DwtWrn_t$, r2 = .59
$GWp_t = .031\ Elk_t + .045\ Hug - .169\ Rch + .799\ DwtWrn_t$, r2 = .46
$GWp_t = .029 Elk_t + .051 Hug + .016 Spr + .776\ DwtWrn_t$, r2 = .44

The respective sites used were Stratford, Texas (Str), Elkhart, Kansas (Elk), Gruver, Texas (Gru), Eva, Oklahoma (Eva), Hugoton, Kansas (Hug), Spearman, Texas (Spr), and Richfield, Kansas (Rch). All coefficients are significant at the 10 percent level or better unless indicated (*).

The variable DwtWrn (inverse distance weighted rainfall) was not significant in the first equation, but was significant in the remaining three equations. The r-square values are in the .4-.5 range. It is notable that on days when all stations were reporting observations, the inverse distance weighting method was not significant. When only a few stations were available, the values of those stations were significant along with the inverse weighted distance value.

Relative Humidity:

Weather stations in the Central High Plains with long reported records of relative humidity (or dewpoint temperature) were limited. The regressions below utilize data from Liberal, Kansas, Elkhart, Kansas, Dalhart, Texas, and Clayton, New Mexico. Relative humidity data were only estimated from 1973-2014.

The regressions obtained were,

$GWh_t = 6.92 + .313\ Li_t + .116\ Am_t + .062\ Da_t + .314\ Elk_t + .255 Cy_t$, $r^2 = .81$
$GWh_t = 8.53 + .321\ Li_t + .174\ Am_t + .491\ Da_t$, $r^2 = .74$
$GWh_t = 10.23 + .423\ Li_t + .501 Am_t$, $r^2 = .69$

Wind Speed:

Prior to the establishment of the MESONET in 1994, the Goodwell Research station was one of the few places in the study area reporting wind speeds. Unfortunately, there were many gaps in this data. Wind speed was recorded by the airport at Liberal, Kansas but the data were not electronically available before 1973. Amarillo, Texas, Dodge City and Garden City, Kansas (Figure 5) had wind

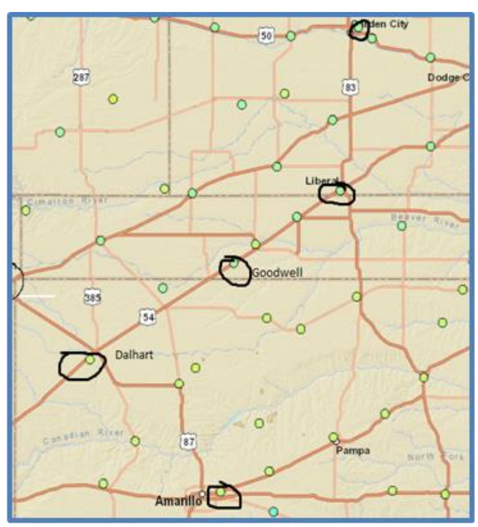


Figure 5. Location of Stations Reporting Windspeeds used in the Regression Analysis

speed records dating back to 1965. The estimated regression equations were,

$GWWt = -0.226 + 0.236\ Gc_t + 0.313\ Cy_t + -0.003\ Am_t + 0.183\ Dh_t + 1.196\ DC_t + 0.085\ Li_t, \quad r^2=0.41$

$GWW_t = -0.104 + 0.361\ Cy_t + -0.003\ Am_t + 0.187\ Dh_t + 1.325\ DC_t + 0.109\ Li_t, \quad r^2= 0.41$

$GWW_t = -0.150 + 0.303\ Gc_t + 0.000\ Am_t + 0.399\ Dh_t + 1.169\ DC_t + 0.076\ Li_t, \quad r^2= 0.37$

$GWW_t = -0.226 + 0.236\ Gc_t + 0.314\ Cy_t + 0.182\ Dht + 1.197DC_t + 0.086\ Li_t, \quad r^2= 0.41$

$GWW_t = -1.01 + 0.252\ Gc + 0.419\ Cy_t -0.0003\ Am_t + 1.202\ DC_t + 0.115Li_t, \quad r^2= 0.41$

$GWW_t = 0.790 + 1.070\ Gc_t + 0.287\ Cy_t -0.005\ Am_t + 0.276\ Dh_t + 0.266\ Li_t, \quad r^2= 0.36$

$GWW_t = -0.396 + 0.273\ Gc_t + 0.320\ Cy_t -0.004\ Am_t + 0.218\ Dh_t + 1.235\ DC_t, \quad r^2= 0.41$

$GWW_t = -2.80 + 0.004\ Am_t + 1.852\ Dct \quad r^2= 0.40$

The respective cities were Garden City (GC), Clayton, New Mexico (Cy), Amrillo, Texas (Am), Dalhart, Texas (Dh), Dodge City, Kansas (DC), and Liberal, Kansas (Li).

Solar Radiation:

Solar Radiation data covers only the period from 1994 through the present and was found only at the more recent MESONET sites. The missing Goodwell MESONET solar radiation values were estimated by the following regressions based on data at Beaver and Boise City. The regression equations estimated were,

$GWS_t = -0.182 + 0.450\ BV_t + 0.561\ BCt, \quad r^2= 0.961$

$GWS_t = 1.660 + 0.939\ BV_t, \quad r^2= 0.908$

$GWS_t = -0.126 + 0.985\ BC_t, \quad r^2= 0.923.$

All coefficients significant at the 10 percent level or better.

The monthly mean values along with their standard deviations, maximum observed value, and maximum observed values for each month are shown below in Table 1.

Table 1. Fifty Year Averages of Monthly Means and Standard Deviations of the Daily Goodwell Weather set.

Item and Unit	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max. Daily Tmp	Mean	9.1	11.3	15.9	21.1	25.9	31.4	34.1	32.8	28.5	22.4	15.0	9.6	21.5
Celsius	Sdev	8.1	8.3	7.9	6.8	6.0	5.0	3.9	4.2	5.7	6.7	7.3	7.9	11.0
	MinObs	-13.3	-16.7	-12.5	-6.1	4.4	12.2	17.2	15.0	4.4	-6.1	-12.2	-17.2	-17.2
	MaxObs	27.2	30.6	34.4	37.8	39.6	43.9	42.1	42.2	42.8	35.8	31.7	32.7	43.9
Min. Daily Tmp.	Mean	-7.0	-5.3	-1.2	4.0	9.5	15.2	18.0	17.1	12.4	5.3	-1.3	-5.9	5.1
Celsius	Sdev	5.3	5.3	5.1	4.6	4.2	3.4	2.4	2.5	4.2	4.5	4.8	5.3	9.9
	MinObs	-25.6	-23.9	-19.0	-12.8	-4.3	4.4	8.3	7.2	-2.2	-11.7	-20.6	-25.0	-25.6
	MaxObs	17.8	9.4	22.2	23.3	32.8	33.9	24.5	23.4	23.3	20.6	10.7	10.4	33.9
Monthly Precp	Mean	7.6	10.3	25.4	34.1	67.8	64.2	58.8	58.4	36.9	32.4	14.8	11.3	34.7
mm	Sdev	1.2	1.7	3.2	4.3	7.6	6.1	6.2	6.1	5.1	5.0	2.4	2.0	4.8
	MinObs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	MaxObs	17.8	23.6	38.4	46.0	91.4	49.8	76.7	80.3	74.7	86.9	28.7	53.3	91.4
Daily Rel. Hum.	Mean	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
proportion	Sdev	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
	MinObs	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.2	0.1	0.1
	MaxObs	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Daily Wind Speed	Mean	9.1	9.5	10.6	11.1	9.9	9.7	8.9	8.4	8.9	9.1	9.1	9.2	9.5
m/sec	Sdev	2.8	3.1	3.5	4.1	4.0	3.8	3.3	3.8	3.8	3.9	3.2	2.8	3.6
	MinObs	2.4	2.1	3.2	1.2	0.3	0.1	0.1	0.5	1.0	0.8	0.1	2.3	0.1
	MaxObs	26.3	25.5	25.2	30.7	27.4	31.3	28.6	75.5	27.3	33.3	26.2	22.1	75.5
Daily Solar Rad.	Mean	10.8	13.7	17.8	24.5	26.4	25.4	22.2	19.3	15.2	11.6	9.9	18.3	22.2
Wats/m^2	Sdev	3.0	4.2	5.5	6.5	5.2	4.9	5.0	4.6	4.4	3.3	3.0	7.4	6.1
	MinObs	1.3	1.3	1.8	2.0	3.1	3.4	4.2	2.3	1.1	1.2	0.5	0.5	2.3
	MaxObs	15.8	21.1	26.1	33.4	32.7	32.1	30.1	26.4	21.7	17.1	20.2	33.4	31.3

Simulated Yields

In this section, the Environmental Policy Impact Calculator (EPIC) yield responses using historical 50-year daily weather data at Goodwell are compared with experimental results from the Oklahoma Panhandle, Southwest Kansas, and the Texas Panhandle. The EPIC simulated yields were averaged over the 50 year weather period (1965-2014). The planting date and the harvesting date for both corn and grain sorghum was held constant for each year. For grain sorghum, the previous studies and experiments from Bushland, Texas, Goodwell, Oklahoma, Guymon, Oklahoma, Tribune, Kansas, and Garden City, Kansas suggests that the reasonable planting date (end of May or Beginning of June) is May 28, and harvested (end of October) on October 31. The plant population for corn and sorghum was 52,000 plants ac^{-1} and 32,000 plants ac^{-1} respectively, also held constant each year. The corn and grain sorghum yields under the center pivot were obtained from the EPIC simulations results where a 36 mm application could be applied any time after the minimum number of days since the previous application if the soil moisture was also below an irrigation stress level. The irrigation triggers (1- stress level) were .9, .8, .7, .6, .5, .4, and .3. The purpose of the irrigation triggers was to test if less than full irrigation would be profitable in the long run. The minimum days between irrigations for each size of well and the application levels when an irrigation did occur are shown in Table 2.

Table 2. Center Pivot System Irrigation Frequency and Application Rates

Well Capacity	**Frequency**		
GPM	**DAYS**	**inches**	**mm**
800	4	1.42	36.00
700	5	1.42	36.00
600	6	1.42	36.00
500	7	1.42	36.00
400	8	1.42	36.00
300	11	1.42	36.00
200	16	1.42	36.00
100	32	1.42	36.00

The subsurface drip was simulated under the assumption of a constant amount per acre being applied every day if the water depletion level was below the allowable limit. The amount per day was determined by spreading the output per well across fields of 50, 75, 100, 125, or 150 acres. As field size is increased, the amount applied per day declines. The yields can be expected to decline with an increase in field size. The amounts applied per day are shown in Table 3.

Table 3. Subsurface Drip System Irrigation Frequency and Application Rates

	Field Size	Maximum Daily Application									
		50 acres		75 acres		100 acres		125 acres		150 acre	
GPM	**DAYS to apply**	**inches**	**mm**	**inches**	**mm**	**inches**	**mm**	**inches**	**mm**	**inches**	**mm**
800	1	0.87	22	0.59	15	0.43	11	0.35	9	0.31	8
700	1	0.75	19	0.51	13	0.39	10	0.31	8	0.28	7
600	1	0.67	17	0.43	11	0.35	9	0.28	7	0.24	6
500	1	0.55	14	0.35	9	0.28	7	0.24	6	0.20	5
400	1	0.43	11	0.31	8	0.24	6	0.20	5	0.16	4
300	1	0.35	9	0.24	6	0.16	4	0.16	4	0.12	3
200	1	0.24	6	0.16	4	0.12	3	0.12	3	0.08	2
100	1	0.12	3	0.08	2	0.08	2	0.08	2	0.04	1

Results of Yield Simulation for Center Pivot System (CPS):

Actual irrigation research experiments with current corn and grain sorghum varieties are limited to a few locations over relatively short time periods. For the Panhandle research and extension site, this period was 2005-2014. Weather occurring during the 2005-2014 period will not have the same mean and variability as might be expected over the next 50 years. The purpose of the simulation was to extend and estimate yields of irrigated corn and grain sorghum that would occur under weather patterns of the past 50 years in the Oklahoma Panhandle counties and under irrigation levels not directly tested by budget limited experiments. The 50 year mean yields and irrigation water use by irrigated corn and grain sorghum using CPS are shown respectively in Tables 4 and 5 below. Mean yields of irrigated grain sorghum varied from 162.8 bushels (800 GPM well, irrigation trigger of .9) to 87.5 bushels per acre (100 GPM well, irrigation trigger of .3). The respective average annual irrigation amounts varied from 15.6 to 2.2 acre inches. It must be remembered that the yields present a static annual view but producers face a dynamic situation as the water table, and consequently the well capacity, declines annually.

Table 4. Results from EPIC Simulation of Irrigated Sorghum Yields and Irrigation rates Using Center Pivot System on a 120 acre Quarter Section

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
800	122.1	124.9	129.0	138.6	148.7	156.5	162.8	8.3	8.6	9.2	9.2	12.6	14.2	15.6
700	122.4	125.3	129.1	137.3	145.3	150.9	155.7	8.2	8.5	9.1	10.3	11.8	13.0	14.1
600	122.3	125.2	128.5	134.0	139.6	144.6	148.4	8.2	8.5	9.0	10.0	10.7	11.9	12.6
500	120.5	123.5	126.0	129.6	134.1	137.5	141.1	8.0	8.3	8.8	9.3	9.8	10.8	11.3
400	116.9	119.7	122.4	124.6	128.6	131.4	133.8	7.7	8.0	8.3	8.6	9.4	9.9	10.4
300	104.8	107.0	108.7	110.4	112.3	115.0	117.2	6.5	6.8	7.1	7.3	7.6	7.8	8.3
200	88.4	89.1	89.6	90.1	90.5	91.1	92.0	2.9	3.1	3.2	3.3	3.4	3.6	4.1
100	87.5	87.8	87.9	88.1	88.2	88.3	88.5	2.2	2.3	2.4	2.4	2.5	2.6	2.8

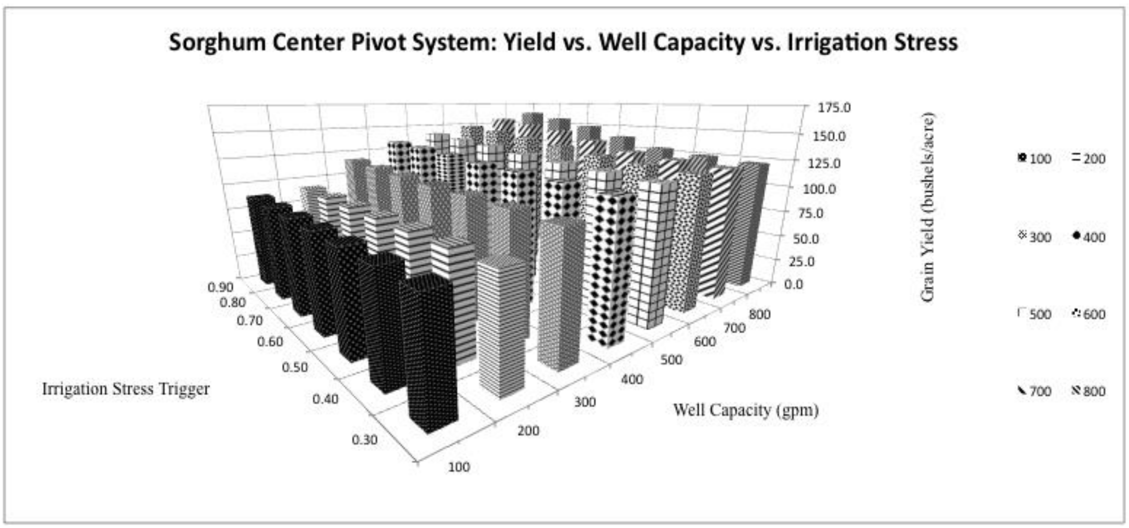


Figure 6. Simulated EPIC Grain Sorghum Yields with a 120 Acre Center Pivot Irrigation by Well Capacity when Irrigation Occurs if Soil Moisture Level Reach Specified Levels

The 50 year mean irrigated corn yields simulated by EPIC varied from 213.4 bushels (800 GPM well and a .9 irrigation trigger) to 96.8 bushels simulated with a 100 GPM well and a .3 irrigation trigger. With low GPM wells, the irrigation trigger had little effect with the center pivot simulation because the moisture level was usually below the trigger by the time the pivot could complete the revolution. That is the pivot system was usually in motion.

Table 5. Results from EPIC Simulation of Irrigated Corn Yields and Irrigation rates Using Center Pivot System on a 120 acre quarter section

	Irrigation Trigger													
GPM	**Yields (bushels/acre)**							**Gross Irrigation (acre-inches)**						
	0.30	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
800	159.3	163.4	166.9	180.8	193.9	206.3	213.4	14.6	15.3	16.2	18.8	21.5	22.5	22.5
700	158.4	161.9	165.1	176.0	186.3	194.6	198.9	14.6	15.3	16.1	18.0	20.4	22.1	23.1
600	156.9	159.8	163.0	170.7	177.2	182.9	186.9	14.6	15.0	15.9	17.2	19.0	20.4	21.6
500	153.8	156.1	158.3	162.2	168.4	172.4	175.0	14.1	14.6	15.3	16.0	17.4	18.6	19.5
400	148.5	150.1	152.1	154.7	157.7	161.2	164.4	13.5	13.9	14.4	15.0	15.9	17.0	17.6
300	133.7	134.9	136.9	138.4	139.3	141.2	142.6	11.0	11.3	11.8	12.3	12.8	13.4	13.9
200	117.5	117.7	118.9	119.2	120.1	121.2	122.2	8.7	8.8	9.1	9.4	9.7	10.1	10.3
100	96.8	97.7	98.1	98.1	98.4	98.9	99.1	5.4	5.5	5.7	5.8	5.9	6.0	6.1

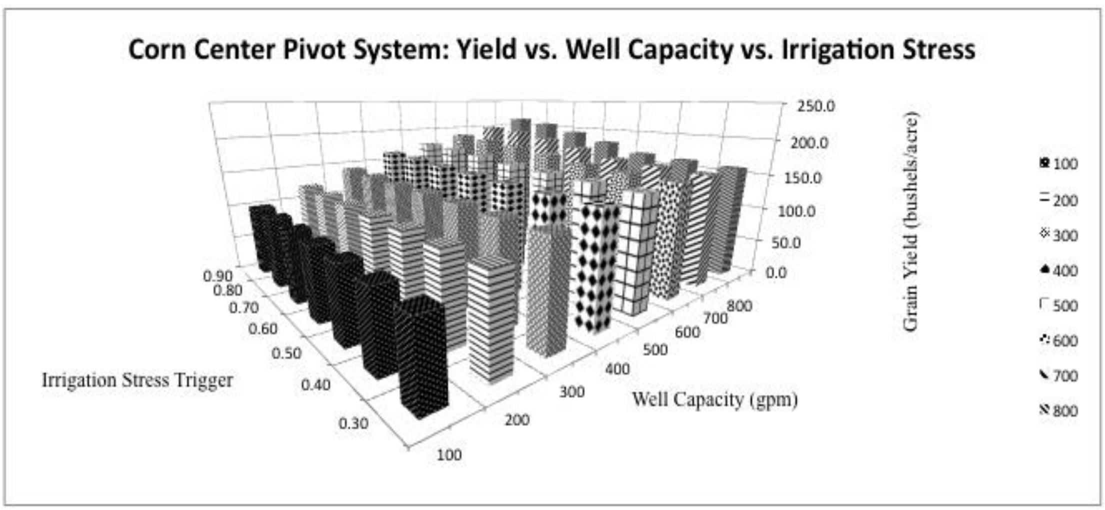


Figure 7. Simulated EPIC Corn Yields with 120 Acre Center Pivot Irrigation by Well Capacity when Irrigation occurs when Soil Moisture Levels fall below the Indicated levels.

Comparison of Simulated Yields and Water Use with Existing Experimental and Variety Trial Results

The general objective of variety trials is often to compare maximum yields among varieties. The averages of irrigated variety trials conducted at Goodwell, Oklahoma, Hereford, Texas, and Garden City, Kansas were used to check the simulated full irrigation yields of corn and grain sorghum. This was done by comparing the EPIC yields for the specific years when variety trials were conducted at the various locations. Variety trial results were available at Goodwell from 2005 through 2014. In Figure 8 below, the EPIC yields for each year from 2005-2014 are compared with the variety trial yields for those years. The simulated yields assume continuous irrigated production whereas crop rotations are often involved with the variety trials. The EPIC simulated corn yields followed the variety trial results reasonably well and caught the 2011 downturn but not the 2014 decline.

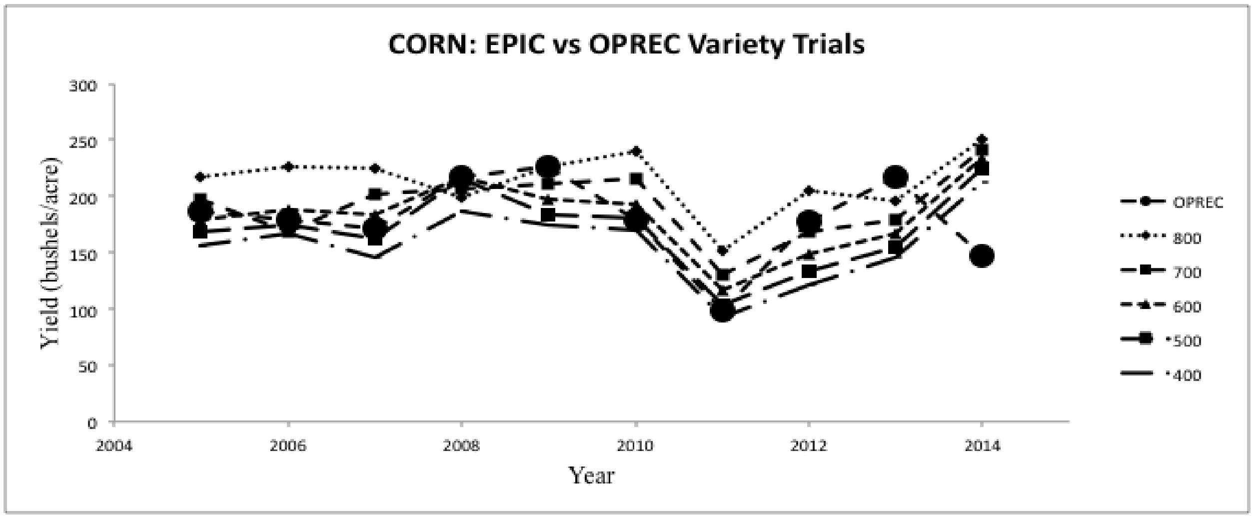


Figure 8. Results from EPIC corn simulation full irrigation comparing with OPREC Variety Trials

The simulated sorghum yields miss the downturn in 2011 but match the upturn in sorghum yields in 2013 and 2014. There are items related to planting dates and soil moisture conditions involved in the trial that cannot readily be simulated.

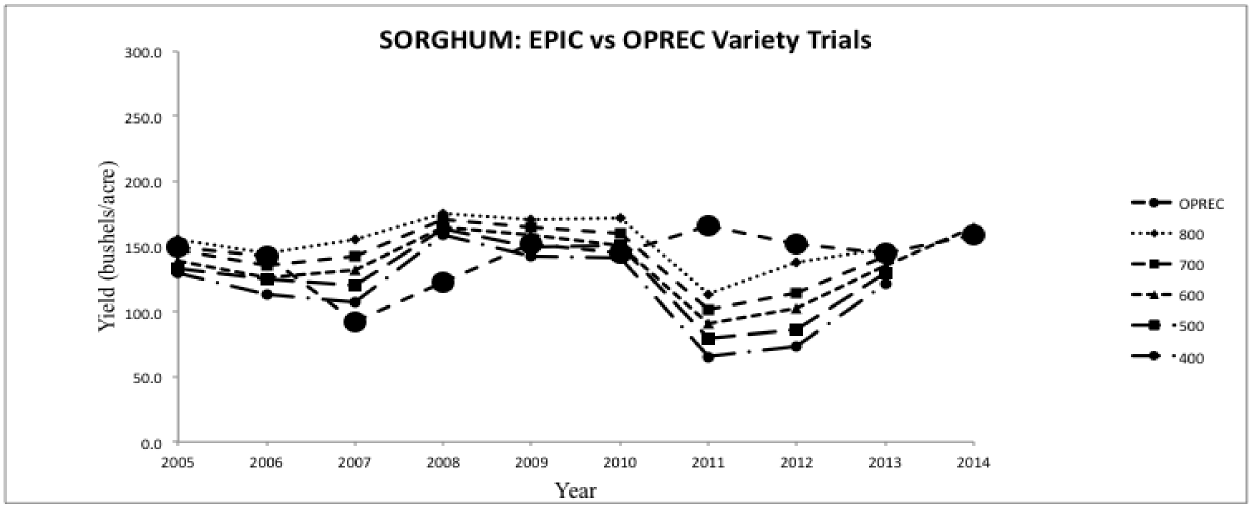


Figure 9. Results from EPIC sorghum simulation full irrigation comparing with OPREC Variety Trials

Water Use Efficiency

The simulated full (.9 trigger) yields and irrigation quantities by well capacity for corn and sorghum are shown below in Figure 10. As expected the corn yields and irrigation requirements for corn are greater than for sorghum.

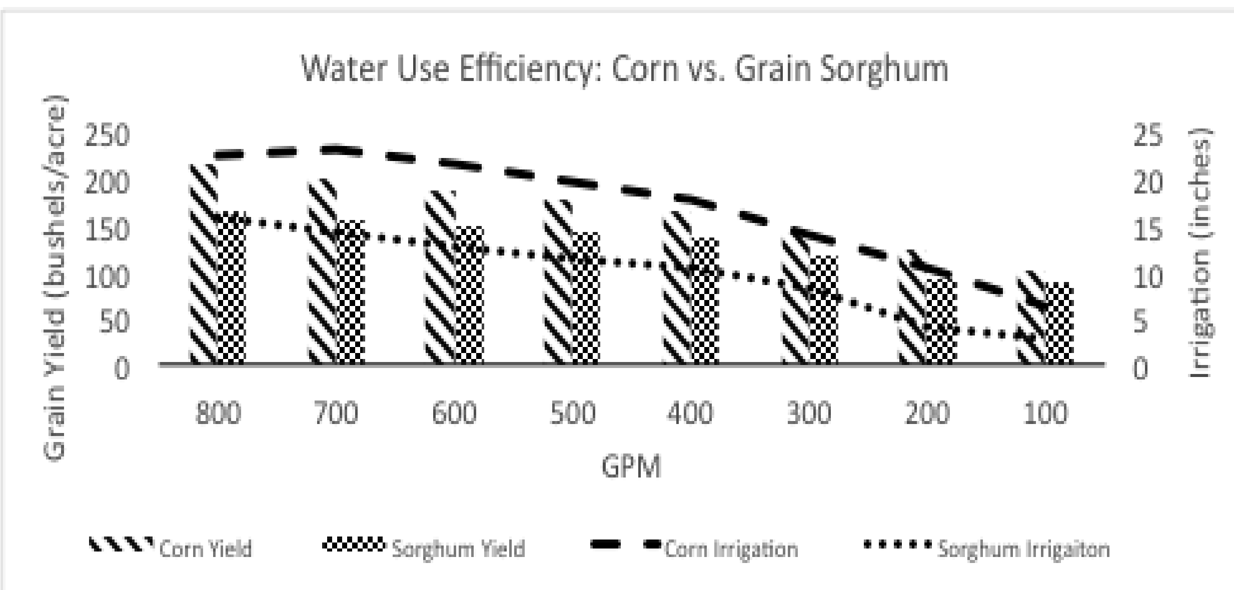


Figure 10. Results from EPIC Corn and Sorghum simulation full irrigation showing its water use efficiency.

The relative grain sorghum yields with irrigation plus rainfall from the simulation are compared with similar results in Garden City, Kansas (Figure 11a) and with an experiment at

Bushland, Texas (Figure 11b) below. The EPIC simulated yields are below those at Garden City where it is assumed there would less evapotranspiration than at Goodwell but approximately equal to those at Bushland where the expected transpiration would be somewhat higher than for Goodwell.

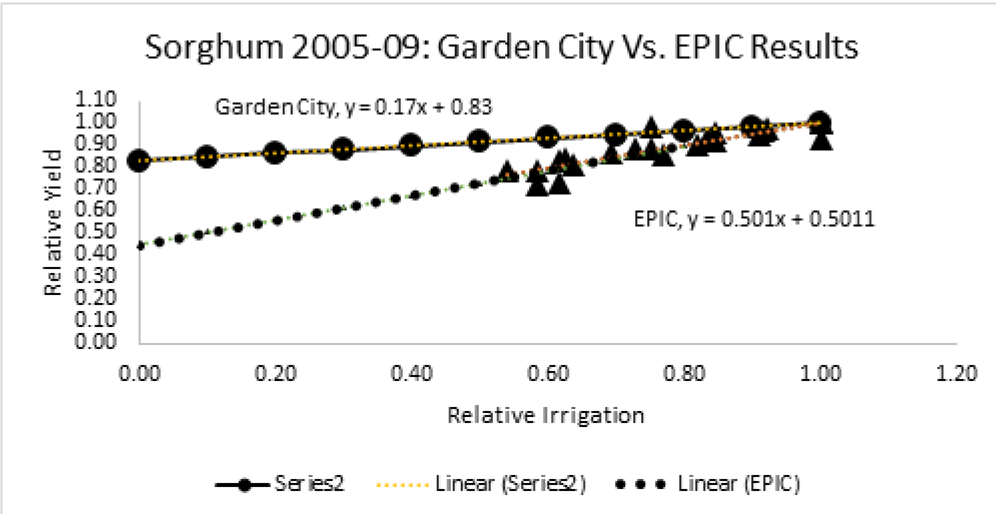


Figure 11a. Results from EPIC Sorghum Simulation as compared to Experimental Data from Garden City, Kansas

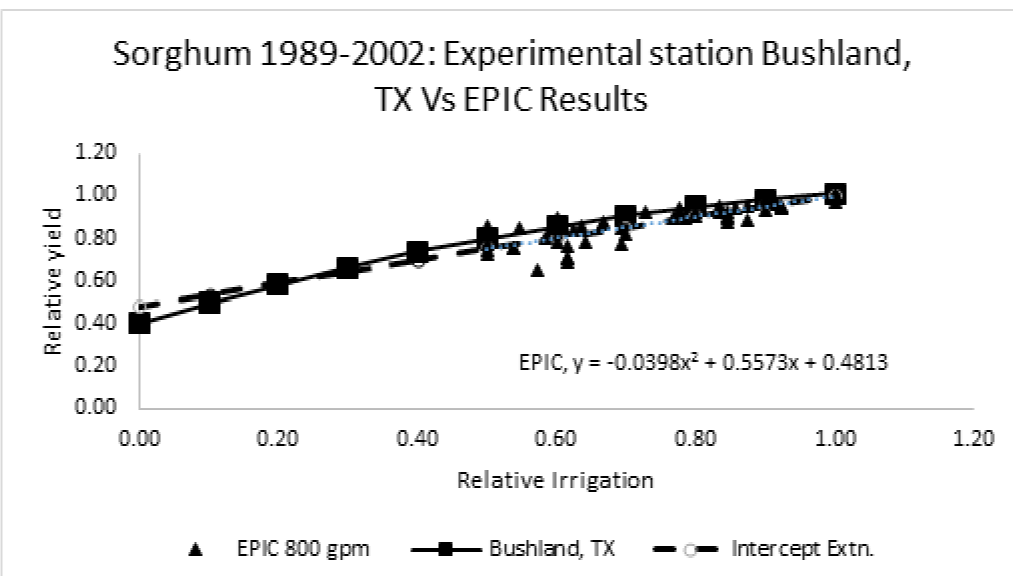


Figure 11b. Results from EPIC Sorghum Simulation as compared to Experimental Data from Bushland, Texas.

SUBSURFACE DRIP SIMULATION RESULTS

Simulations of Subsurface Drip Irrigated Grain Sorghum

There are large economies of size with the center pivot system so only one size was simulated. There are economies of size with the subsurface drip system but of a smaller magnitude than with the pivot system, thus the producer is more likely to consider the capacity of the well in selecting the size of the area to be irrigated by a subsurface drip system. Field sizes of 50, 75, 100, 125, and 150 acres were assumed. The EPIC simulations were based on the assumption of a constant amount per day per acre if soil moisture was below the irrigation trigger. As the field size covered by a given well is increased, the amount applied per day declines. The highest yields would be expected from the smaller fields.

The average simulated yields and average annual water use are shown in Tables 5 to 9 below. The simulated subsurface irrigated corn yields varied from 222.9 bushels (slightly higher than with the pivot) for the fifty acre field with an 800 GPM well down to 93.3 bushels for the 150 acre field with a 100 GPM well and a .3 irrigation trigger. Again the irrigation trigger had little effect when well capacity dropped below 300 GPM because the field moisture was usually below the trigger level.

Table 6. Results from EPIC Simulation of Irrigated Sorghum Yields and Irrigation Rates Using a Subsurface System on a 50 Acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	141.3	144.7	149.4	154.1	158.0	163.4	172.1	9.3	9.8	10.4	11.3	11.9	12.9	14.9
700	137.1	142.0	146.6	151.1	155.6	162.6	170.7	8.6	9.2	9.8	10.6	11.2	12.6	14.3
600	134.3	139.8	144.5	149.4	154.5	161.2	168.7	8.1	8.8	9.4	10.2	10.9	12.1	13.7
500	129.3	134.4	141.4	145.3	150.4	156.6	166.4	7.3	8.0	8.8	9.3	10.1	11.2	13.1
400	122.8	128.6	134.0	138.8	142.9	149.5	168.3	6.4	7.1	7.7	8.3	8.9	9.9	13.2
300	115.6	121.1	125.7	130.7	137.1	150.6	166.6	5.7	6.2	6.7	7.2	8.0	9.9	12.7
200	89.3	91.0	92.2	93.6	95.5	97.9	100.9	1.4	1.7	2.0	2.2	2.7	3.2	4.1
100	87.1	88.5	90.5	92.3	93.7	95.1	96.6	0.9	1.1	1.5	1.8	2.1	2.5	2.9

Table 7. Results from EPIC Simulation of Irrigated Sorghum Yields and Irrigation Rates Using a Subsurface System on a 75 Acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	131.6	136.5	142.2	147.2	151.9	158.5	166.1	7.6	8.3	9.0	9.7	10.4	11.5	13.0
700	128.2	133.7	138.6	143.4	148.6	154.1	167.8	7.1	7.8	8.3	9.0	9.8	10.7	13.2
600	122.8	128.6	134.0	138.8	142.9	149.5	168.3	6.4	7.1	7.7	8.3	8.9	9.9	13.2
500	115.6	121.1	125.7	130.7	137.1	150.6	166.6	5.7	6.2	6.7	7.2	8.0	9.9	12.7
400	110.2	115.8	120.8	127.6	136.8	152.9	164.5	5.2	5.7	6.2	6.8	7.9	10.1	12.1
300	96.7	103.1	112.7	124.8	137.7	147.4	155.2	4.1	4.6	5.3	6.4	7.7	9.0	10.3
200	87.9	89.3	90.8	92.8	94.9	96.9	99.1	1.1	1.3	1.6	2.0	2.4	2.9	3.6
100	86.4	88.1	89.4	90.3	91.1	91.9	93.0	0.7	1.0	1.2	1.4	1.6	1.8	2.1

Table 8. Results from EPIC Simulation of Irrigated Sorghum Yields and Irrigation Rates Using a Subsurface System on a 100 Acre Field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	122.8	128.6	134.0	138.8	142.9	149.5	168.3	6.4	7.1	7.7	8.3	8.9	9.9	13.2
700	119.9	125.2	130.3	135.0	140.0	149.2	167.8	6.1	6.7	7.2	7.8	8.4	9.7	13.0
600	115.6	121.1	125.7	130.7	137.1	150.6	166.6	5.7	6.2	6.7	7.2	8.0	9.9	12.7
500	104.3	109.5	116.2	124.7	137.9	150.7	161.0	4.7	5.1	5.7	6.5	7.9	9.7	11.4
400	96.7	103.1	112.7	124.8	137.7	147.4	155.2	4.1	4.6	5.3	6.4	7.7	9.0	10.3
300	83.4	95.9	108.8	118.1	124.5	130.1	135.4	3.1	3.9	4.8	5.6	6.2	6.8	7.6
200	87.1	88.5	90.5	92.3	93.7	95.1	96.6	0.9	1.1	1.5	1.8	2.1	2.5	2.9
100	86.4	88.1	89.4	90.3	91.1	91.9	93.0	0.7	1.0	1.2	1.4	1.6	1.8	2.1

Table 9. Results from EPIC Simulation of Irrigated Sorghum Yields and Irrigation Rates Using a Subsurface System on a 125 Acre Field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	115.6	121.1	125.7	130.7	137.1	150.6	166.6	5.7	6.2	6.7	7.2	8.0	9.9	12.7
700	110.2	115.8	120.8	127.6	136.8	152.9	164.5	5.2	5.7	6.2	6.8	7.9	10.1	12.1
600	104.3	109.5	116.2	124.7	137.9	150.7	161.0	4.7	5.1	5.7	6.5	7.9	9.7	11.4
500	96.7	103.1	112.7	124.8	137.7	147.4	155.2	4.1	4.6	5.3	6.4	7.7	9.0	10.3
400	89.5	98.4	111.0	124.1	133.7	140.8	147.0	3.6	4.1	5.1	6.2	7.2	8.1	9.0
300	83.4	95.9	108.8	118.1	124.5	130.1	135.4	3.1	3.9	4.8	5.6	6.2	6.8	7.6
200	87.1	88.5	90.5	92.3	93.7	95.1	96.6	0.9	1.1	1.5	1.8	2.1	2.5	2.9
100	86.4	88.1	89.4	90.3	91.1	91.9	93.0	0.7	1.0	1.2	1.4	1.6	1.8	2.1

Table 10. Results from EPIC Simulation of Irrigated Sorghum Yields and Irrigation Rates Using a Subsurface System on a 150 Acre Field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	110.2	115.8	120.8	127.6	136.8	152.9	164.5	5.2	5.7	6.2	6.8	7.9	10.1	12.1
700	104.3	109.5	116.2	124.7	137.9	150.7	161.0	4.7	5.1	5.7	6.5	7.9	9.7	11.4
600	96.7	103.1	112.7	124.8	137.7	147.4	155.2	4.1	4.6	5.3	6.4	7.7	9.0	10.3
500	89.5	98.4	111.0	124.1	133.7	140.8	147.0	3.6	4.1	5.1	6.2	7.2	8.1	9.0
400	83.4	95.9	108.8	118.1	124.5	130.1	135.4	3.1	3.9	4.8	5.6	6.2	6.8	7.6
300	80.3	91.0	99.8	104.9	109.6	114.7	119.1	2.8	3.5	4.1	4.5	4.9	5.4	5.9
200	86.4	88.1	89.4	90.3	91.1	91.9	93.0	0.7	1.0	1.2	1.4	1.6	1.8	2.1
100	85.2	85.7	86.2	86.6	87.0	87.5	88.2	0.5	0.6	0.7	0.8	0.9	1.0	1.1

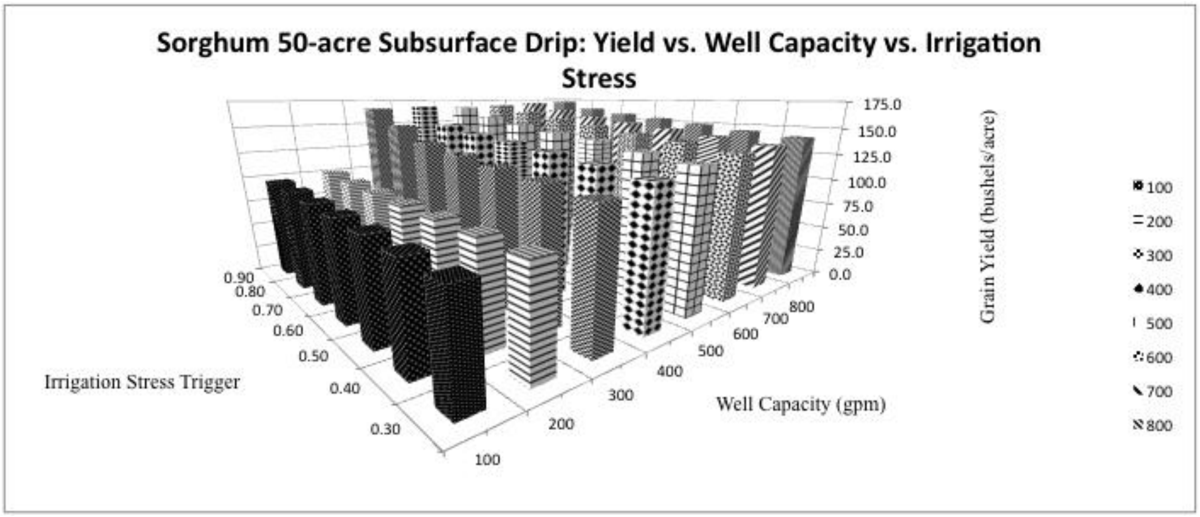


Figure 12. Results from EPIC Sorghum Subsurface Simulation showing Yields and Irrigation along with the Well Capacity for a 50 Acre Field.

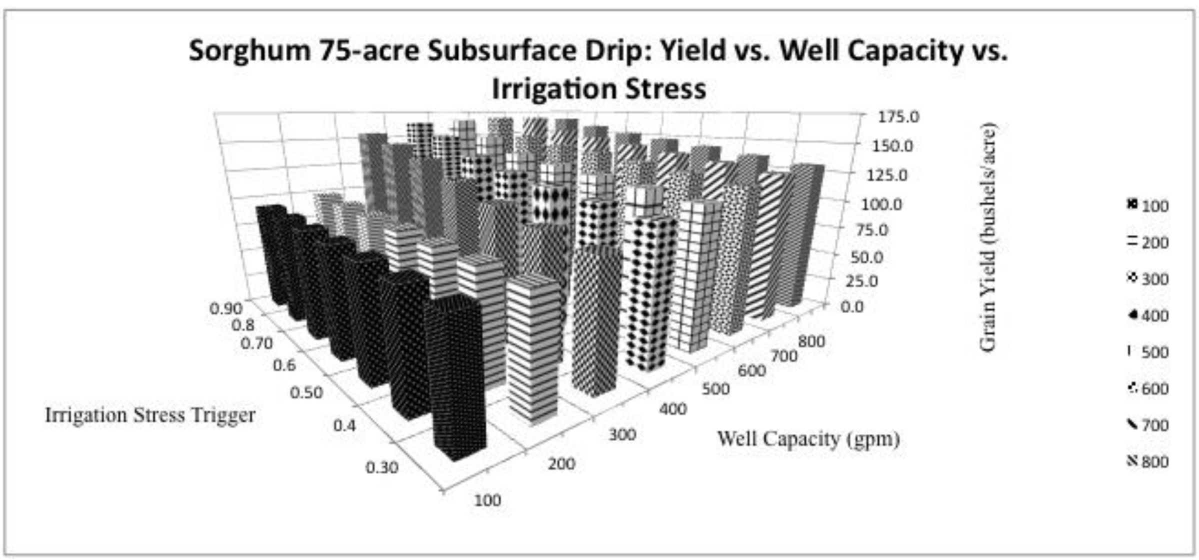


Figure 13. Results from EPIC Sorghum Subsurface Simulation showing Yields and Irrigation along with the Well Capacity for a 75 Acre Field.

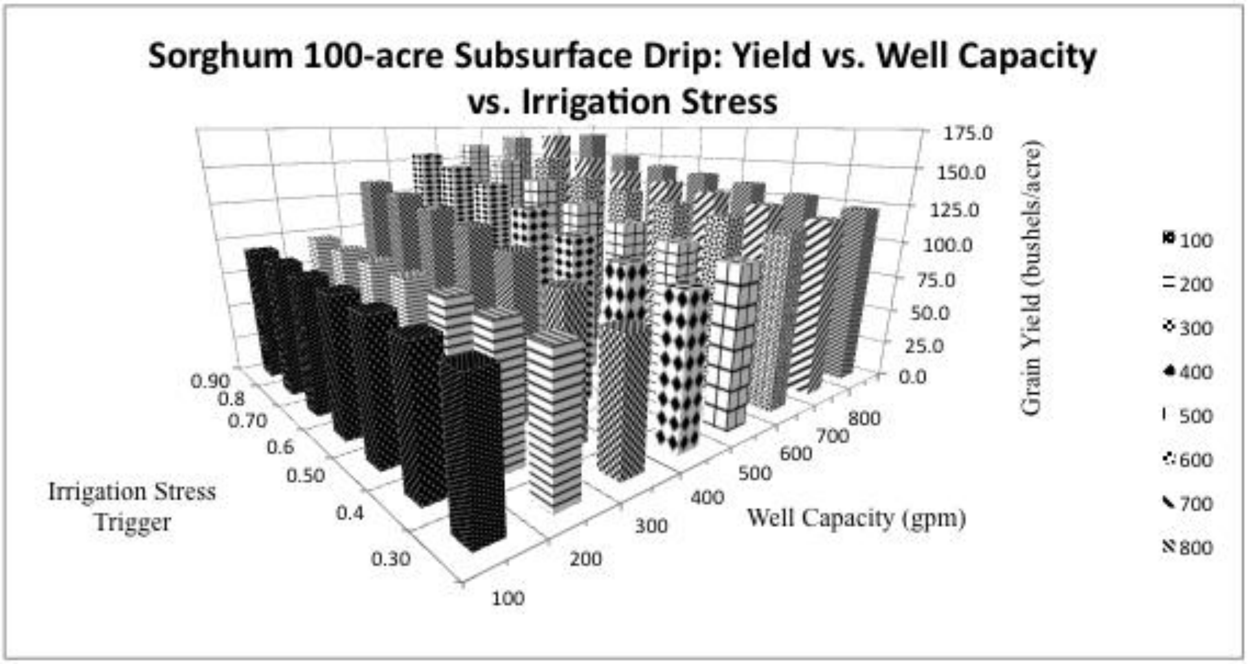


Figure 14. Results from EPIC Sorghum Subsurface Simulation showing Yields and Irrigation along with the Well Capacity for a 100 Acre Field.

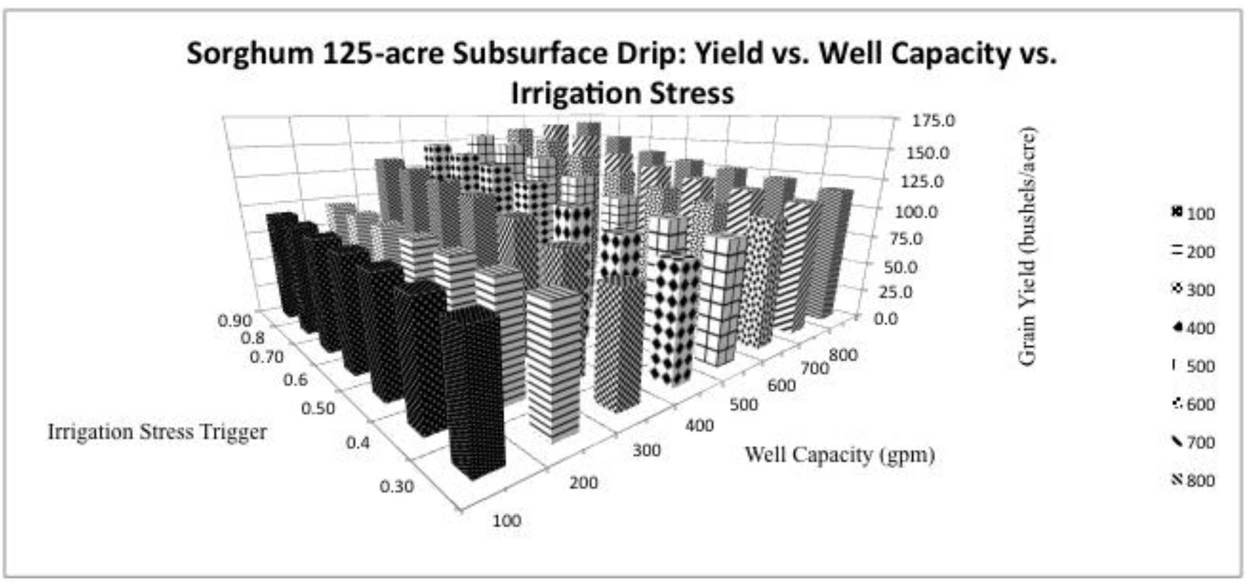


Figure 15. Results from EPIC Sorghum Subsurface Simulation showing Yields and Irrigation along with the Well Capacity for a 125 Acre field.

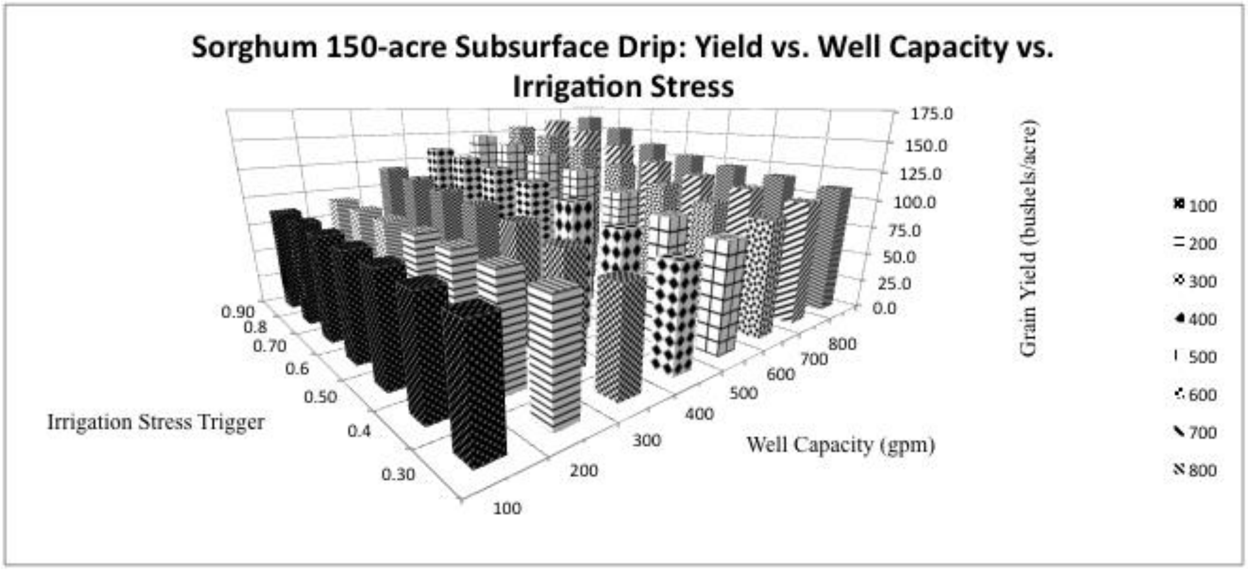


Figure 16. Results from EPIC Sorghum Subsurface Simulation showing Yields and Irrigation along with the Well Capacity for a 150 Acre field.

Simulation of Drip Irrigated Corn

The same field sizes, daily application rates, and irrigation triggers that were used in simulating irrigated grain sorghum were used in simulating subsurface drip irrigated corn. The simulated yields ranged from 222.9 bushels for the 50 acre field with an 800 GPM well, (.9 irrigation trigger) to 93.9 bushels per acre for the 150 acre field with a 100 GPM well (.3 irrigation trigger). The respective gross per acre application rates varied from 26.8 acre inches to 2.4 acre inches. The respective maximum CP yields and water use for the 120 acre pivot were 213.4 bushes and 22.5 acre inches. The maximum yield and related water use for the 125 acre drip field were 214.9 and 22.6 acre inches.

Table 11. Results from EPIC Simulation of Irrigated Corn Yields and Irrigation rates using a Subsurface Drip System on a 50 acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.30	0.4	0.50	0.6	0.70	0.8	0.90
800	179.6	184.9	190.7	196.1	201.5	209.4	222.9	17.1	18.1	19.3	20.3	21.7	23.5	26.8
700	174.3	179.9	185.2	191.2	197.0	205.6	218.5	16.0	17.0	18.1	19.2	20.5	22.4	25.6
600	169.8	175.0	181.0	186.8	192.9	202.2	213.0	15.1	16.1	17.3	18.3	19.7	21.7	24.4
500	161.8	167.0	173.6	179.0	185.9	193.6	210.0	13.6	14.6	15.8	16.7	18.1	19.8	23.7
400	152.3	157.6	162.7	168.6	174.5	182.3	208.4	11.8	12.8	13.6	14.7	15.9	17.5	23.2
300	143.3	147.4	152.6	158.0	164.9	182.7	202.3	10.3	11.0	12.0	12.9	14.3	17.7	22.0
200	125.4	130.2	137.8	149.0	162.7	173.2	182.0	7.4	8.2	9.5	11.3	13.6	15.6	17.6
100	110.4	119.0	125.5	129.7	133.4	137.2	140.6	5.1	6.3	7.2	7.8	8.4	9.0	9.8

Table 12. Results from EPIC Simulation of Irrigated Corn Yields and Irrigation rates using a Subsurface Drip System on a 75 acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	0.30	0.4	0.50	0.6	0.70	0.8	0.90	0.30	0.4	0.50	0.6	0.70	0.8	0.90
800	168.2	173.9	180.3	186.1	193.2	201.7	214.3	14.2	15.3	16.5	17.6	18.9	20.7	23.7
700	162.6	168.8	174.3	180.4	186.8	194.3	216.2	13.2	14.2	15.3	16.3	17.6	19.2	24.1
600	156.0	161.3	166.4	172.8	178.9	187.1	214.2	12.0	12.9	13.8	14.9	16.1	17.8	23.6
500	147.4	151.5	157.0	162.7	169.8	188.4	208.9	10.5	11.1	12.1	13.1	14.5	18.0	22.3
400	141.0	144.8	150.1	157.1	166.3	186.9	202.4	9.5	10.1	11.1	12.3	12.8	17.8	21.2
300	127.8	132.8	140.5	152.3	165.9	177.1	185.9	7.4	8.3	9.6	11.5	13.7	15.7	17.7
200	115.3	124.4	135.6	143.4	150.0	154.7	159.5	5.7	7.0	8.6	9.7	10.8	11.7	12.7
100	105.4	110.0	112.5	115.1	117.6	120.0	122.1	4.2	4.8	5.1	5.5	5.9	6.3	6.7

Table 13. Results from EPIC Simulation of Irrigated Corn Yields and Irrigation rates using a Subsurface Drip System on a 100 acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	0.30	0.4	0.50	0.6	0.70	0.8	0.90	0.30	0.4	0.50	0.6	0.70	0.8	0.90
800	158.3	164.0	169.2	175.6	181.6	190.0	217.9	12.1	13.0	13.9	15.0	16.2	17.9	23.8
700	153.7	159.2	164.3	169.9	176.3	188.0	215.5	11.3	12.2	13.0	14.1	15.3	17.6	23.3
600	148.8	153.4	158.4	164.3	171.5	190.7	211.4	10.5	11.2	12.1	13.2	14.6	18.1	22.5
500	137.6	141.1	148.4	156.0	171.2	186.8	199.8	8.6	9.2	10.5	11.7	14.2	17.1	19.9
400	129.9	134.9	142.8	154.8	168.6	179.9	189.1	7.5	8.3	9.7	11.6	13.8	15.8	17.9
300	117.6	126.8	138.3	146.3	152.7	157.8	162.9	5.7	7.1	8.7	9.9	10.9	11.8	12.9
200	117.6	121.7	128.5	132.9	136.7	140.6	144.1	5.2	6.4	7.3	7.9	8.5	9.2	9.9
100	105.4	110.0	112.5	115.1	117.6	120.0	122.1	4.2	4.8	5.1	5.5	5.9	6.3	6.7

Table 14. Results from EPIC Simulation of Irrigated Corn Yields and Irrigation rates using a Subsurface Drip System on a 125 acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	150.9	156.1	161.1	167.0	174.5	193.9	214.9	10.5	11.4	12.2	13.3	14.7	18.2	22.6
700	145.5	149.8	154.9	162.0	173.4	193.3	209.8	9.7	10.3	11.3	12.5	14.5	18.0	21.5
600	138.8	142.6	150.1	157.8	173.0	188.8	202.1	8.6	9.3	10.5	11.8	14.3	17.2	20.0
500	131.5	136.4	144.7	156.9	171.1	182.3	191.7	7.5	8.3	9.7	11.6	13.9	15.9	18.0
400	124.1	130.9	141.2	154.7	164.1	171.9	178.7	6.5	7.6	9.2	11.2	12.7	14.1	15.6
300	117.6	126.8	138.3	146.3	152.7	157.8	162.9	5.7	7.1	8.7	9.9	10.9	11.8	12.9
200	112.9	121.7	128.5	132.9	136.7	140.6	144.1	5.2	6.4	7.3	7.9	8.5	9.2	9.9
100	105.4	110.0	112.5	115.1	117.6	120.0	122.1	4.2	4.8	5.1	5.5	5.9	6.3	6.7

Table 15. Results from EPIC Simulation of Irrigated Corn Yields and Irrigation Rates Using a Subsurface Drip System on a 150 acre field

	Yields (bushels/acre)							Gross Irrigation (acre-inches)						
	Stress Levels							Stress Levels						
GPM	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**	**0.30**	**0.4**	**0.50**	**0.6**	**0.70**	**0.8**	**0.90**
800	146.5	150.6	156.0	163.3	174.6	194.8	211.3	9.7	10.4	11.3	12.6	14.5	18.1	21.6
700	140.1	143.8	151.2	159.1	174.7	190.6	204.1	8.7	9.3	10.6	11.9	14.4	17.3	20.1
600	132.8	137.8	146.3	158.6	172.8	184.3	140.1	7.6	8.4	9.8	11.7	14.0	16.0	8.7
500	125.5	132.3	143.0	156.7	166.3	174.2	181.1	6.6	7.6	9.3	11.2	12.8	14.2	15.7
400	119.4	128.8	140.5	148.6	155.1	160.4	165.6	5.8	7.1	8.8	9.9	10.9	11.9	13.0
300	115.1	124.0	131.0	135.5	139.3	143.4	147.0	5.2	6.4	7.4	8.0	8.6	9.3	10.0
200	107.8	112.5	115.1	117.7	120.4	122.8	125.0	4.2	4.8	5.2	5.6	6.0	6.3	6.8
100	93.9	94.7	96.1	97.4	98.6	99.7	100.8	2.4	2.5	2.7	2.9	3.1	3.2	3.4

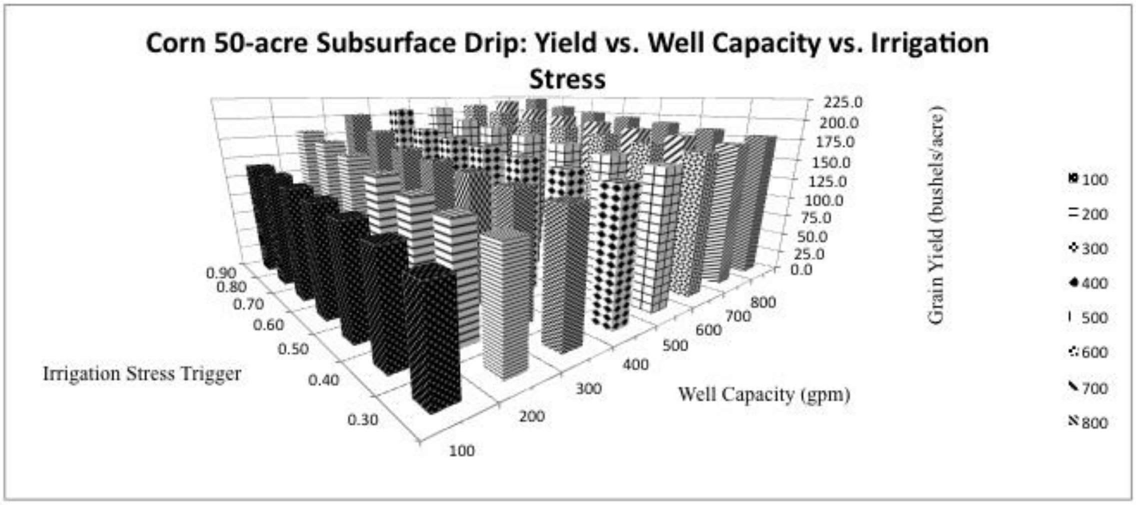


Figure 17. Results from EPIC Corn Subsurface Simulation showing Yields and Irrigation along the Well Capacity for a 50 Acre Field

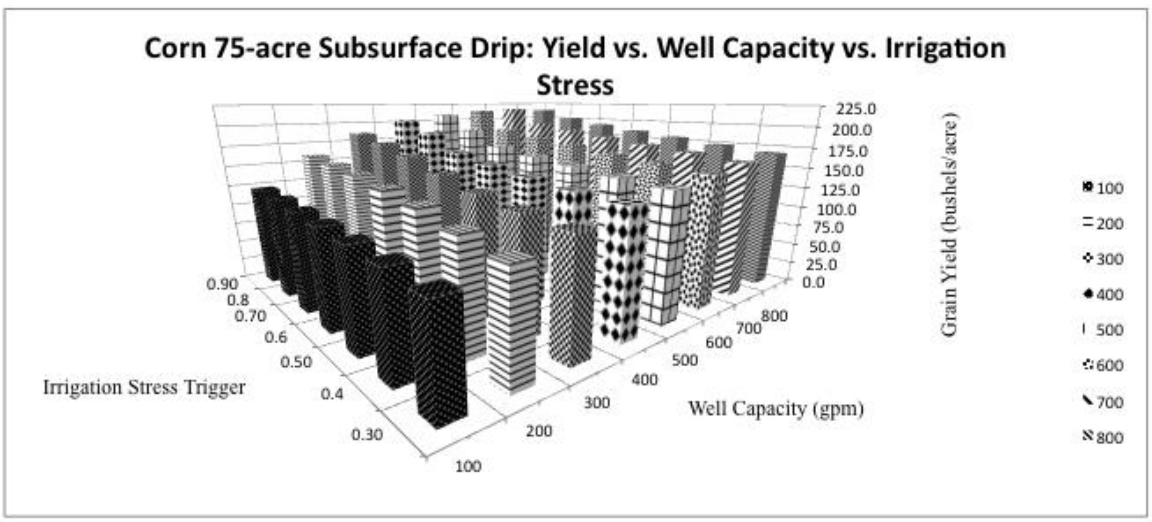


Figure 18. Results from EPIC Corn Subsurface Simulation showing Yields and Irrigation along the Well Capacity for a 75 Acre Field

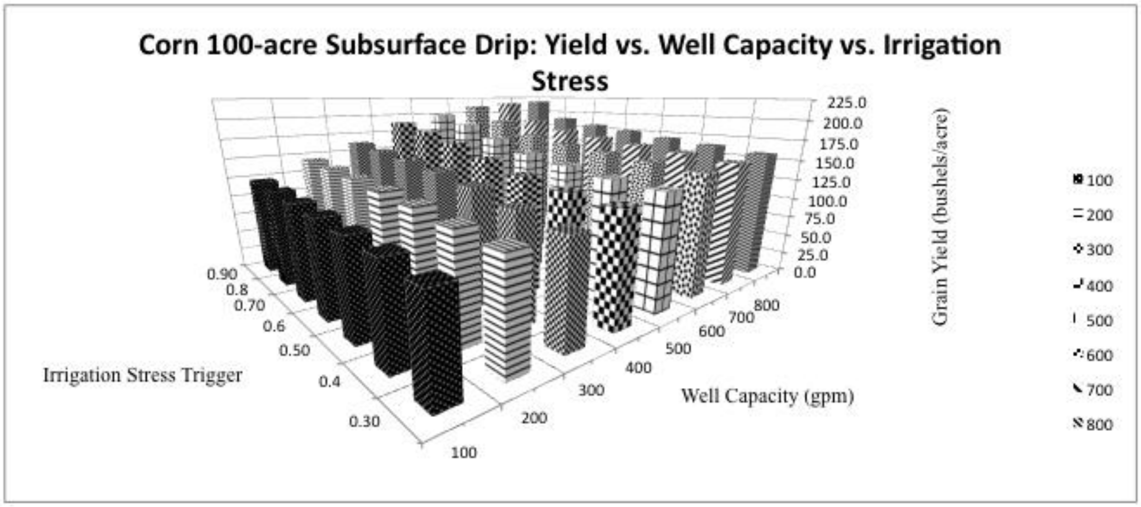


Figure 19. Simulated Yields Results from EPIC Corn Subsurface Simulation showing Yields and Irrigation along with the Well Capacity for a 100 Acre Field

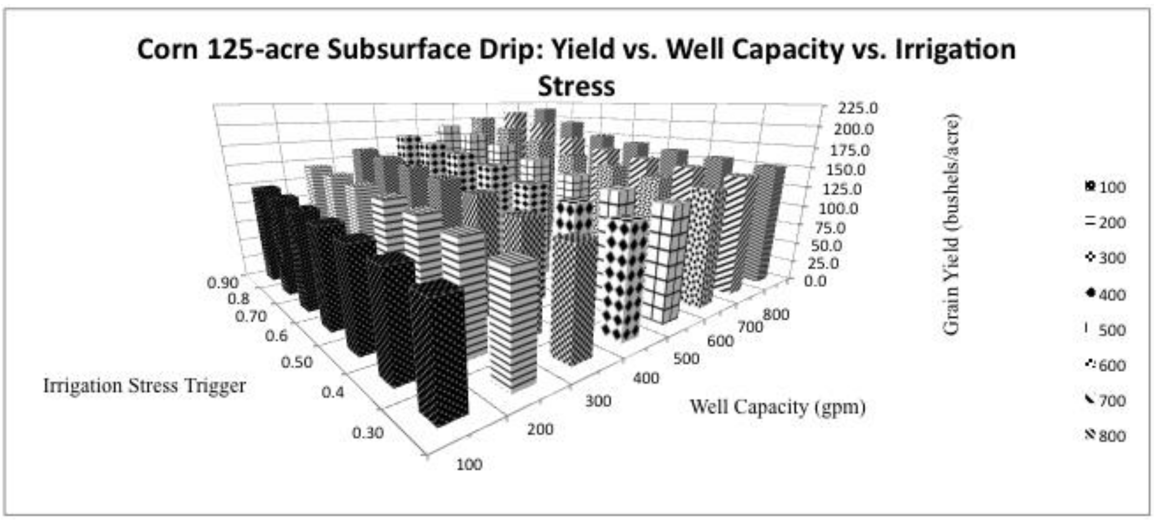


Figure 20. Results from EPIC Corn Subsurface Simulation showing Yields and Irrigation along the Well Capacity for a 125 Acre Field

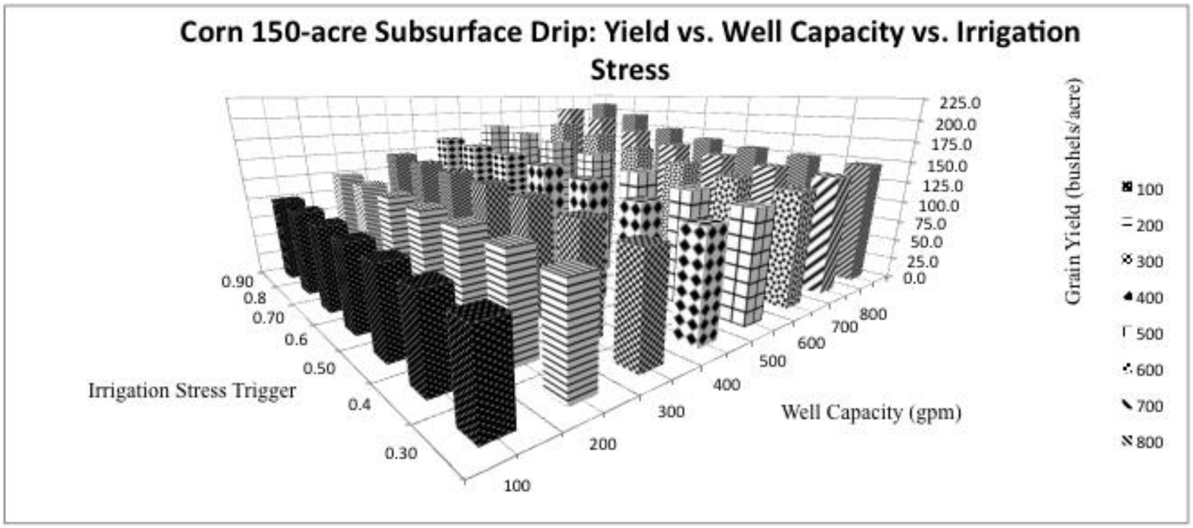


Figure 21. Results from EPIC Corn Subsurface Simulation showing yields and Irrigation along the Well Capacity for a 150 Acre Field.

Static Budget Analysis

Pumping Cost:

Pumping cost for the case of a producer with a single 160 quarter section field with a 120 acre pivot irrigation system were based on the diagram in Figure 22. The well was assumed located outside the irrigated area.

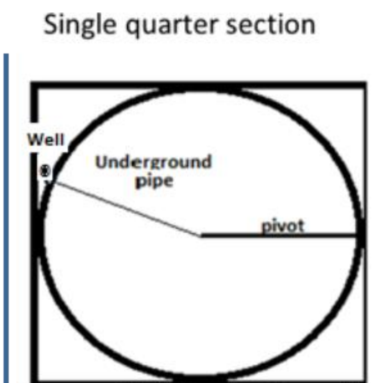


Figure 22. Illustration of a Single One-fourth Section with a 120 acre pivot

It was assumed the maximum well capacity would be 800 GPM and that with 10 feet of drawn down per 100 GPM, the bowl height would be 5 feet, and the top of the safety zone would be 35 feet above the pump bowls. The static water table would be 140 feet above the base of

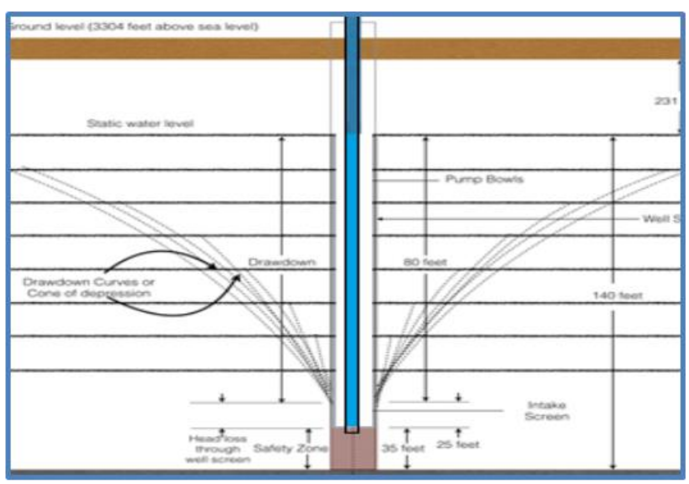


Figure 23. Illustration of well depth and water table level used in Pumping Cost Calculations

the aquifer. The land surface was assumed to be 200 feet above the 800 GPM water table.

Pumping cost calculations were based on the assumption of natural gas at $6 per thousand MCF. Pump efficiency was assumed to be 70 percent, the motor efficiency 17.7 percent, and the drive efficiency was 95 percent. The overall efficiency was 11.8 percent. The pressure at the pivot head was 35 PSI.

The cost of pumping an acre foot of water from each of the well sizes used in the Center Pivot Analysis are shown below in Table 15. It should be noted that because the bottom of the pumping draw down cone is always at the maximium depth (top of the safety zone), that the power required and cost decreases slightly as well capacity declines. This is because the total pumping height does not change. As the water table declines, the depth of the drawdown cone declines to match the increased height above the static water table. The water horse power (WHP) requirements decline with the water table because the volume of water being pumped each minute declines with the water table.

Table 16. Parameters used to Estimate the Cost of Pumping an Acre Foot of Water by Well Size for the Center Pivot Irrigation System.

Parameters and Pumping Costs used for Center Pivot							
800 GPM Well			700 GPM Well			600 GPM Well	
L8 S.W.T (ft)	200		L7 S.W.T. (ft)	210		L6 S.W.T. (ft)	220
Tot. Head (ft)	390		Tot. Head (ft)	381		Tot. Head (ft)	376
WHP	79		WHP	67		WHP	57
Cost/af	$ 69.46		Cost/af	$ 67.86		Cost/af	$ 66.97
500 GPM Well			400 GPM Well			300 GPM Well	
L5 S.W.T. (ft)	230		L4 S.W.T. (ft)	240		L3 S.W.T. (ft)	250
Tot. Head (ft)	372		Tot. Head (ft)	368		Tot. Head (ft)	365
WHP	47		WHP	37		WHP	28
Cost/af	$ 66.21		Cost/af	$ 65.53		Cost/af	$ 65.02
200 GPM Well			100 GPM Well				
L5 S.W.T. (ft)	260		L5 S.W.T. (ft)	270			
Tot. Head (ft)	363		Tot. Head (ft)	362			
WHP	18		WHP	9			
Cost/af	$ 64.71		Cost/af	$ 64.24			

Abbreviations used: S.W.T. is static water table, Tot. head is total dynamic head in feet, af is acre foot, WHP is water horse power.

Effect of System Choice on Pumping Cost and Annual Fixed Cost:

The first step in the economic analysis is the construction of standard static enterprise budgets for irrigated corn and sorghum with center pivot and subsurface drip irrigation. Static budgets are quite common but can also be deceiving in dynamic situations. In this study, the water table and well capacity are declining over time. Tables 17 and 18 provide estimates of returns over irrigation fixed costs for grain sorghum under CP and SDI. Similarly, Tables 19 and 20 provide estimates of returns over irrigation fixed costs for corn under CP and SDI. The budgets are based on the simulated crop yields and water use. The requirements for nitrogen and phosphorus are also given by the simulation model. The budgets assume the irrigation trigger is .9 or that the producer is essentially practicing full irrigation. The pivot and subsurface drip irrigation budgets are most closely comparable at the 120-125 acre sizes. At this size, the CP shows slightly lower profits per acre with the four dollar feed grain prices.

Table 17. Estimated Net Revenue over Variable Cost for Grain Sorghum Irrigated by Central Pivot when Irrigation Occurs with a 10 Percent or Greater Moisture Deficit by Well Capacity for a 120 Acre Pivot

Well Capacity	GPM	800	700	600	500	400	300	200	100
Yield	bu/ac	162.8	155.7	148.4	141.1	133.8	117.2	92.0	88.5
Nitrogen	lbs/ac	181.6	173.6	165.5	157.3	149.2	130.7	102.5	98.7
Phosphorous	lbs/ac	29.4	28.1	26.8	25.4	24.1	21.1	16.6	16.0
Irrigation	acre-inch	15.6	14.1	12.6	11.3	10.4	8.3	4.1	2.8
Net Revenue ($4.16/bu)	$	677.4	647.7	617.3	586.8	556.5	487.6	382.6	368.2
Fertilizer-Nitrogen	$	99.9	95.5	91.0	86.5	82.0	71.9	56.4	54.3
Fertilizer-Phosphorous	$	15.3	14.6	13.9	13.2	12.5	11.0	8.6	8.3
Seed Cost	$	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Herbicide Cost	$	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4
Insecticide Cost	$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crop Consulting	$	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Drying	$	21.2	20.2	19.3	18.3	17.4	15.2	12.0	11.5
Miscelleneous	$	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Custom Hire	$	132.5	129.4	126.2	122.9	119.7	112.5	101.3	99.8
Non Machinery Labor	$	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Interest	$	15.7	15.1	14.4	13.8	13.1	11.7	9.5	9.2
Irrigation Cost	$	90.4	79.8	70.3	62.6	56.8	44.9	21.9	14.8
Sub Total	$	477.7	457.3	437.9	420.1	404.4	369.9	312.5	300.7
Crop Insurance	$	22.9	22.0	21.0	20.2	19.4	17.8	15.0	14.4
Total Varible Cost	$	500.6	479.3	458.9	440.3	423.8	387.7	327.5	315.1
Net Revenue-Var Cost	$	176.8	168.4	158.4	146.5	132.7	100.0	55.1	53.1
Annual System Cost[a]	$	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Net Ret-system Cost	$	131.8	123.5	113.4	101.6	87.7	55.0	10.2	8.1

[a] Initial system cost of $60,000 over 15 years at four percent.

Table 18. Estimated net revenue over Irrigation Cost for Grain Sorghum Irrigated by Subsurface Drip if Irrigation Occurs with a Ten Percent or Greater Moisture Deficit by Well Capacity for a 125 Acre Field.

GPM		800	700	600	500	400	300	200	100
Yield (bu/acre)		166.6	164.5	161.0	155.2	147.0	135.4	96.6	93.0
N (lbs/a)		185.7	183.4	179.5	173.0	163.9	151.0	107.7	103.7
P (lbs/a)		30.0	29.7	29.0	28.0	26.5	24.4	17.4	16.8
Irrigation (inches)		12.7	12.1	11.4	10.3	9.0	7.6	2.9	2.1
Net Revenue ($4.48/bu)	$	693.0	684.3	669.7	645.4	611.6	563.3	401.9	387.0
Fertilizer-nitrogen	$	102.2	100.9	98.7	95.2	90.2	83.1	59.2	57.0
Fertilizer-phosphorus	$	15.6	15.4	15.1	14.6	13.8	12.7	9.1	8.7
Seed cost	$	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
herbicide Cost	$	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4
Insecticide Cost	$	-	-	-	-	-	-	-	-
Crop Consulting	$	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Drying	$	21.7	21.4	20.9	20.2	19.1	17.6	12.6	12.1
Miscellaneous	$	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Custom Hire	$	134.2	133.3	131.7	129.2	125.6	120.5	103.4	101.8
Non Machinery Labor	$	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Interest	$	16.0	15.8	15.5	15.0	14.3	13.3	9.9	9.6
Irrigation Cost	$	66.7	62.3	57.6	51.6	44.7	30.7	14.2	10.1
Sub Total ($)	$	459.1	389.5	384.7	376.8	365.7	349.9	296.9	292.0
Crop Insurance	$	22.0	18.7	18.5	18.1	17.6	16.8	14.3	14.0
Total Variable Cost	$	481.1	473.6	463.6	449.0	430.1	398.9	326.0	316.6
Net Returns - Var. Cost	$	211.9	210.7	206.1	196.4	181.5	164.5	75.9	70.5
Annual System Cost* $/a	$	65.3	65.3	65.3	65.3	65.3	65.3	65.3	65.3
Net Returns - Syst. Cost	$	146.6	145.5	140.8	131.2	116.3	99.2	10.6	5.2

[a] Annual cost for 125 acre subsurface drip system costing 90,700 for a 125 acre field over 15 years at four percent interest.

Table 19. Detailed Costs and Returns for Center Pivot irrigated Corn by Well Capacity when irrigation occurs when the soil moisture depletion is 10 percent of capacity or less.

GPM		800	700	600	500	400	300	200	100
Yield	bu/ac	213.41	198.86	186.90	174.99	164.37	142.64	122.23	99.08
N	lbs/ac	196.8	183.0	171.9	160.9	151.0	130.9	112.1	90.9
P	lbs/ac	28.5	26.5	25.0	23.4	21.9	19.0	16.3	13.2
Irrigation (inches)	acre-inch	22.5	23.1	21.6	19.5	17.6	13.9	10.3	6.1
Net Revenue ($4.48/bu)	$	956.1	890.9	837.3	784.0	736.4	639.0	547.6	443.9
Fertilizer-Nitrogen	$	108.2	100.7	94.6	88.5	83.0	72.0	61.7	50.0
Fertilizer-Phosphorous	$	14.8	13.8	13.0	12.1	11.4	9.9	8.5	6.9
Seed Cost	$	112.6	112.6	112.6	112.6	112.6	112.6	112.6	112.6
Herbicide Cost	$	61.0	61.0	61.0	61.0	61.0	61.0	61.0	61.0
Insecticide Cost	$	16.0	15.7	15.5	15.2	15.0	14.6	14.1	13.6
Crop Consulting	$	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Drying	$	27.7	25.9	24.3	22.7	21.4	18.5	15.9	12.9
Miscelleneous	$	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Custom Hire	$	161.5	155.1	149.9	144.7	140.0	130.5	121.5	111.4
Non Machinery Labor	$	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Interest	$	20.0	19.0	18.1	17.3	16.5	14.9	13.4	11.8
Irrigation Cost	$	130.0	130.5	120.4	107.4	96.1	75.3	55.5	32.7
Sub Total	$	686.5	668.8	643.9	616.0	591.6	543.8	498.8	447.4
Crop Insurance	$	33.0	32.1	30.9	29.6	28.4	26.1	23.9	21.5
Total Varible Cost	$	719.4	700.9	674.8	645.6	620.0	569.9	522.7	468.8
Net Returns-Var Cost	$	236.6	190.0	162.5	138.4	116.4	69.1	24.9	-25.0
Annual System Cost[a]	$	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Net Ret-system Cost	$	191.7	145.0	117.6	93.4	71.4	24.2	-20.1	-69.9

a Initial system cost of $60,000 over 15 years at four percent.

Table 20. Costs and Returns over Irrigation Costs for Subsurface Drip Irrigated Corn by Well Capacity on a 125 Acre Field if Irrigation Occurs when Soil Moisture is 10 Percent of Capacity or Less.

GPM		800	700	600	500	400	300	200	100
Yield (bu/acre)		214.9	209.8	202.1	191.7	178.7	162.9	144.1	122.1
N (lbs/a)		204.4	199.5	192.1	191.7	169.6	154.6	136.6	115.8
P (lbs/a)		29.5	28.8	27.7	26.3	24.5	22.3	19.7	16.7
Irrigation (inches)		22.6	21.5	20.0	18.0	15.6	12.9	9.9	6.7
Net Revenue ($4.48/bu)	$	962.9	939.9	905.5	859.0	800.5	729.8	645.4	547.2
Fertilizer-nitrogen	$	112.4	109.7	105.6	105.5	93.3	85.0	75.1	63.7
Fertilizer-phosphorus	$	15.3	15.0	14.4	13.7	12.7	11.6	10.3	8.7
Seed cost	$	112.6	112.6	112.6	112.6	112.6	112.6	112.6	112.6
herbicide Cost	$	61.0	61.0	61.0	61.0	61.0	61.0	61.0	61.0
Insecticide Cost	$	16.1	16.0	15.8	15.6	15.3	15.0	14.6	14.1
Crop Consulting	$	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Drying	$	27.9	27.3	26.3	24.9	23.2	21.2	18.7	15.9
Miscellaneous	$	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Custom Hire	$	162.2	159.9	156.6	152.0	146.3	139.4	131.1	121.5
Non Machinery Labor	$	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Interest	$	20.1	19.8	19.2	18.5	17.5	16.4	15.0	13.4
Irrigation Cost	$	119.1	110.6	101.4	90.0	77.1	52.3	48.0	32.3
Sub Total ($)	$	681.3	666.3	647.4	628.2	593.6	548.9	521.0	477.7
Crop Insurance	$	32.7	32.0	31.1	30.2	28.5	26.4	25.0	22.9
Total Variable Cost	$	714.0	698.3	678.5	658.4	622.1	575.3	546.0	500.7
Net Returns - Var. Cost	$	248.9	241.6	227.0	200.6	178.4	154.5	99.4	46.6
Annual System Cost*	$	65.3	65.3	65.3	65.3	65.3	65.3	65.3	65.3
Net Returns - Syst. Cost	$	183.7	176.4	161.8	135.3	113.1	89.3	34.2	-18.7

a Annual cost for an SDI system for a 125 acre field with initial cost of $90,700 over 15 years at four percent interest.

Crop and Irrigation Choices with Limited Groundwater Supplies

Two long term scenarios are examined in this analysis. The first is when the producer makes a series of "Best Single Year Choices" (BSYC). The second is when the producer makes a series of choices that "Maximize the Net Present Value" of returns (MNPV) over the life of a limited resource. The major objective of this research was to determine how producers could gain the maximum value from the remaining water supply. One factor affecting the value of the remaining water supply is the objective of the producers. Researchers have long known that optimal long term rates, MNPV of extracting a non-renewable resource differ from that which would be received by a series of BSYC annual rates of extraction. Analysis of the difference in expected returns from following a BSYC VS. a MNVP path are examined below.

Annual net crop returns over fixed costs are presented in an enterprise budget for a representative acre. The budget represents returns to land which is usually the producer's most limiting resource. Other choices may be made when labor or capital are limiting. This is also true when groundwater resources are limiting. The BSYC case is followed by always selecting the crop that has the highest single year return per acre. In the budget tables listed above, irrigated corn (if the producer's well supplies 500 GPM or more per quarter section), provides higher net returns over variable costs than grain sorghum. Under high feed grain prices, the annual profit advantage of corn over sorghum is even more pronounced than in the budgets shown in Tables 17 to 20 above. However the fact that corn requires more groundwater than sorghum, has long-term implications that may easily be overlooked when making a crop choice based only on expected one-year returns.

> Consider a producer who has one quarter section with one 600 GPM irrigation well. We assume that to continue irrigation, the producer must purchase a new pivot that will irrigate 120 acres at a cost of $60,000. The producer will choose between irrigated corn and grain sorghum based on the data shown above in Tables 17 and 19. Based on annual profits (Table 19), with a 600 GPM well, irrigated corn yielding approximately 187 bushels per acre provides the highest expected net return over variable cost at $165 per acre. The net return for the 160 acre field would be $20,443. An acre of irrigated corn is expected to require 1.79 acre feet of groundwater. The 120 acre field would use approximately 215 acre feet of ground water per year.

The results depend on the availability of groundwater to the producer's well. A 600 GPM well would mean the producer has about 60 feet of water saturated sand above a safety zone 35 feet above the aquifer base and pump bowls. The output of the well would decline about 100 GPM for each 10 feet of decline in water saturated sand. For this example, assume the producer has 1,680 acre feet of groundwater that can be extracted or about 280 acre feet in each 10 foot layer of saturated sand. This example represents the case for a producer with a single quarter section that is surrounded by irrigated fields so that the producer has access only to the water that underlies the 160 acre parcel.

Table 21 shows that the 15 year returns for the MNPV strategy begin to exceed annual returns from the BSYC strategy by year 3 and Cumulative NPV (at four percent) after year 6. The Cumulative 15 year NPV for the BSYC is $69,959 as compared to the $100,681 for the MNPV strategy.

One reason for the lower eventual returns from the BSYC strategy is that the initial choice of irrigated corn draws down the aquifer at a faster rate (Figure 24, upper left). The returns from the MNPV strategy eventually begin to exceed returns from BSYC strategy because the higher groundwater level reduced pumping cost. The BYSC producer produces nearly three years of irrigated corn which draws down the aquifer. In contrast, the MNPV producer begins with stressed (IrT is .6) irrigated sorghum and uses less water per acre. The MNPV producer is still obtaining 300 GPM from the well by year 13 whereas the BYSC producer is pumping from the 100 GPM level of the aquifer.

The BSYC was also compared with the MNPV strategy on a 640 acre field (section) where the available water supply (6,720 acre feet) was limited to that under the producer's field and where the producer had twice the water supply (13,440 acre feet). Center pivot irrigation was assumed in this analysis. The results shown in Figures 25 and 26 below again indicate the MNPV strategy yields the higher cumulative NPV in all of the situations.

Table 21. Importance of Considering Long-Returns from Crop Choice of Irrigated Corn or Grain Sorghum when Initial Groundwater Supplies are 1680 Acre Feet

BSYC Qt. Section Pivot Irrigation								MNPV Qt. Section Pivot Irrigation							
Year	Crop, Irt	Well GPM	Ir Yield	Dac	Net Ret.	Cumulative NPV	GW (aft)	Year	Crop, Irt	Well GPM	Ir Yield	Dac	Net Ret.	Cumulative NPV	GW (aft)
1	C, .9	600	187	20	20422	$ (40,363)	1464	1	S, .6	600	120	40	17760	$ (42,923)	1595
2	C, .9	500	187	20	18334	$ (23,413)	1263	2	S, .6	600	120	40	17760	$ (26,503)	1511
3	C,.9,S.9	400	182	20	17005	$ (8,295)	1090	3	S, .6	600	120	40	17760	$ (10,714)	1426
4	S, .9	400	133	20	15767	$ 5,182	975	4	S, .6	500	120	40	16732	$ 3,589	1341
5	S, .9	400	133	20	15767	$ 18,142	860	5	S, .6	500	120	40	16320	$ 17,002	1256
6	S, .9	300	94	20	12239	$ 27,814	759	6	S, .6	500	120	40	16320	$ 29,900	1172
7	S, .9	200	89	20	11506	$ 36,558	662	7	S, .6	400	120	40	15654	$ 41,796	1087
8	S, .9	200	89	20	11506	$ 44,966	564	8	S, .6	400	120	40	14760	$ 52,581	1003
9	S, .4	200	89	20	5894	$ 49,106	522	9	S, .6	400	120	40	14760	$ 62,951	918
10	S, .4	200	89	20	5662	$ 52,931	482	10	S, .6	300	120	40	14377	$ 72,663	835
11	S, .4	100	88	20	5662	$ 56,609	442	11	S, .6	300	120	40	10680	$ 79,601	758
12	S, .4	100	88	20	5662	$ 60,145	402	12	S, .6	300	120	40	10680	$ 86,272	682
13	S, .4	100	88	20	5662	$ 63,545	362	13	S, .6	300	120	40	10680	$ 92,686	605
14	S, .4	100	88	20	5662	$ 66,815	322	14	S, .5	200	120	40	8422	$ 97,549	545
15	S, .4	100	88	20	5662	$ 69,959	282	15	S, .5	200	120	40	5640	$100,681	504

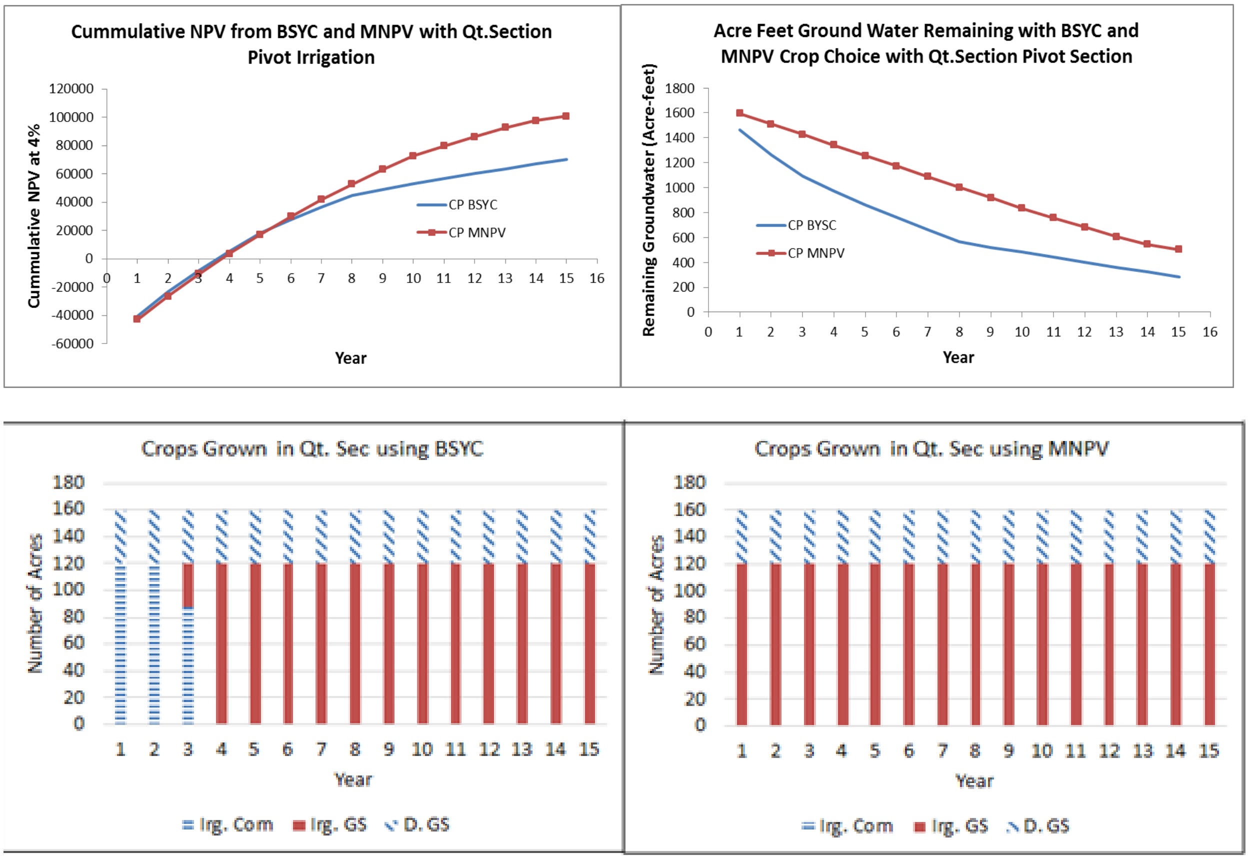

Cummulative NPV from BSYC and MNPV with Qt.Section Pivot Irrigation
Cummulative NPV at 4%
Year
CP BSYC
CP MNPV
Acre Feet Ground Water Remaining with BSYC and MNPV Crop Choice with Qt.Section Pivot Section
Remaining Groundwater (Acre-feet)
Year
CP BYSC
CP MNPV
Crops Grown in Qt. Sec using BSYC
Number of Acres
Year
Irg. Com
Irg. GS
D. GS
Crops Grown in Qt. Sec using MNPV
Number of Acres
Year
Irg. Com
Irg. GS
D. GS

Figure 24. BSYC and MNPV strategies from a 120 Acre Pivot with Limited Groundwater.

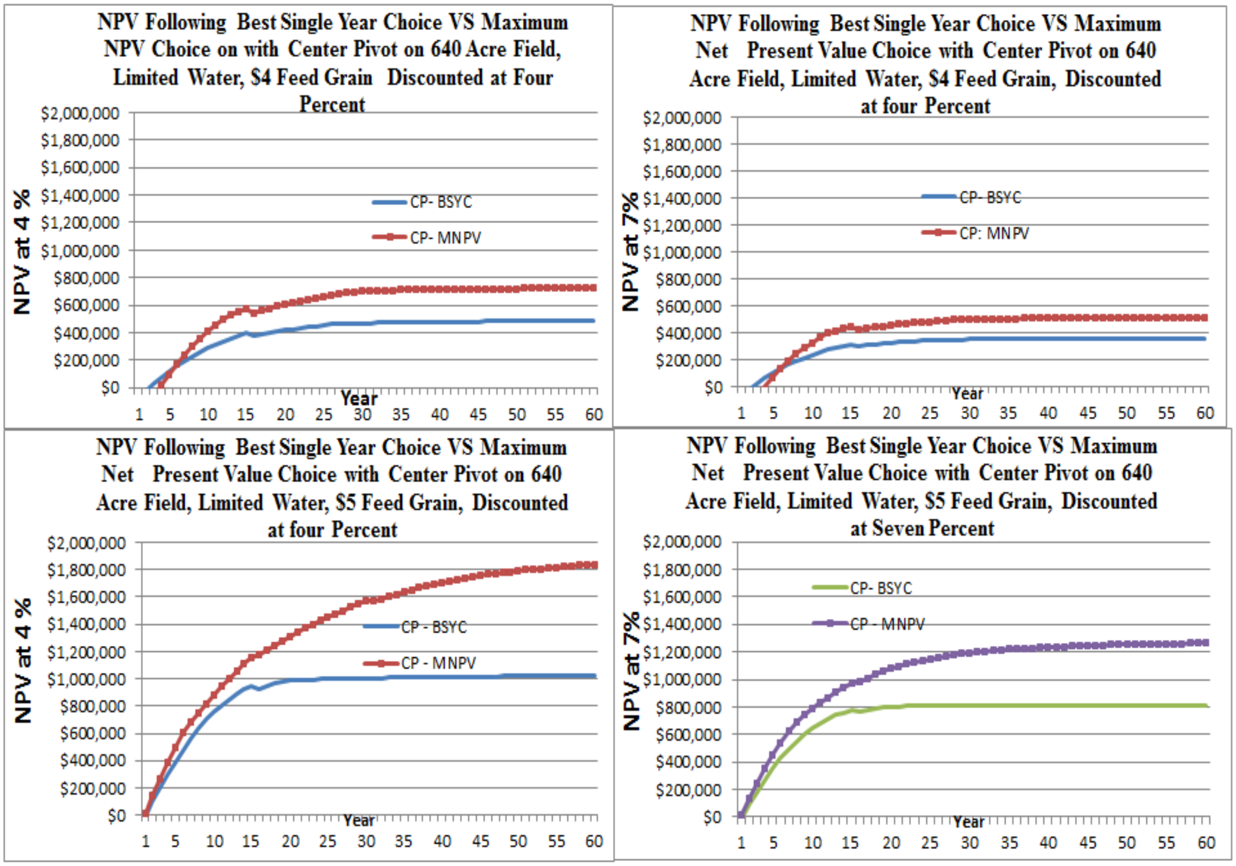


Figure 25. Comparison of BSYC VS MNPV Paths on Cumulative NPV from 640 Acre Field with a CP system with 6720 Acre Feet, Four and Five Dollar Feed Grain, Discounted at Four and Seven Percent

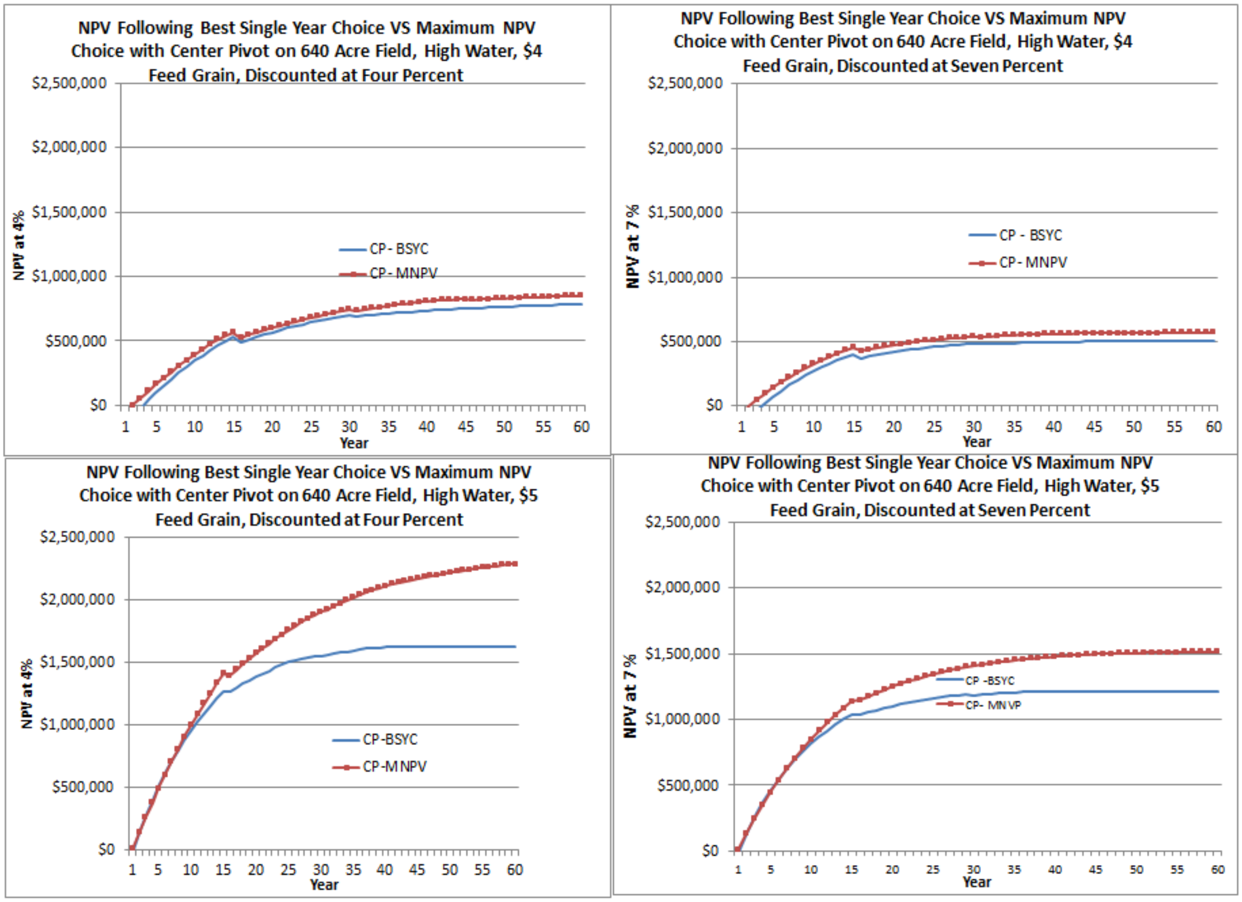


Figure 26. Comparison of BSYC VS MNPV Paths on Cumulative NPV from 640 Acre Field with a CP system with 13,440 Acre Feet, Four and Five Dollar Feed Grain, Discounted at Four and Seven Percent

Determination of Maximum Net Present Value for Center Pivot and Sub Surface Drip Systems

The MNPV optimal investment and groundwater use paths are compared over a 30 year planning horizon for the 160 acre field and over a 60 year planning horizon for the 640 acre field. Two initial water supplies are considered for the 640 acre field. The sensitivity of discounted returns and economic length of irrigation for the SDI and CP were compared with two crop prices for producers with a quarter section of land and with a full section of land. The returns for a producer with 160 acres of land and 60 feet of water saturated sand were estimated with SDI and CP over a 30 year period. For the quarter section case, it was assumed that 100 percent of the surrounding land was irrigated. Then, returns were estimated for producers with a 640 acre section of land with 60 feet of water saturated sand over a 60 year period. Two water supply cases were considered. In one case, it was assumed 100 percent of the surrounding land was irrigated and in the second case that only 50 percent of the surrounding land was irrigated. The 60 year period was used for the 640 acre producer because it was desirable to test whether the producer would leave one or more quarters unirrigated but would increase the supply of water to the irrigated portion by drawing water from all four wells.

One size of CP system was considered while five alternative sizes of SDI systems were budgeted. The irrigation system costs used for the CP and SDI systems were,

CP Acres	CP Cost	SDI Acres	SDI Cost
120	$60,000	50	$ 43,000
		75	$ 58,000
		100	$ 74,300
		125	$ 90,700
		150	$ 107,000.

The feed grain prices used were,

	Four Dollar Feed Grain	Five Dollar Feed Grain
Corn	$4.48/bus	$5.48/bus
Grain Sorghum	$4.16/bus	$5.09/bus.

MNPV Quarter Section Results with Pivot Irrigation and Sub Surface Drip Irrigation

This part of the analysis compares producer returns from CP and SDI systems. Each system is assumed to have a 15 year life. The initial cost of the center pivot is $60,000. The five sizes of SDI systems range from 50 to 150 acres in 25 acre increments. The planning horizon is 30 years and it was assumed the producer has only 60 feet of water saturated sand underlying the 160 acre parcel. Based on the specific yield of .175, (USGS, 2012) for much of Texas County, it is assumed the producer has 1,680 acre feet of ground water that can be extracted from under the 160 acre field. The results are examined under two feed grain prices and two discount rates.

The optimal results were determined by solving a MIP model for each type of system with GAMS-CPLEX. The subheadings below are in the form of System (acres, Feed Grain Price, Discount Rate) and are used indicate which system and parameters are being discussed.

CP(160a, $4, 4%) The left side of Table 22 compares the NPV and water use over a 30 year period with the four dollar feed grain prices (Corn price = $4.48/bus, GS price = $4.16/bus.) with a four percent discount rate. If the producer chose the pivot system, the results indicate the crop choice would be GS (not corn) for the first 15 years and then the 160 acres would be converted to dryland with 504 acre feet of groundwater remaining. The optimal solution has the CP producer irrigating GS with some stress (irrigate when the IrT is .6 or less). The 30-year NPV from both irrigated and dry GS production over the 30 year period is $106,607.

Figure 27 compares the NPV from the quarter section CP and SDI investments under the four dollar feed grain prices (Corn price = $4.48/bus, GS price = $4.16/bus.) with four and seven percent discount rates and under the five dollar feed grain prices (Corn price = $5.48, GS price=$5.09) discounted at four and seven percent. As shown in Figure 27, the SDI system always had the higher NPV.

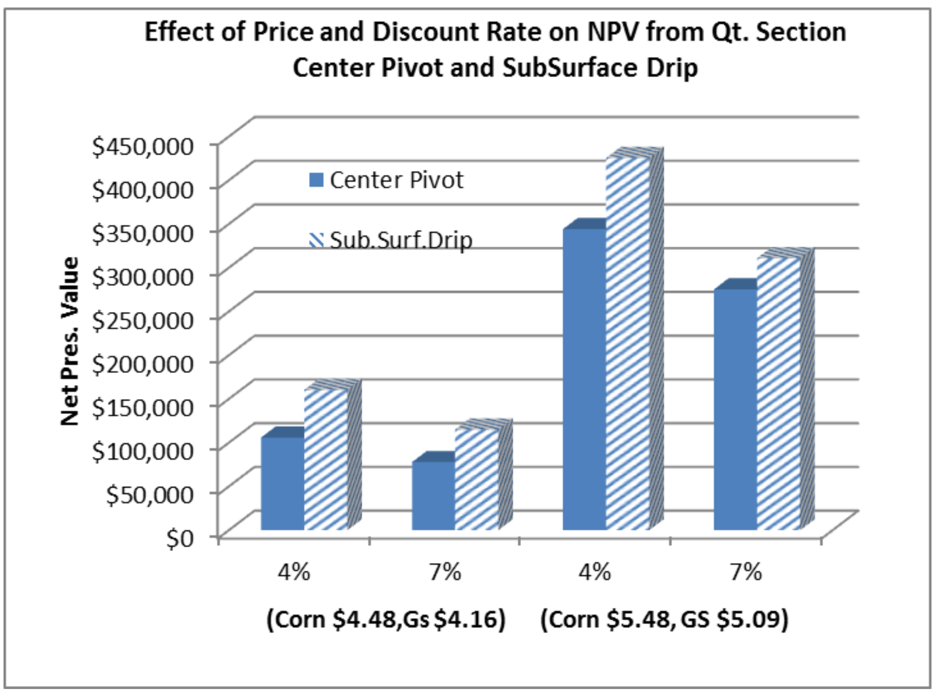


Figure 27. NPV of Center Pivot and Sub Surface Drip Systems with Feed Grain Prices at Four Dollars/bushel and Five Dollars/bushel when Discounted at Four and Seven Percent Interest

SDI(160a, $4, 4%) The right side of Table 22 presents the NPV and optimal groundwater use from an SDI system. The results indicate that for the first 15 years, the 125 acre SDI would be used which would be followed by a smaller 50 acre SDI system for years 16-30. During the first 15 years, it fully irrigated GS (irrigation initiated when soil moisture reaches the .9 level or less). The SDI system used slightly more water during the first 15 years (1,194 VS 1176 remaining) than did the CP. During years 16-21, with the smaller 50 acre SDI, water becomes relatively less limiting than the irrigated area and irrigated corn is produced. In years 22-30, the producer switches back to fully irrigated GS. The 1,680 acre feet of groundwater is exhausted by year 30. The NPV from the SDI system plus dryland GS production is estimated to be $160,861 or 50 percent higher than for the CP system.

CP(160a, $4, 7%) Table 23 (left side) shows effects of the higher discount rate on 30-year CP are shown in Table 23 with the same feed grain prices as in Table 22. In the case of the single quarter section producer with 1,680 acre feet of groundwater, the increase in the interest rate from four to seven percent did not affect either the level of investment or the rate of groundwater use. It was still optimal for the CP producer to buy a pivot only for the first 15 years.

SDI(160a, $4, 7%) For the SDI producer, (Table 23, right side), the optimal size was still 125 acres for the first 15 years and 50 acres for the second 15 years. The NPV for both systems were greatly reduced (NPV CP = $78,286 VS NPV SDI= $115,296). The NPV of the SDI system over the NPV of the CP system was reduced to 47 percent and the SDI has higher capital costs and is more sensitive to higher discount rates.

Table 22. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 160 Acres in Texas County when Corn price is $4.48 and the Grain Sorghum Price is $4.16 per Bushel and the Discount Rate is Four Percent

	Center Pivot Irrigation							Subsurface Drip Irrigation						
Year	Crop, IrT[a]	Yield bus	Irrig. Acres	Dry Acres	160acre Net.Rev.	Cumulative NPV $	GW(aft) 1680	Crop, IrT	Yield Bus	Irrig. Acres	Dry Acres	160 acre Net Rev.	Cumulative NPV $	GW(aft) 1680
1	S, .6	134	120	40	$17,760	$ (42,923)	1595	S, .9	155	125	35	$ 26,210	$(65,498)	1572
2	S, .6	134	120	40	$17,760	$ (26,503)	1511	S, .9	155	125	35	$ 26,210	$(41,265)	1465
3	S, .6	134	120	40	$17,760	$ (10,714)	1426	S, .9	160	125	35	$ 26,259	$(17,921)	1353
4	S, .6	132	120	40	$16,732	$ 3,589	1341	S, .9	147	125	35	$ 26,335	$ 4,590	1234
5	S, .6	130	120	40	$16,320	$ 17,002	1256	S, .9	147	125	35	$ 26,223	$ 26,143	1117
6	S, .6	130	120	40	$16,320	$ 29,900	1172	S, .9	147	125	35	$ 23,335	$ 44,585	1023
7	S, .6	128	120	40	$15,654	$ 41,796	1087	S, .9	141	125	35	$ 23,335	$ 62,318	929
8	S, .6	124	120	40	$14,760	$ 52,581	1003	S, .9	134	125	35	$ 23,170	$ 79,248	836
9	S, .6	124	120	40	$14,760	$ 62,951	918	S, .9	134	125	35	$ 20,085	$ 93,360	757
10	S, .6	124	120	40	$14,377	$ 72,663	835	S, .9	134	125	35	$ 20,085	$ 106,928	679
11	S, .6	105	120	40	$10,680	$ 79,601	758	S, .9	134	125	35	$ 20,085	$ 119,975	600
12	S, .6	87	120	40	$10,680	$ 86,272	682	S, .9	114	125	35	$ 14,637	$ 129,118	550
13	S, .6	87	120	40	$10,680	$ 92,686	605	S, .9	93	125	35	$ 9,085	$ 134,574	528
14	S, .5	87	120	40	$ 8,422	$ 97,549	545	S, .9	93	125	35	$ 9,085	$ 139,820	507
15	S, .5	87	120	40	$ 5,640	$ 100,681	504	S, .9	93	125	35	$ 9,085	$ 144,865	486
16	-	-	-	160	$ 960	$ 101,193	504	C, .9	182	50	110	$ 9,810	$ 127,144	413
17	-	-	-	160	$ 960	$ 101,686	504	C, .9	182	50	110	$ 9,810	$ 132,181	339
18	-	-	-	160	$ 960	$ 102,160	504	C, .9	161	50	110	$ 9,810	$ 137,023	266
19	-	-	-	160	$ 960	$ 102,616	504	C, .9	141	50	110	$ 9,062	$ 141,324	198
20	-	-	-	160	$ 960	$ 103,054	504	C, .9	141	50	110	$ 5,260	$ 143,725	158
21	-	-	-	160	$ 960	$ 103,475	504	C, .9	141	50	110	$ 5,260	$ 146,033	117
22	-	-	-	160	$ 960	$ 103,880	504	S, .9	96	50	110	$ 4,775	$ 148,048	95
23	-	-	-	160	$ 960	$ 104,270	504	S, .9	96	50	110	$ 4,510	$ 149,878	83
24	-	-	-	160	$ 960	$ 104,644	504	S, .9	96	50	110	$ 4,510	$ 151,637	71
25	-	-	-	160	$ 960	$ 105,004	504	S, .9	96	50	110	$ 4,510	$ 153,329	59
26	-	-	-	160	$ 960	$ 105,351	504	S, .9	96	50	110	$ 4,510	$ 154,956	47
27	-	-	-	160	$ 960	$ 105,684	504	S, .9	96	50	110	$ 4,510	$ 156,520	35
28	-	-	-	160	$ 960	$ 106,004	504	S, .9	96	50	110	$ 4,510	$ 158,024	23
29	-	-	-	160	$ 960	$ 106,311	504	S, .9	96	50	110	$ 4,510	$ 159,470	11
30	-	-	-	160	$ 960	$ 106,607	504	S, .9	96	50	110	$ 4,510	$ 160,861	0

IrT: Irrigation Trigger, Soil Moisture Content to trigger an irrigation

GW(aft): Acre feet of groundwater remaining at end of year

Table 23. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 160 Acres in Texas County when Corn price is $4.48 and the Grain Sorghum Price is $4.16 per Bushel and the Discount Rate is Seven Percent

Year	Center Pivot Irrigation							Sub Surface Drip Irrigation						
	Crop, IrT	Yield bus	Irrig. Acres	Dry Acres	160 acre N.Rev	Cumulative NPV $	GW (aft) 1680	Crop, IrT	Yield bus	Irrig. Acres	Dry Acre	160 acre Net Rev.	Cumulative NPV $	GW (aft) 1680
1	S, .6	134	120	40	$ 17,760	$ (43,402)	1595	S, .9	155	125	35	$26,210	-$66,205	1572
2	S, .6	134	120	40	$ 17,760	$ (27,890)	1511	S, .9	155	125	35	$26,210	-$43,312	1465
3	S, .6	134	120	40	$ 17,760	$ (13,392)	1426	S, .9	160	125	35	$26,259	-$21,876	1353
4	S, .6	132	120	40	$ 16,732	$ (627)	1341	S, .9	160	125	35	$26,335	-$1,785	1234
5	S, .6	130	120	40	$ 16,320	$ 11,009	1256	S, .9	147	125	35	$26,223	$16,911	1117
6	S, .6	130	120	40	$ 16,320	$ 21,884	1172	S, .9	147	125	35	$23,335	$32,460	1023
7	S, .6	128	120	40	$ 15,654	$ 31,632	1087	S, .9	147	125	35	$23,335	$46,992	929
8	S, .6	124	120	40	$ 14,760	$ 40,222	1003	S, .9	147	125	35	$23,170	$60,477	836
9	S, .6	124	120	40	$ 14,760	$ 48,251	918	S, .9	135	125	35	$20,085	$71,402	757
10	S, .6	124	120	40	$ 14,377	$ 55,559	835	S, .9	135	125	35	$20,085	$81,612	679
11	S, .6	105	120	40	$ 10,680	$ 60,633	758	S, .9	135	125	35	$20,085	$91,154	600
12	S, .6	87	120	40	$ 10,680	$ 65,375	682	S, .9	135	125	35	$14,637	$97,653	550
13	S, .6	87	120	40	$ 10,680	$ 69,807	605	S, .9	93	125	35	$9,085	$101,423	528
14	S, .5	87	120	40	$ 8,422	$ 73,073	545	S, .9	93	125	35	$9,085	$104,947	507
15	S, .5	87	120	40	$ 5,640	$ 75,117	504	S, .9	93	125	35	$9,085	$108,240	486
16	-	-	-	160	$ 960	$ 75,443	504	C, .9	182	50	110	$9,810	$96,997	413
17	-	-	-	160	$ 960	$ 75,746	504	C, .9	182	50	110	$9,810	$100,102	339
18	-	-	-	160	$ 960	$ 76,030	504	C, .9	182	50	110	$9,810	$103,005	266
19	-	-	-	160	$ 960	$ 76,296	504	C, .9	182	50	110	$9,062	$105,510	198
20	-	-	-	160	$ 960	$ 76,544	504	C, .9	141	50	110	$5,260	$106,870	158
21	-	-	-	160	$ 960	$ 76,776	504	C, .9	141	50	110	$5,260	$108,140	117
22	-	-	-	160	$ 960	$ 76,993	504	S, .9	141	50	110	$4,775	$109,218	95
23	-	-	-	160	$ 960	$ 77,195	504	S, .9	97	50	110	$4,510	$110,169	83
24	-	-	-	160	$ 960	$ 77,384	504	S, .9	97	50	110	$4,510	$111,058	71
25	-	-	-	160	$ 960	$ 77,561	504	S, .9	97	50	110	$4,510	$111,889	59
26	-	-	-	160	$ 960	$ 77,726	504	S, .9	97	50	110	$4,510	$112,666	47
27	-	-	-	160	$ 960	$ 77,881	504	S, .9	97	50	110	$4,510	$113,392	35
28	-	-	-	160	$ 960	$ 78,025	504	S, .9	97	50	110	$4,510	$114,070	23
29	-	-	-	160	$ 960	$ 78,160	504	S, .9	97	50	110	$4,510	$114,704	11
30	-	-	-	160	$ 960	$ 78,286	504	S, .9	97	50	110	$4,510	$115,296	0

Irt: Irrigation Trigger, moisture level to trigger an irrigation
GW(aft): Acre feet of remaining ground water at end of year

CP(160a, $5, 4%) The optimal 30-year investments (Table 24) and ground water use with the higher feed grain prices (corn price = $5.48/bus, GS price = $5.09/bus) with the discount rate at four percent are shown in Table 24. For the CP choice, the crop selection and rate of groundwater use over the first 15 years increased irrigation intensity slightly in the first 15 years ending with 442 acre feet rather than 540 shown in Table 22. The higher price did make it slightly profitable to purchase a replacement pivot and irrigate 120 acres in years 16-24. The irrigation ended in year 24 when the aquifer was exhausted. The 30 year NPV for the CP system was $344,489.

SDI(160a, $5, 4%) With the higher feed grain price, the SDI systems size was increased to 150 acres for the entire thirty year period. The crop choice is GS except for year 13 when corn was grown. (This is likely an anomaly in the budgets). The initial net revenue over variable costs was $52,100 (with 155 bushel GS) in year 1 and declined to $22,400 (with 88 bushel GS) by year 30. The 30-year cumulative NPV at seven percent reached $436,103 as compared to $344,489 for the above CP example.

CP(160a, $5, 7%) In general an increased discount discourages investments. However in this study, the irrigation investments are a lumpy yes or no choice. In this example, (Table 25), the profitability of the CP investment is reduced but it was still optimal to purchase a 120 acre system for use in years 1-15 and replace the system in year 16. Irrigation continued through 28 years of the 30 year planning horizon. The 30-year cumulative NPV, at a seven percent discount rate, was $260,312.

SDI(160a, $5, 7%) The 150 acre SDI was purchased for the first 15-year period and replaced in year 16 for the 16-30 year period. Intensively irrigated GS was the selected crop except for years 13 and 14. Irrigation continued for the 30 year period. The 30-year cumulative NPV, at a seven percent discount rate, reached $318,318 in year 30.

Table 24. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 160 Acres in Texas County when Corn price is $5.48 and the Grain Sorghum Price is $5.09 per Bushel and the Discount Rate is Four Percent

Year	Center Pivot Irrigation							Sub Surface Drip Irrigation						
	Crop, IrT	Yield bus	Irrig. Acres	Dry Acres	160 acre N.Rev	Cumulative NPV $	GW (aft) 1680	Crop, IrT	Yield bus	Irrig. Acres	Dry Acre	160 acre Net Rev.	Cumulativ NPV $	GW (aft) 1680
1	S, .6	134	120	40	$ 35,000	$(26,346)	1595	S, .9	155	150	10	$52,100	-$56,904	1551
2	S, .6	134	120	40	$ 35,000	$ 6,013	1511	S, .9	155	150	10	$52,100	-$8,734	1422
3	S, .6	134	120	40	$ 35,000	$ 37,128	1426	S, .9	155	150	10	$50,358	$36,034	1306
4	S, .6	132	120	40	$ 33,715	$ 65,948	1341	S, .9	147	150	10	$50,000	$78,774	1193
5	S, .6	130	120	40	$ 33,200	$ 93,236	1256	S, .9	147	150	10	$47,752	$118,023	1086
6	S, .6	130	120	40	$ 33,200	$119,475	1172	S, .9	135	150	10	$43,400	$152,322	992
7	S, .6	128	120	40	$ 32,277	$144,003	1087	S, .9	135	150	10	$43,400	$185,303	897
8	S, .6	124	120	40	$ 31,040	$166,683	1003	S, .9	135	150	10	$40,511	$214,904	811
9	S, .6	124	120	40	$ 31,040	$188,492	918	S, .9	119	150	10	$35,750	$240,022	737
10	S, .6	124	120	40	$ 30,058	$208,798	838	S, .9	119	150	10	$35,750	$264,173	664
11	S, .6	110	120	40	$ 25,400	$225,297	762	S, .9	119	150	10	$35,750	$287,395	590
12	S, .6	108	120	40	$ 25,400	$241,162	685	S, .9	119	150	10	$31,234	$306,904	511
13	S, .5	108	120	40	$ 24,800	$256,056	612	C, .9	125	150	10	$27,800	$323,600	426
14	S, .5	108	120	40	$ 23,141	$269,419	533	S, .9	93	150	10	$24,350	$337,661	401
15	C, .5	108	120	40	$ 19,760	$280,391	442	S, .9	93	150	10	$24,350	$351,182	375
16	C, .5	118	120	40	$ 19,760	$258,907	351	S, .9	93	150	10	$24,350	$307,055	350
17	C, .5	118	120	40	$ 19,263	$268,796	274	S, .9	93	150	10	$24,350	$319,555	324
18	S, .4	88	120	40	$ 17,840	$277,602	234	S, .9	93	150	10	$24,350	$331,575	299
19	S, .4	88	120	40	$ 17,840	$286,070	194	S, .9	88	150	10	$23,989	$342,962	275
20	S, .4	88	120	40	$ 17,840	$294,212	154	S, .9	88	150	10	$22,400	$353,185	262
21	S, .4	88	120	40	$ 17,840	$302,041	114	S, .9	88	150	10	$22,400	$363,014	248
22	S, .4	88	120	40	$ 17,840	$309,569	74	S, .9	88	150	10	$22,400	$372,466	235
23	S, .4	88	120	40	$ 17,840	$316,807	34	S, .9	88	150	10	$22,400	$381,554	221
24	S, .4	88	120	40	$ 16,439	$323,220	1	S, .9	88	150	10	$22,400	$390,293	208
25	-	-	-	160	$ 10,400	$327,121	1	S, .9	88	150	10	$22,400	$398,696	194
26	-	-	-	160	$ 10,400	$330,872	1	S, .9	88	150	10	$22,400	$406,775	181
27	-	-	-	160	$ 10,400	$334,479	1	S, .9	88	150	10	$22,400	$414,544	167
28	-	-	-	160	$ 10,400	$337,947	1	S, .9	88	150	10	$22,400	$422,014	154
29	-	-	-	160	$ 10,400	$341,282	1	S, .9	88	150	10	$22,400	$429,196	140
30	-	-	-	160	$ 10,400	$344,489	1	S, .9	88	150	10	$22,400	$436,103	127

Irt: Irrigation Trigger, moisture level to trigger an irrigation
GW(aft): Acre feet of remaining ground water at end of year

Table 25. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 160 Acres in Texas County when Corn price is $5.48 and the Grain Sorghum Price is $5.09 per Bushel and the Discount Rate is Seven Percent

Year	Center Pivot Irrigation							Sub Surface Drip Irrigation						
	Crop, IrT	Yield bus	Irrig. Acres	Dry Acres	160 acre N.Rev	Cumulative NPV $	GW (aft) 1680	Crop, IrT	Yield bus	Irrig. Acres	Dry Acre	160 acre Net Rev	Cumulati NPV $	GW (aft) 1680
1	S,.6	134	120	40	$35,000	$ (27,290)	1595	S, .9	155	150	10	$52,100	-$58,308	1551
2	S,.6	134	120	40	$35,000	$ 3,281	1511	S, .9	155	150	10	$52,100	-$12,802	1422
3	S,.6	134	120	40	$35,000	$ 31,851	1426	S, .9	155	150	10	$50,358	$28,305	1306
4	S,.6	134	120	40	$33,715	$ 57,572	1341	S, .9	147	150	10	$50,000	$66,450	1193
5	S,.6	130	120	40	$33,200	$ 81,244	1256	S, .9	147	150	10	$47,752	$100,496	1086
6	S,.6	130	120	40	$33,200	$ 103,366	1172	S, .9	135	150	10	$43,400	$129,416	992
7	S,.6	130	120	40	$32,277	$ 123,467	1087	S, .9	135	150	10	$43,400	$156,443	897
8	S,.6	125	120	40	$31,040	$ 141,532	1003	S, .9	135	150	10	$40,511	$180,021	811
9	S,.6	125	120	40	$31,040	$ 158,416	918	S, .9	119	150	10	$35,750	$199,467	737
10	S,.6	125	120	40	$30,510	$ 173,926	835	S, .9	119	150	10	$35,750	$217,640	664
11	S,.6	110	120	40	$25,400	$ 185,993	758	S, .9	119	150	10	$35,750	$234,625	590
12	S,.6	110	120	40	$25,400	$ 197,271	682	S, .9	119	150	10	$31,234	$248,493	511
13	S,.6	110	120	40	$25,400	$ 207,811	605	C, .9	125	150	10	$27,800	$260,029	426
14	S,.6	110	120	40	$22,335	$ 216,473	544	C, .9	125	150	10	$27,800	$270,810	342
15	S,.5	90	120	40	$18,560	$ 223,200	503	S, .9	93	150	10	$24,350	$279,636	316
16	S,.5	90	120	40	$18,560	$ 209,163	461	S, .9	93	150	10	$24,350	$251,639	291
17	S,.5	90	120	40	$18,560	$ 215,039	420	S, .9	93	150	10	$23,416	$259,052	271
18	S,.5	90	120	40	$18,560	$ 220,530	379	S, .9	88	150	10	$22,400	$265,679	257
19	S,.5	90	120	40	$18,560	$ 225,662	337	S, .9	88	150	10	$22,400	$271,873	244
20	S,.5	90	120	40	$18,560	$ 230,458	296	S, .9	88	150	10	$22,400	$277,661	230
21	S,.5	90	120	40	$18,139	$ 234,839	255	S, .9	88	150	10	$22,400	$283,071	217
22	S,.5	90	120	40	$17,840	$ 238,866	215	S, .9	88	150	10	$22,400	$288,127	203
23	S,.4	88	120	40	$17,840	$ 242,629	175	S, .9	88	150	10	$22,400	$292,852	190
24	S,.4	88	120	40	$17,840	$ 246,146	135	S, .9	88	150	10	$22,400	$297,269	176
25	S,.4	88	120	40	$17,840	$ 249,433	95	S, .9	88	150	10	$22,400	$301,396	163
26	S,.4	88	120	40	$17,840	$ 252,505	55	S, .9	88	150	10	$22,400	$305,253	149
27	S,.4	88	120	40	$17,840	$ 255,376	15	S, .9	88	150	10	$22,400	$308,858	136
28	S,.4	88	58	102	$14,011	$ 257,483	0	S, .9	88	150	10	$22,400	$312,227	122
29	S,.4	88	-	160	$10,400	$ 258,945	0	S, .9	88	150	10	$22,400	$315,375	109
30	-	-	-	160	$10,400	$ 260,312	0	S, .9	88	150	10	$22,400	$318,318	95

Irt: Irrigation Trigger, moisture level to trigger an irrigation
GW(aft): Acre feet of remaining ground water at end of year

In the one fourth section examples addressed above, investment is the SDI system always provided higher discounted net returns than did the CP system. In the four cases above, aquifer life was prolonged. However, there are periods where the SDI producer would irrigate a larger area than the CP producer and use more water in a given year. There are cases in the next section where the economic life of the aquifer was not prolonged by choosing the SDI over the CP.

One question is the the relation between adoption of the SDI system and "Conservation of Groundwater" of the Ogallala Aquifer. The definition of conservation given by Ciriacy-Wantrup (1963) can help answer this question. S. V. Ciriacy -Wantrup (1963) defined conservation as the wise use of resources over time. He went on to describe "the optimal state of conservation as that time distribution of use rates that maximizes the present value of the flow of expected net revenues". The total bushels of irrigated corn and sorghum produced over the 30-year period divided by the total acre-feet of groundwater used in Tables 22 and 24 above are presented below in Figure 28. The results show the SDI system would allow producers to produce more feed grain per acre-foot of water used than does the conventional CP. The amount of feed grain produced per unit of ground water increased with the feed grain price because the SDI with lower pumping costs and higher application efficiency was able to make greater use of ground water pumped even as well yields declined.

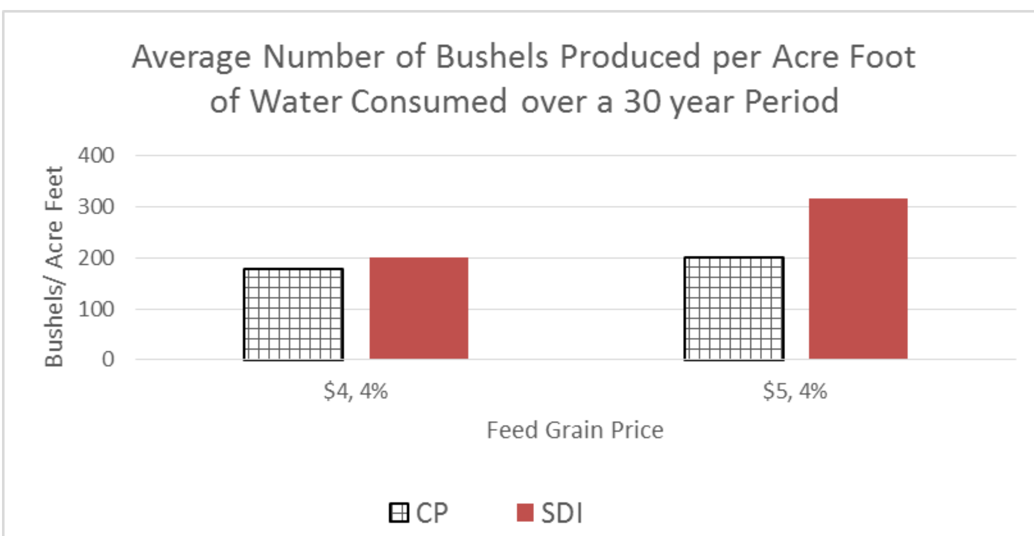


Figure 28. Comparison Potential Production of Grain Sorghum on a Quarter Section over a 30-year Planning Horizon at Two Feed Grain Prices and Four Percent Interest.

Effect of Holding Size on Irrigation Investments and Optimal Long Term Water Use

In this section the producer is assumed to control a 640 acre section of land developed for irrigation as shown below in Figure 29. It is assumed the producer has one well on each quarter section of land and that the wells have been interconnected by an underground pipe as shown in Figure 29.

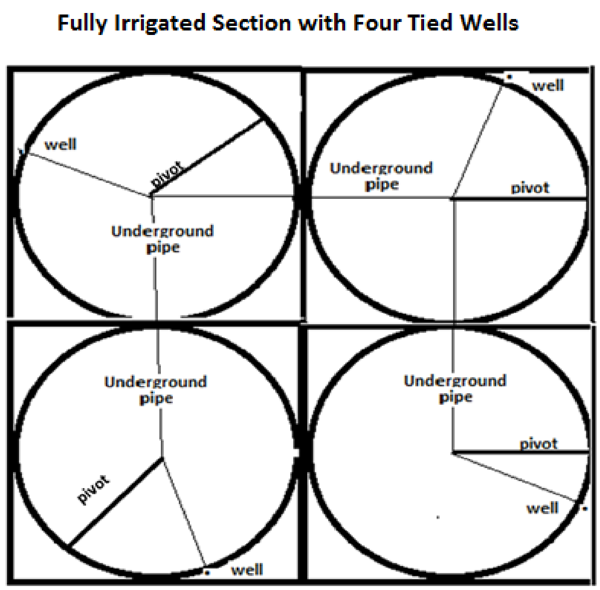


Figure 29. Diagram of 640 Acre Section with Four Connected Irrigation Wells.

It is assumed the producer must invest in either a CP or an SDI irrigation system to continue irrigation. The analysis is conducted first assuming the producer has only the 60 feet of water saturated sand under the 640 acre holding (6,720 acre feet) and second assuming the producer is in a location where only 50 percent of the surrounding land is irrigated (And has twice the supply (13,440 acre feet). The effects of two feed grain prices ($4.48/bus corn, $4.16/bus GS, $5.48/ bus corn and $5.09/bus GS) and two discount rates (four percent and seven percent) on the investment are considered with each water supply. The initial output of each well is assumed to be 600 GPM.

Irrigation Systems, Water Use with 640 Acres, Limited Water, and Four Dollar Feed Grain

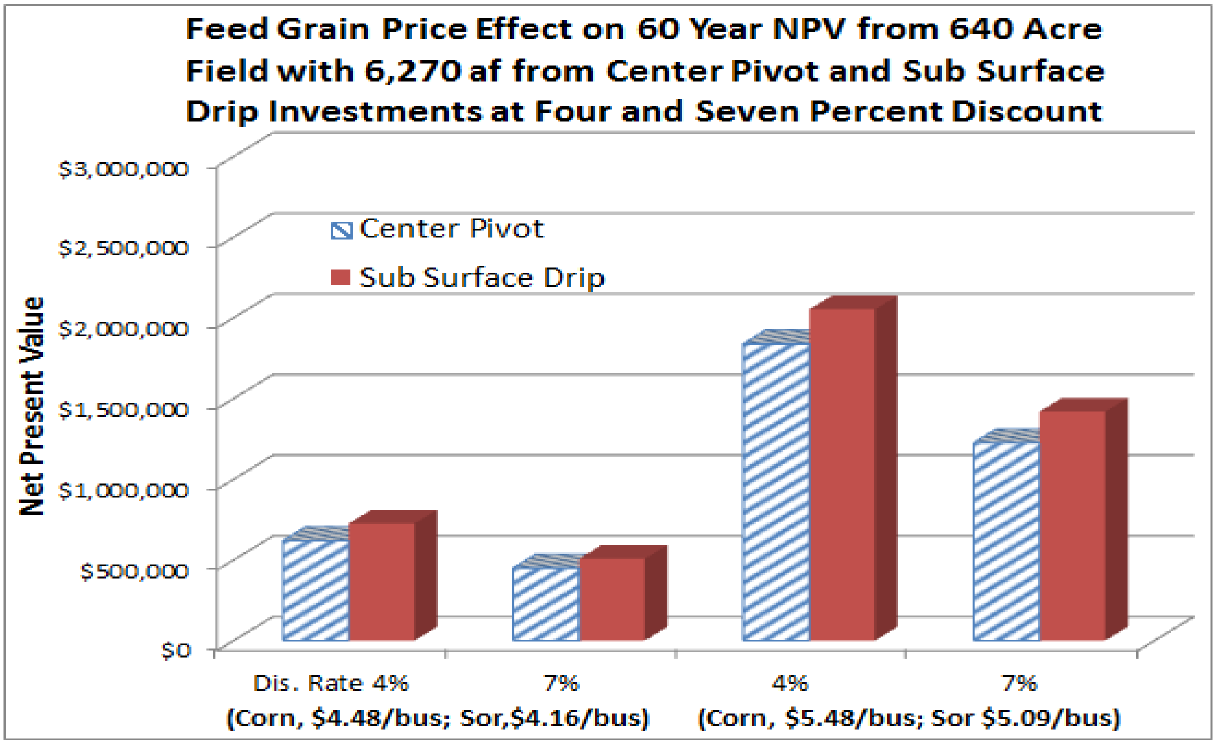
The 60-year results for the producer choosing either a CP or a SDI systems and continuing with that type of system until the aquifer is exhausted are compared in Table 26 . The producer with the 640 acre system of land has more flexibility than with a single quarter system because irrigation systems can be established on 0 to four quarters. If the producer establishes irrigation on one quarter section, then the producer may still draw from four wells to increase the GPM delivered to the irrigation system over the amount that could be delivered if an irrigation system were established on all four quarter sections.

CP(640a, $4, 4%, Lw) The results on the left side of Table 26 show the producer investing in the CP would purchase only two CP systems for the first 15 years (irrigating 240) acres. The price received for corn and GS over the 60 period is $4.48/bus and $4.16/bus respectively. The discount rate is four percent. The producer intensively irrigates corn (Irt = .9) and obtains estimated yields of 214 bus/acre for the first four years. Then the producer would switch to GS for years 5 through 15. In year 16, the producer would purchase only one 120 acre CP. As the supply of irrigated land becomes more limited and the supply of water delivered to the pivot is increased back to 800 GPM, the producer grows 213 bushel corn for three years. As the ground water table declines to where less than 400 GPM can be delivered to the irrigated area, the producer switches to GS for the remainder of the aquifer life. A third CP system purchased in year 31 would be used to produce 124 bushel GS until the aquifer is exhausted at the end of year 45. Only dryland GS would be produced in years 46-60.

Initial net cash receipts in years 1-4 are estimated to be $63,840 (machinery expenses are not deducted). These decline to $37,680 by year 15. Annual net cash receipts continue to decline with the water table to $17,760 in the last year of irrigation in year 45. Returns from dryland production are expected to average $3,840 in years 46-60. The cumulative NPV from 60 years of operating the 640 acre parcel with the pivot system are estimated to $618,708. Figure 30compares the sensitivity of the NPV to changes in the ground water supply, feed grain price, and discount rate.

SDI(640a, $4, 4%, Lw) Results for the producer investing in a series of SDI systems are shown on the right side of Table 26. Initially, the SDI system would provide irrigation to 450 acres (three, 150-acre SDI systems) of sorghum for the first 15 years. The GS would be intensively irrigated (IrT = .9) and the estimate GS yields would be 164 bus/acre. However as the aquifer declines, the IrT for irrigation of GS declines to .6 by year 15. In year 16, the producer replaces only 125 acres of the previous 450 acres. With the smaller systems and the ability to draw water from 4 wells, the producer grows three years of intensively irrigated corn

(Irt = .9, yields = 214 bus/acre). The producer then switches back to intensively (IrT=.9) irrigated GS for years 19-30. At the end of year 30, there was only 31 acre-feet of groundwater



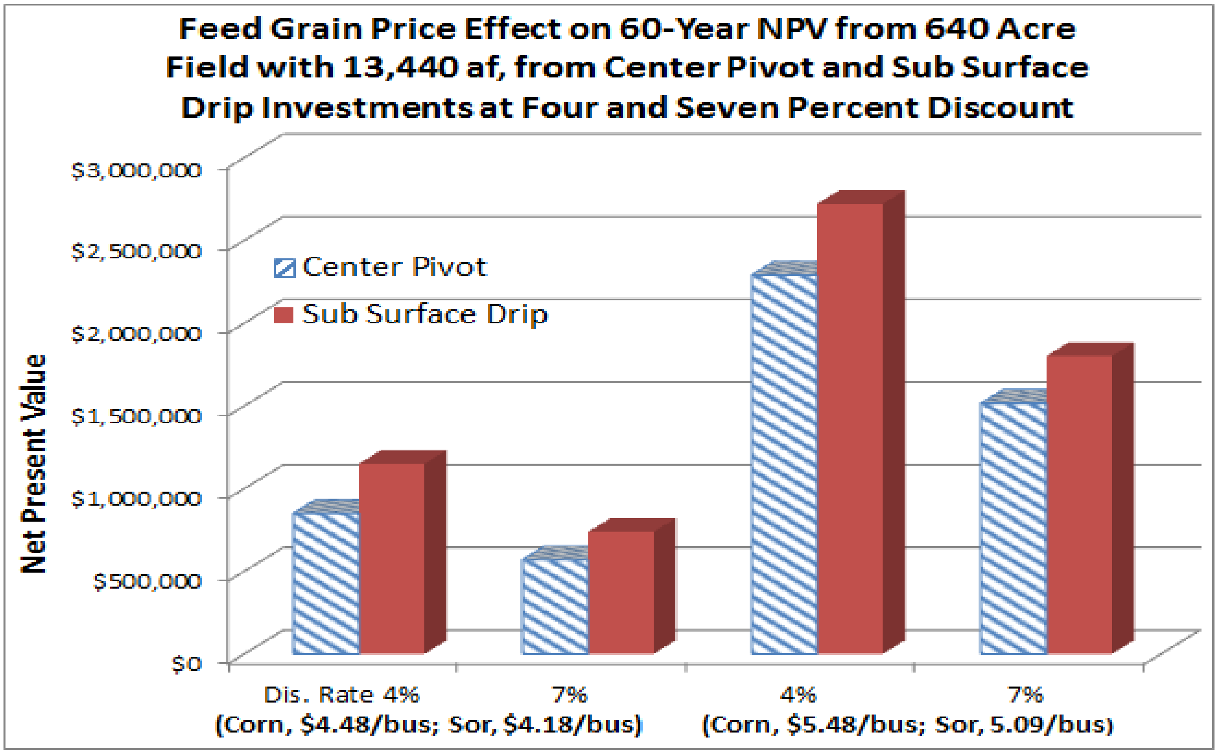


Figure 30. Comparison of NPV from Center Pivot and Subsurface Drip Investments on a 640 Acre Field with Initial Water Supplies of 6,240 and 13,440 Acre Feet Under Two Feed Grain Prices and Two Discount Rates.

Table 26. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 6,720 Acre Feet of Groundwater in Texas County when Corn price is $4.48 and the Grain Sorghum Price is $4.16 per Bushel and the Discount Rate is Four Percent.

	Center Pivot							Sub Surface Drip						
Year	Crop	Yield	Irrig.	Dry	640Acre	Cumulative	GW (aft)	Crop	Ir.Yield	Irrig.	Dry	640Acre	Cumulative	GW (aft)
	IrT	Bus	Acres	Acres	Net Rev.	NPV 4	6720	IrT	Bus	Acres	Acres	Net Rev.	NPV 4	6,720
1	C, .9	213	240	400	$ 63,840	$ (58,615)	6271	S,.9	164	450	515	$ 96,990	$(227,740)	6,265
2	C, .9	213	240	400	$ 63,840	$ 408	5822	S,.9	164	450	515	$ 96,990	$(138,068)	5,810
3	C, .9	213	240	400	$ 63,356	$ 56,731	5373	S,.9	160	450	515	$ 93,615	$ (54,845)	5,391
4	C, .9	213	240	400	$ 62,880	$ 110,481	4923	S,.9	155	450	515	$ 90,690	$ 22,678	5,004
5	S, .6	138	240	400	$ 59,438	$ 159,335	4525	S,.9	155	450	515	$ 90,690	$ 97,218	4,617
6	S, .6	138	240	400	$ 43,029	$ 193,342	4365	S,.9	152	450	515	$ 89,246	$ 167,751	4,260
7	S, .6	138	240	400	$ 42,960	$ 225,988	4205	S,.9	147	450	515	$ 88,440	$ 234,958	3,921
8	S, .6	138	240	400	$ 42,960	$ 257,378	4045	S,.9	135	450	515	$ 88,440	$ 299,580	3,582
9	S, .6	138	240	400	$ 42,960	$ 287,562	3885	S,.9	147	450	515	$ 83,350	$ 358,141	3,261
10	S, .6	138	240	400	$ 42,960	$ 316,584	3725	S,.9	140	450	515	$ 72,690	$ 407,247	2,978
11	S, .6	138	240	400	$ 42,960	$ 344,490	3565	S,.9	135	450	515	$ 72,690	$ 454,465	2,694
12	S, .6	138	240	400	$ 42,960	$ 371,322	3405	S,.8	135	450	515	$ 72,690	$ 499,867	2,411
13	S, .6	136	240	400	$ 39,019	$ 394,756	3238	S,.8	135	450	515	$ 57,937	$ 534,663	2,204
14	S, .6	134	240	400	$ 37,680	$ 416,515	3068	S,.6	115	450	515	$ 33,090	$ 553,771	2,126
15	S, .6	134	240	400	$ 37,680	$ 437,438	2899	S,.6	93	450	515	$ 33,090	$ 572,145	2,048
16	C, .9	213	120	510	$ 33,600	$ 423,343	2674	C, .9	214	125	515	$ 35,840	$ 542,855	1,812
17	C, .9	213	120	510	$ 33,600	$ 440,592	2450	C, .9	214	125	515	$ 35,840	$ 561,254	1,577
18	C, .9	213	120	510	$ 33,555	$ 457,156	2225	C, .9	214	125	515	$ 35,840	$ 578,946	1,341
19	S, .6	138	120	510	$ 23,400	$ 468,262	2145	S,.9	166	125	515	$ 35,779	$ 595,928	1,107
20	S, .6	138	120	510	$ 23,400	$ 478,942	2065	S,.9	166	125	515	$ 26,215	$ 607,892	1,012
21	S, .6	138	120	510	$ 23,400	$ 489,211	1985	S,.9	166	125	515	$ 26,215	$ 619,396	918
22	S, .6	138	120	510	$ 23,400	$ 499,084	1905	S,.9	155	125	515	$ 26,215	$ 630,458	824
23	S, .6	138	120	510	$ 23,400	$ 508,578	1825	S,.9	147	125	515	$ 26,215	$ 641,094	730
24	S, .6	138	120	510	$ 23,400	$ 517,707	1745	S,.9	147	125	515	$ 26,215	$ 651,321	636
25	S, .6	138	120	510	$ 23,400	$ 526,485	1665	S,.9	147	125	515	$ 26,215	$ 661,155	542
26	S, .6	138	120	510	$ 23,400	$ 534,925	1585	S,.9	147	125	515	$ 26,215	$ 670,610	447
27	S, .6	138	120	510	$ 23,400	$ 543,040	1505	S,.9	147	125	640	$ 26,215	$ 679,702	353
28	S, .6	138	120	510	$ 23,400	$ 550,844	1425	S,.9	147	125	640	$ 26,215	$ 688,444	259
29	S, .6	138	120	510	$ 23,400	$ 558,347	1345	S,.9	147	125	640	$ 26,215	$ 696,850	165
30	S, .6	138	120	510	$ 23,400	$ 565,562	1265	S,.9	147	125	640	$ 26,215	$ 704,932	71
31	S, .6	138	120	510	$ 23,400	$ 554,711	1185	-	-	-	640	$ 3,840	$ 706,071	71
32	S, .6	138	120	510	$ 21,520	$ 560,845	1104	-	-	-	640	$ 3,840	$ 707,165	71
33	S, .6	124	120	510	$ 17,760	$ 565,713	1019	-	-	-	640	$ 3,840	$ 708,218	71
34	S, .6	124	120	510	$ 17,760	$ 570,394	935	-	-	-	640	$ 3,840	$ 709,230	71
35	S, .6	124	120	510	$ 17,760	$ 574,895	851	-	-	-	640	$ 3,840	$ 710,203	71
36	S, .6	124	120	510	$ 17,760	$ 579,222	766	-	-	-	640	$ 3,840	$ 711,139	71
37	S, .6	124	120	510	$ 17,760	$ 583,383	682	-	-	-	640	$ 3,840	$ 712,039	71
38	S, .6	124	120	510	$ 17,760	$ 587,384	597	-	-	-	640	$ 3,840	$ 712,904	71
39	S, .6	124	120	510	$ 17,760	$ 591,231	513	-	-	-	640	$ 3,840	$ 713,735	71
40	S, .6	124	120	510	$ 17,760	$ 594,931	428	-	-	-	640	$ 3,840	$ 714,535	71
41	S, .6	124	120	510	$ 17,760	$ 598,488	344	-	-	-	640	$ 3,840	$ 715,304	71
42	S, .6	124	120	510	$ 17,760	$ 601,908	260	-	-	-	640	$ 3,840	$ 716,044	71
43	S, .6	124	120	510	$ 17,760	$ 605,196	175	-	-	-	640	$ 3,840	$ 716,755	71
44	S, .6	124	120	510	$ 17,760	$ 608,358	91	-	-	-	640	$ 3,840	$ 717,439	71
45	S, .6	124	120	510	$ 17,760	$ 611,399	6	-	-	-	640	$ 3,840	$ 718,096	71
46-59					$ 3,840	$ 618,343	6				640	$ 3,840	$ 725,040	71
60					$ 3,840	$ 618,708	6				640	$ 3,840	$ 725,405	71

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV, GW remaining in year 59

remaining, so there was no further irrigation system investment. Dryland GS is produced from years 30 through 60. Compared to the CP system, the SDI used more water in the initial period and exhausted in 30 years as compared to 45 years for the CP system.

Net receipts, (no deduction for fixed machinery or irrigation system costs) reached $96,990 for the first three years, but declined to $35,840 by year 15. Net receipts in year 16 (with 125 acres of irrigated corn) are $35,779 but decline to $26,215 by year 30. Annual net receipts are $3,840 for years 31-60. The investment cost of the 450 acre system was not recovered until year 3 whereas the investment cost of the CP system was recovered by year 2. The 60-year cumulative NPV (at 4 percent) (with irrigation system costs deducted) reached $725,405. This compares to the cumulative NPV of the CP system which was $618,708.

An increase in the discount rate from four to seven percent (Table 27) lowers the NPV from each system but was also expected to increase the near term use of ground water and make capital investments more expensive. For the CP system, the producer still buys two pivots and irrigates 240 acres. However, the producer raises 240 acres of 213 bushel corn for six years rather than four years with the four percent discount. Grain Sorghum is grown in years 7-15. At the end of year 15 there is 2,243 acre feet of ground water remaining compared to 2,225 acre feet at the four percent discount rate.

It was profitable to drop to a 120 acre pivot in year 16 and to replace this system again in year 31. In year 16, the irrigated corn is grown, but then GS is grown for years 17 to 41. Under the seven percent discount rate, irrigation was terminated after year 41. Production was limited to dryland sorghum from years 42-60. The cumulative NPV at seven percent discount reached $448,906 by year 60.

Irrigation Systems, Water Use with 640 Acres, Limited Water, and Five Dollar Feed Grain

CP(640a, $5, 4%, Lw) If the price of corn increased from $4.48 to $5.49/bus, and the price of GS increased from $4.16 to $5.09/bus., it is anticipated all irrigation system investments would become more profitable. Table 28 shows that at the four percent discount rate, the producer would still invest in two, 120 acres pivots and then purchase one 120 acre pivot in year 16 and again in year 31.

With the higher corn price, long-term profits would be increased by growing seven years of 213 bushel irrigated corn (rather than four years with $4.48 corn) before switching to irrigated GS in year 7. Because there are four years of less intensively irrigated GS, the producer ends the first 15 year period with slightly more groundwater than was the case with four dollar feed grain.

In years 16-45, the production of five dollar GS with a single 120 acre pivot, (fed by four wells) gives similar results as with respect to water use and irrigation intensity as found with the four dollar GS. Irrigation terminated in year 45 and only dryland GS was grown in years 46-60.

Annual net returns were higher with the five dollar feed grain than with the four dollar feed grain. With the four percent discount rate, the 60-year cumulative NPV from the CP system was $1,839,290. The NPV is very sensitive to the price of feed grain. The 22 percent increase in price caused the NPV to increase by three times.

SDI(640a, $5, 4%, Lw) (Table 28) For the SDI system, higher feed grain prices made it profitable to install four, 150 SDI systems for the first 15 years. In contrast to the CP system, intensively irrigated GS was the crop of choice. The irrigation of 600 acres was not sustainable for the full 15 year period and the area of irrigated GS declined from 600 to 582 acres in year 15. There were 1818 acre feet of ground water remaining after the first 15 year period. In the second 15-year period, the irrigated area was limited to a single 125 acre system. The aquifer was exhausted by year 30 and dryland GS was grown from years 31-60.

Net receipts (no deduction of machinery fixed cost) were $208,000 in the first two years but declined to $73,600 by year 30. Dryland receipts were $41,600 over the 31-60 year period. The cumulative 60-year NPV at four percent was $2,052,066.

CP(640a, $5, 7%, Lw) Increasing the discount rate from four to seven percent naturally reduced the NPV of both investments. For the pivot system the investment pattern (240 acres in years 1-15 and 120 acres in years 16-30) remain unchanged from the four percent rate. There was more initial use of ground water as eight years of corn were produced rather than seven years with the four percent discount rate. There were seven years of corn production after the irrigated acreage was reduced from 240 to 120 acres in the second 15 year period. The rate of ground water extraction was

Table 27. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 6,720 Acre Feet of Groundwater in Texas County when Corn price is $4.48 and the Grain Sorghum Price is $4.16 per Bushel and the Discount Rate is Seven Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yielc Bus	Irrig. Year	Dry Acres	640Acre Net Rev.	Cumulative NPV 4	GW (aft 6720	Crop IrT	Ir.Yielc Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) GPM
1	C, .9	213	240	400	$63,840	$ (60,336)	6271	S,.9	155	500	140	$104,840	$(264,819)	6,290
2	C, .9	213	240	400	$63,840	$ (4,576)	5822	S,.9	155	500	140	$104,840	$(173,247)	5,860
3	C, .9	213	240	400	$63,356	$ 47,141	5373	S,.9	161	500	140	$105,038	$ (87,505)	5,412
4	C, .9	213	240	400	$62,880	$ 95,112	4923	S,.9	161	500	140	$105,340	$ (7,142)	4,937
5	C, .9	213	240	400	$62,874	$ 139,940	4474	S,.9	161	500	140	$104,872	$ 67,630	4,466
6	C, .9	213	240	400	$62,160	$ 181,360	4025	S,.9	147	500	140	$ 92,840	$ 129,493	4,089
7	S, .6	139	240	400	$57,152	$ 216,951	3651	S,.9	147	500	140	$ 92,840	$ 187,309	3,713
8	S, .6	139	240	400	$42,960	$ 241,954	3491	S,.9	147	500	140	$ 92,205	$ 240,974	3,339
9	S, .6	139	240	400	$42,290	$ 264,957	3324	S,.9	135	500	140	$ 80,340	$ 284,673	3,024
10	S, .7	140	240	400	$39,120	$ 284,843	3123	S,.9	135	500	140	$ 80,340	$ 325,514	2,709
11	S, .7	140	240	400	$39,120	$ 303,429	2921	S,.9	135	500	140	$ 80,340	$ 363,683	2,394
12	S, .6	134	240	400	$37,680	$ 320,159	2752	S,.9	135	500	140	$ 65,978	$ 392,978	2,031
13	S, .6	134	240	400	$37,680	$ 335,795	2582	S,.9	97	500	140	$ 45,640	$ 411,917	1,758
14	S, .6	134	240	400	$37,680	$ 350,408	2413	S,.9	97	500	140	$ 39,340	$ 427,174	1,636
15	S, .6	134	240	400	$37,680	$ 364,065	2243	S,.9	93	500	140	$ 36,340	$ 440,345	1,550
16	C, .9	213	120	520	$33,120	$ 354,960	2019	S,.9	167	125	515	$ 30,465	$ 419,942	1,418
17	S, .6	139	120	520	$23,400	$ 362,368	1939	S,.9	167	125	515	$ 30,465	$ 429,586	1,286
18	S, .6	139	120	520	$23,400	$ 369,291	1859	S,.9	167	125	515	$ 30,465	$ 438,600	1,154
19	S, .6	139	120	520	$23,400	$ 375,761	1779	S,.9	167	125	515	$ 30,295	$ 446,977	1,024
20	S, .6	139	120	520	$23,400	$ 381,808	1699	S,.9	147	125	515	$ 26,215	$ 453,751	929
21	S, .6	139	120	520	$23,400	$ 387,460	1619	S,.9	147	125	515	$ 26,215	$ 460,082	835
22	S, .6	139	120	520	$23,400	$ 392,741	1539	S,.9	147	125	515	$ 26,215	$ 465,999	741
23	S, .6	139	120	520	$23,400	$ 397,678	1459	S,.9	147	125	515	$ 26,215	$ 471,529	647
24	S, .6	139	120	520	$23,400	$ 402,291	1379	S,.9	147	125	515	$ 26,215	$ 476,698	553
25	S, .6	139	120	520	$23,400	$ 406,602	1299	S,.9	147	125	515	$ 26,215	$ 481,528	459
26	S, .6	139	120	520	$23,400	$ 410,632	1219	S,.9	147	125	515	$ 26,215	$ 486,042	364
27	S, .6	139	120	520	$23,400	$ 414,397	1139	S,.9	147	125	515	$ 26,215	$ 490,261	270
28	S, .6	139	120	520	$18,546	$ 417,187	1055	S,.9	147	125	515	$ 26,215	$ 494,203	176
29	S, .6	125	120	520	$17,760	$ 419,683	971	S,.9	147	125	515	$ 26,215	$ 497,888	82
30	S, .6	125	120	520	$17,760	$ 422,016	886	S,.9	147	125	515	$ 26,215	$ 501,332	0
31	S, .6	125	120	520	$17,760	$ 431,563	802	-	-	-	640	$ 3,840	$ 501,803	0
32	S, .6	125	120	520	$17,760	$ 433,600	717	-	-	-	640	$ 3,840	$ 502,244	0
33	S, .6	125	120	520	$17,760	$ 435,505	633	-	-	-	640	$ 3,840	$ 502,656	0
34	S, .6	125	120	520	$17,760	$ 437,285	548	-	-	-	640	$ 3,840	$ 503,041	0
35	S, .6	125	120	520	$17,760	$ 438,948	464	-	-	-	640	$ 3,840	$ 503,400	0
36	S, .6	125	120	520	$17,760	$ 440,503	380	-	-	-	640	$ 3,840	$ 503,736	0
37	S, .5	122	120	520	$17,280	$ 441,917	300	-	-	-	640	$ 3,840	$ 504,051	0
38	S, .5	122	120	520	$17,280	$ 443,238	220	-	-	-	640	$ 3,840	$ 504,344	0
39	S, .5	122	120	520	$17,280	$ 444,472	140	-	-	-	640	$ 3,840	$ 504,619	0
40	S, .5	122	120	520	$17,280	$ 445,626	60	-	-	-	640	$ 3,840	$ 504,875	0
41	S, .5	122	80.7	559	$12,884	$ 446,431	6	-	-	-	640	$ 3,840	$ 505,115	0
42	-	-	-	640	$ 3,840	$ 446,655	6	-	-	-	640	$ 3,840	$ 505,339	0
43	-	-	-	640	$ 3,840	$ 446,864	6	-	-	-	640	$ 3,840	$ 505,548	0
44	-	-	-	640	$ 3,840	$ 447,059	6	-	-	-	640	$ 3,840	$ 505,744	0
45	-	-	-	640	$ 3,840	$ 447,242	6	-	-	-	640	$ 3,840	$ 505,926	0
46-5	-	-	-	640	$ 3,840	$ 448,841	6	-	-	-	640	$ 3,840	$ 507,525	0
60	-	-	-	640	$ 3,840	$ 448,908	6	-	-	-	640	$ 3,840	$ 507,592	0

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV year 59, GW remaining in year 59

Table 28. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 6,720 Acre Feet of Groundwater in Texas County when Corn price is $5.48 and the Grain Sorghum Price is $5.09 per Bushel and the Discount Rate is Four Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 6,720	Crop IrT	Ir.Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 6,720
1	C,.9	213	240	400	$138,560	$ 13,231	6,271	S,.9	155	600	40	$ 208,400	$ (227,615)	6,204
2	C,.9	213	240	400	$138,560	$ 141,337	5,822	S,.9	155	600	40	$ 208,400	$ (34,938)	5,687
3	C,.9	213	240	400	$138,076	$ 264,086	5,373	S,.9	155	600	40	$ 201,433	$ 144,135	5,224
4	C,.9	213	240	400	$137,600	$ 381,707	4,923	S,.9	147	600	40	$ 200,000	$ 315,096	4,772
5	C,.9	213	240	400	$137,594	$ 494,799	4,474	S,.9	147	600	40	$ 191,009	$ 472,091	4,345
6	C,.9	213	240	400	$136,880	$ 602,977	4,025	S,.9	135	600	40	$ 173,600	$ 609,290	3,968
7	C,.9	213	240	400	$101,899	$ 680,412	3,833	S,.9	135	600	40	$ 173,600	$ 741,211	3,590
8	S,.6	139	240	400	$ 97,520	$ 751,669	3,673	S,.9	135	600	40	$ 162,045	$ 859,616	3,243
9	S,.6	139	240	400	$ 97,520	$ 820,185	3,513	S,.9	119	600	40	$ 143,000	$ 960,086	2,949
10	S,.6	139	240	400	$ 97,196	$ 885,847	3,353	S,.9	119	600	40	$ 143,000	$ 1,056,692	2,654
11	S,.6	139	240	400	$ 91,040	$ 944,985	3,183	S,.9	119	600	40	$ 143,000	$ 1,149,582	2,360
12	S,.6	134	240	400	$ 91,040	$ 1,001,848	3,014	S,.9	119	600	40	$ 117,095	$ 1,222,719	2,173
13	S,.6	134	240	400	$ 91,040	$ 1,056,525	2,844	S,.9	93	600	40	$ 97,400	$ 1,281,215	2,070
14	S,.6	134	240	400	$ 91,040	$ 1,109,098	2,675	S,.9	93	600	40	$ 97,400	$ 1,337,461	1,966
15	S,.6	134	240	400	$ 91,040	$ 1,159,649	2,505	S,.9	93	582	58	$ 102,016	$ 1,394,107	1,818
16	S,.6	134	120	520	$ 89,840	$ 1,175,581	2,281	C,.9	144	125	515	$ 93,100	$ 1,395,389	1,582
17	C,.9	213	120	520	$ 69,612	$ 1,211,318	2,201	C,.9	215	125	515	$ 93,100	$ 1,443,184	1,347
18	S,.6	139	120	520	$ 69,560	$ 1,245,655	2,121	C,.9	215	125	515	$ 93,100	$ 1,489,141	1,111
19	S,.6	139	120	520	$ 69,560	$ 1,278,671	2,041	C,.9	215	125	515	$ 73,953	$ 1,524,242	1,015
20	S,.6	139	120	520	$ 69,560	$ 1,310,418	1,961	S,.9	147	125	515	$ 73,600	$ 1,557,832	921
21	S,.6	139	120	520	$ 69,560	$ 1,340,943	1,881	S,.9	147	125	515	$ 73,600	$ 1,590,130	827
22	S,.6	139	120	520	$ 69,560	$ 1,370,294	1,801	S,.9	147	125	515	$ 73,600	$ 1,621,186	733
23	S,.6	139	120	520	$ 69,560	$ 1,398,516	1,721	S,.9	147	125	515	$ 73,600	$ 1,651,048	638
24	S,.6	139	120	520	$ 69,560	$ 1,425,653	1,641	S,.9	147	125	515	$ 73,600	$ 1,679,761	544
25	S,.6	139	120	520	$ 69,560	$ 1,451,746	1,561	S,.9	147	125	515	$ 73,600	$ 1,707,369	450
26	S,.6	139	120	520	$ 69,560	$ 1,476,836	1,481	S,.9	147	125	515	$ 73,600	$ 1,733,916	356
27	S,.6	139	120	520	$ 69,560	$ 1,500,960	1,401	S,.9	147	125	515	$ 73,600	$ 1,759,442	262
28	S,.6	139	120	520	$ 69,560	$ 1,524,157	1,321	S,.9	147	125	515	$ 73,600	$ 1,783,986	167
29	S,.6	139	120	520	$ 69,560	$ 1,546,461	1,241	S,.9	147	125	515	$ 73,600	$ 1,807,585	73
30	S,.6	139	120	520	$ 69,560	$ 1,567,908	1,161	S,.9	147	125	515	$ 73,600	$ 1,830,278	0
31	S,.6	139	120	520	$ 65,000	$ 1,569,390	1,078	S,.9	147	0	640	$ 41,600	$ 1,842,610	0
32	S,.6	139	120	520	$ 62,360	$ 1,587,166	994	-	-	0	640	$ 41,600	$ 1,854,469	0
33	S,.6	125	120	520	$ 62,360	$ 1,604,259	909	-	-	0	640	$ 41,600	$ 1,865,871	0
34	S,.6	125	120	520	$ 62,360	$ 1,620,694	825	-	-	0	640	$ 41,600	$ 1,876,835	0
35	S,.6	125	120	520	$ 62,360	$ 1,636,497	740	-	-	0	640	$ 41,600	$ 1,887,377	0
36	S,.6	125	120	520	$ 62,360	$ 1,651,692	656	-	-	0	640	$ 41,600	$ 1,897,514	0
37	S,.6	125	120	520	$ 62,360	$ 1,666,303	571	-	-	0	640	$ 41,600	$ 1,907,260	0
38	S,.6	125	120	520	$ 61,640	$ 1,680,189	491	-	-	0	640	$ 41,600	$ 1,916,632	0
39	S,.5	122	120	520	$ 61,640	$ 1,693,542	411	-	-	0	640	$ 41,600	$ 1,925,644	0
40	S,.5	122	120	520	$ 61,640	$ 1,706,381	331	-	-	0	640	$ 41,600	$ 1,934,308	0
41	S,.5	122	120	520	$ 61,640	$ 1,718,726	251	-	-	0	640	$ 41,600	$ 1,942,640	0
42	S,.5	122	120	520	$ 61,640	$ 1,730,596	171	-	-	0	640	$ 41,600	$ 1,950,651	0
43	S,.5	122	120	520	$ 61,640	$ 1,742,010	91	-	-	0	640	$ 41,600	$ 1,958,354	0
44	S,.5	122	120	520	$ 61,640	$ 1,752,985	11	-	-	0	640	$ 41,600	$ 1,965,761	0
45	S,.5	122	0	640	$ 41,600	$ 1,760,106	11	-	-	0	640	$ 41,600	$ 1,972,883	0
46-59	-	-	0	640	$ 41,600	$ 1,835,335	11	-	-	0	640	$ 41,600	$ 2,048,111	0
60	-	-	0	640	$ 41,600	$ 1,839,290	11	-	-	0	640	$ 41,600	$ 2,052,066	0

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV year 59, GW remaining in year 59

increased and irrigation was terminated with aquifer exhaustion in year 30 as opposed to year 45 in the four percent discount case.

SDI(640a, $5, 7%, Lw) The increase in the discount rate from four to seven percent caused the initial irrigated area to decline from 600 to 500 acres (four 125-acres systems). This might be anticipated because the higher initial cost of the SDI system makes it more sensitive to increased discount rates. Irrigated GS was the crop of choice for the first 13 years. Irrigated corn was produced in years 14 and 15. This can occur when the model anticipates the scarcity of water may be reduced relative to the scarcity of irrigated land if the irrigated area will soon be reduced. The irrigated area was reduced to a single 125 acre drip system for years 16-30 but irrigation terminated with aquifer exhaustion in year 29. Dryland GS was produced for years 30-60.

In the limited water situation examined above, the SDI system was more profitable than the conventional CP system under both four dollar and five dollar feed grain prices. The SDI was also more profitable than the CP under both four and seven percent discount rates.

Table 29. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 6,720 Acre Feet of Groundwater in Texas County when Corn price is $5.48 and the Grain Sorghum Price is $5.09 per Bushel and the Discount Rate is Seven Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 6720	Crop IrT	Ir.Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 6720
1	C,.9	213	240	400	$ 138,560	$ 9,495	6271	S,.9	161	500	140	$ 188,100	$ (187,006)	6245
2	C,.9	213	240	400	$ 138,560	$ 130,519	5822	S,.9	161	500	140	$ 188,100	$ (22,712)	5771
3	C,.9	213	240	400	$ 138,076	$ 243,230	5373	S,.9	161	500	140	$ 186,495	$ 129,524	5325
4	C,.9	213	240	400	$ 137,600	$ 348,204	4923	S,.9	155	500	140	$ 185,600	$ 271,117	4894
5	C,.9	213	240	400	$ 137,594	$ 446,307	4474	S,.9	155	500	140	$ 184,982	$ 403,006	4466
6	C,.9	213	240	400	$ 136,880	$ 537,516	4025	S,.9	147	500	140	$ 169,100	$ 515,685	4089
7	C,.9	213	240	400	$ 136,880	$ 622,758	3576	S,.9	147	500	140	$ 169,100	$ 620,992	3713
8	C,.9	213	240	400	$ 114,281	$ 689,270	3260	S,.9	147	500	140	$ 168,211	$ 718,892	3339
9	S,.6	134	240	400	$ 91,040	$ 738,790	3091	S,.9	135	500	140	$ 151,600	$ 801,353	3024
10	S,.6	134	240	400	$ 91,040	$ 785,070	2921	S,.9	135	500	140	$ 151,600	$ 878,418	2709
11	S,.6	134	240	400	$ 91,040	$ 828,323	2752	S,.9	135	500	140	$ 151,600	$ 950,443	2394
12	S,.6	134	240	400	$ 91,040	$ 868,746	2582	S,.9	135	500	140	$ 141,695	$ 1,013,357	2031
13	S,.6	134	240	400	$ 91,040	$ 906,524	2413	C, .9	144	500	140	$ 131,600	$ 1,067,966	1620
14	S,.6	134	240	400	$ 91,040	$ 941,831	2243	C, .9	144	500	140	$ 113,887	$ 1,112,134	1343
15	S,.6	134	240	400	$ 82,880	$ 971,870	2075	S,.6	90	500	140	$ 85,100	$ 1,142,978	1284
16	S,.6	125	120	520	$ 89,360	$ 981,816	1850	S,.9	167	125	515	$ 80,225	$ 1,139,430	1152
17	C,.9	213	120	520	$ 89,360	$ 1,010,105	1625	S,.9	167	125	515	$ 79,632	$ 1,164,639	1023
18	C,.9	213	120	520	$ 89,360	$ 1,036,543	1401	S,.9	147	125	515	$ 73,600	$ 1,186,415	929
19	C,.9	213	120	520	$ 89,360	$ 1,061,252	1176	S,.9	147	125	515	$ 73,600	$ 1,206,766	835
20	C,.9	213	120	520	$ 73,360	$ 1,080,209	988	S,.9	147	125	515	$ 73,600	$ 1,225,785	741
21	C,.9	213	120	520	$ 68,240	$ 1,096,690	812	S,.9	147	125	515	$ 73,600	$ 1,243,561	646
22	C,.9	164	120	520	$ 64,212	$ 1,111,184	701	S,.9	147	125	515	$ 73,600	$ 1,260,173	552
23	C,.9	164	120	520	$ 63,320	$ 1,124,541	605	S,.8	141	125	515	$ 71,475	$ 1,275,251	468
24	S,.7	129	120	520	$ 63,320	$ 1,137,024	508	S,.8	141	125	515	$ 71,475	$ 1,289,342	384
25	S,.7	129	120	520	$ 62,360	$ 1,148,514	424	S,.8	141	125	515	$ 71,475	$ 1,302,511	300
26	S,.6	125	120	520	$ 62,360	$ 1,159,252	339	S,.8	141	125	515	$ 71,475	$ 1,314,818	215
27	S,.6	125	120	520	$ 62,360	$ 1,169,288	255	S,.7	134	125	515	$ 68,600	$ 1,325,858	141
28	S,.6	125	120	520	$ 62,360	$ 1,178,667	170	S,.7	134	125	515	$ 68,600	$ 1,336,176	66
29	S,.6	125	120	520	$ 62,360	$ 1,187,432	86	S,.7	134	125	515	$ 68,600	$ 1,345,818	0
30	S,.6	125	120	520	$ 62,360	$ 1,195,624	1	-	-	-	640	$ 41,600	$ 1,351,283	0
31	S,.6	125	-	640	$ 41,600	$ 1,200,732	1	-	-	-	640	$ 41,600	$ 1,356,391	0
32	-	-	-	640	$ 41,600	$ 1,205,505	1	-	-	-	640	$ 41,600	$ 1,361,164	0
33	-	-	-	640	$ 41,600	$ 1,209,966	1	-	-	-	640	$ 41,600	$ 1,365,625	0
34	-	-	-	640	$ 41,600	$ 1,214,135	1	-	-	-	640	$ 41,600	$ 1,369,794	0
35	-	-	-	640	$ 41,600	$ 1,218,032	1	-	-	-	640	$ 41,600	$ 1,373,690	0
36	-	-	-	640	$ 41,600	$ 1,221,673	1	-	-	-	640	$ 41,600	$ 1,377,332	0
37	-	-	-	640	$ 41,600	$ 1,225,076	1	-	-	-	640	$ 41,600	$ 1,380,735	0
38	-	-	-	640	$ 41,600	$ 1,228,257	1	-	-	-	640	$ 41,600	$ 1,383,916	0
39	-	-	-	640	$ 41,600	$ 1,231,229	1	-	-	-	640	$ 41,600	$ 1,386,888	0
40	-	-	-	640	$ 41,600	$ 1,234,007	1	-	-	-	640	$ 41,600	$ 1,389,666	0
41	-	-	-	640	$ 41,600	$ 1,236,604	1	-	-	-	640	$ 41,600	$ 1,392,263	0
42	-	-	-	640	$ 41,600	$ 1,239,030	1	-	-	-	640	$ 41,600	$ 1,394,689	0
43	-	-	-	640	$ 41,600	$ 1,241,298	1	-	-	-	640	$ 41,600	$ 1,396,957	0
44	-	-	-	640	$ 41,600	$ 1,243,417	1	-	-	-	640	$ 41,600	$ 1,399,076	0
45	-	-	-	640	$ 41,600	$ 1,245,398	1	-	-	-	640	$ 41,600	$ 1,401,057	0
46-59	-	-	-	640	$ 41,600	$ 1,221,673		-	-	-	640	$ 41,600	$ 1,418,379	0
60	-	-	-	640	$ 41,600	$ 1,225,076		-	-	-	640	$ 41,600	$ 1,419,097	0

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV year 59, GW remaining in year 59

Irrigation Systems, Water Use with 640 Acres, High Water, and Four Dollar Feed Grain

In the solution below, the results for the producer with 640 acres are repeated with the assumption that the producer is more isolated and can draw water from twice as much land (1,280 acres) as is farmed. The producer is assumed to have 4 tied wells with 60 feet of water saturated sand and can use up to 13,440 acre feet. The planning horizon is 60 years.

CP(640a, $4, 4%, Hw) (Table 30) The increased groundwater supply did not change to the optimal CP investment pattern (2, 120 acre pivots) from the limited water situation under the lower feed grain prices in the first 15 years. However, irrigated corn was grown for 13 years before the switch was made to irrigated sorghum. During the second 15 year period, two 120-acre pivots were used as opposed to one pivot under the low water situation. The irrigated acres declined to 120 acres during the 31-45 year period and 120 acres were irrigated during the 46-60 year period. A second 10-year period of irrigated corn production began when the irrigated area declined from 240 the 120 acres in year 31. Aquifer depletion occurred at the end of year 59.

As anticipated the increased water supply increased annual net returns for longer periods than was possible with the limited water case. The cumulative CP NPV at 4% reached $850,152 by year 60

SDI(640a, $4, 4%, Hw) The SDI system showed more sensitivity to the increased water supply than did the CP system. Six hundred of the 640 acres were developed for irrigation purchasing four 150 systems in years 1-15. In years 16-30, three 125 acre systems were used, and a single 125 acre systems were used during years 31-45 and years 46-60. Aquifer depletion occurred in year 60. (Table 30)

Intensively irrigated GS grown in the SDI system for the entire 60 year period. Initial annual returns were in excess of $100,000 for the 10 years because of the larger area irrigated. The 60-year cumulative NPV at 4% reached $1,120,173.

CP(640a, $4, 7%, Hw) An increase in the discount rate (Table 31) with other factors held constant is expected to encourage near term resource use and discourage capital intensive investments. The optimal investment pattern of 30 years with one 120 acre CP system used for years 31-45. Aquifer depletion occurred in year 45 and the last 15 years were dryland production. This was accomplished in part by a longer (15-year) period of intensively irrigated corn. (The period of corn production was limited to 13 years with the four percent discount rate). The second period of corn production (years 31-36) was limited to six years. Again, the corn production began when only one quarter section was irrigated and the pivot could be fed by three wells. The 60-year cumulative CP NPV was $569,682.

SDI(640a, $4, 7%, Hw) The optimal pattern of SDI investment (Table 31) was also unchanged, 600 acres (4 150-acre SDI systems) for the first 15 years. However only 2 125-acre systems were used in years 16-30 followed by single 125-acre systems in years 31-45 and years 46-60. Intensively irrigated grain sorghum was produced in most years. Three years of irrigated corn were produced following the acre reduction from 600 to 250 (when two wells could feed each system). Irrigated corn was again produced when further downsizing occurred in year 31 when four wells could tie into a single system. Aquifer depletion occurred in year 60. The cumulative 60-year NPV at seven percent reached $739,125.

Table 30. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 13,440 Acre Feet of Groundwater in Texas County when Corn price is $4.48 and the Grain Sorghum Price is $4.16 per Bushel and the Discount Rate is Four Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yiel Bus	Irrig. Acre	Dry Acre	640Acre Net Rev.	Cumulative NPV 4	GW (af 13440	Crop IrT	Yiel Bus	Irrig. Acres	Dry Acre	640Acre Net Rev.	Cumulative NPV @4%	GW (aft) 13440
1	C,.9	213	240	400	$ 63,840	$ (58,615)	12991	S,.9	155	600	40	$ 119,040	$ (313,538)	12924
2	C,.9	213	240	400	$ 63,840	$ 408	12542	S,.9	155	600	40	$ 119,040	$ (203,479)	12407
3	C,.9	213	240	400	$ 63,840	$ 57,162	12093	S,.9	155	600	40	$ 119,040	$ (97,653)	11891
4	C,.9	213	240	400	$ 63,840	$ 111,732	11643	S,.9	155	600	40	$ 119,040	$ 4,103	11375
5	C,.9	213	240	400	$ 63,831	$ 164,197	11194	S,.9	155	600	40	$ 117,063	$ 100,320	10901
6	C,.9	213	240	400	$ 62,880	$ 213,892	10745	S,.9	147	600	40	$ 116,040	$ 192,028	10449
7	C,.9	213	240	400	$ 62,880	$ 261,676	10296	S,.9	147	600	40	$ 116,040	$ 280,209	9997
8	C,.9	213	240	400	$ 62,880	$ 307,622	9847	S,.9	147	600	40	$ 116,040	$ 364,998	9545
9	C,.9	213	240	400	$ 62,880	$ 351,800	9398	S,.9	147	600	40	$ 116,040	$ 446,526	9093
10	C,.9	213	240	400	$ 62,867	$ 394,271	8949	S,.9	147	600	40	$ 102,145	$ 515,532	8691
11	C,.9	213	240	400	$ 62,160	$ 434,649	8500	S,.9	135	600	40	$ 95,640	$ 577,658	8313
12	C,.9	213	240	400	$ 62,160	$ 473,474	8050	S,.9	135	600	40	$ 95,640	$ 637,394	7935
13	C,.9	213	240	400	$ 62,160	$ 510,806	7601	S,.9	135	600	40	$ 95,640	$ 694,833	7557
14	S,.6	139	240	400	$ 55,462	$ 542,833	7253	S,.9	135	600	40	$ 95,640	$ 750,063	7179
15	S,.6	139	240	400	$ 42,960	$ 566,687	7093	S,.9	135	600	40	$ 95,640	$ 803,168	6801
16	S,.6	139	240	400	$ 42,960	$ 525,555	6933	S,.9	155	375	265	$ 73,547	$ 697,160	6507
17	S,.6	139	240	400	$ 42,960	$ 547,610	6773	S,.9	147	375	265	$ 70,965	$ 733,591	6225
18	S,.6	139	240	400	$ 40,430	$ 567,567	6586	S,.9	147	375	265	$ 70,965	$ 768,621	5942
19	S,.7	140	240	400	$ 39,120	$ 586,135	6384	S,.9	147	375	265	$ 70,965	$ 802,304	5659
20	S,.7	140	240	400	$ 39,120	$ 603,989	6182	S,.9	147	375	265	$ 70,965	$ 834,692	5377
21	S,.6	134	240	400	$ 37,680	$ 620,524	6013	S,.9	147	375	265	$ 70,965	$ 865,834	5094
22	S,.6	134	240	400	$ 37,680	$ 636,424	5844	S,.9	147	375	265	$ 70,965	$ 895,778	4812
23	S,.6	134	240	400	$ 37,680	$ 651,711	5674	S,.9	147	375	265	$ 70,965	$ 924,570	4529
24	S,.6	134	240	400	$ 37,680	$ 666,411	5505	S,.9	147	375	265	$ 47,664	$ 943,165	4227
25	S,.6	134	240	400	$ 37,680	$ 680,546	5335	C,.9	144	375	265	$ 39,840	$ 958,109	3919
26	S,.6	134	240	400	$ 37,680	$ 694,136	5166	C,.9	144	375	265	$ 39,840	$ 972,479	3610
27	S,.6	134	240	400	$ 37,680	$ 707,204	4996	S,.9	97	375	265	$ 35,769	$ 984,885	3396
28	S,.6	134	240	400	$ 37,680	$ 719,770	4827	S,.9	97	375	265	$ 30,465	$ 995,044	3305
29	S,.6	134	240	400	$ 37,680	$ 731,852	4657	S,.9	97	375	265	$ 30,465	$ 1,004,813	3214
30	S,.6	134	240	400	$ 37,680	$ 743,469	4488	S,.9	93	375	265	$ 28,215	$ 1,013,512	3149
31	C,.9	213	120	520	$ 33,120	$ 735,500	4263	C,.9	215	125	515	$ 35,840	$ 997,248	2913
32	C,.9	213	120	520	$ 33,120	$ 744,941	4039	S,.9	167	125	515	$ 30,465	$ 1,005,932	2781
33	C,.9	213	120	520	$ 33,120	$ 754,019	3814	S,.9	167	125	515	$ 30,465	$ 1,014,282	2649
34	C,.9	213	120	520	$ 33,120	$ 762,748	3590	S,.9	167	125	515	$ 30,465	$ 1,022,312	2517
35	C,.9	213	120	520	$ 33,120	$ 771,141	3365	S,.9	167	125	515	$ 30,465	$ 1,030,032	2386
36	C,.9	213	120	520	$ 33,120	$ 779,211	3141	S,.9	167	125	515	$ 30,465	$ 1,037,455	2254
37	C,.9	213	120	520	$ 33,120	$ 786,971	2916	S,.9	167	125	515	$ 29,558	$ 1,044,381	2130
38	C,.9	213	120	520	$ 33,120	$ 794,433	2691	S,.9	147	125	515	$ 26,215	$ 1,050,286	2036
39	C,.9	213	120	520	$ 33,120	$ 801,607	2467	S,.9	147	125	515	$ 26,215	$ 1,055,965	1941
40	C,.9	213	120	520	$ 32,863	$ 808,452	2244	S,.9	147	125	515	$ 26,215	$ 1,061,425	1847
41	S,.9	134	120	520	$ 18,720	$ 812,201	2129	S,.9	147	125	515	$ 26,215	$ 1,066,676	1753
42	S,.9	134	120	520	$ 18,720	$ 815,806	2014	S,.9	147	125	515	$ 26,215	$ 1,071,724	1659
43	S,.9	134	120	520	$ 18,720	$ 819,273	1899	S,.9	147	125	515	$ 26,215	$ 1,076,578	1565
44	S,.9	134	120	520	$ 18,720	$ 822,606	1784	S,.9	147	125	515	$ 26,215	$ 1,081,246	1471
45	S,.9	134	120	520	$ 18,720	$ 825,811	1669	S,.9	147	125	515	$ 26,215	$ 1,085,734	1376
46-59	S,.9	134	120	520	$ 18,720	$ 849,787	60	S,.9	147	125	515	$ 26,215	$ 1,118,211	58
60	-	-	0	640	$ 3,840	$ 850,152	60	S,.9	147	125	515	$ 26,215	$ 1,120,703	0

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV, GW remaining in year 59

Table 31. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 13,440 Acre Feet of Groundwater in Texas County when Corn price is $4.48 and the Grain Sorghum Price is $4.16 per Bushel and the Discount Rate is Seven Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yielc Bus	Irrig. Acre:	Dry Acre	640Acre Net Rev.	Cumulative NPV 4	GW (aft) 13440	Crop IrT	Yield Bus	Irrig Acre	Dry Acres	640Acre Net Rev.	Cumulative NPV @4%	GW (aft) 13440
1	C,.9	213	240	400	$ 63,840	$ (60,336)	12,991	S,.9	155	600	40	$119,040	$(316,748)	12,924
2	C,.9	213	240	400	$ 63,840	$ (4,576)	12,542	S,.9	155	600	40	$119,040	$(212,774)	12,407
3	C,.9	213	240	400	$ 63,840	$ 47,536	12,093	S,.9	155	600	40	$119,040	$(115,601)	11,891
4	C,.9	213	240	400	$ 63,840	$ 96,240	11,643	S,.9	155	600	40	$119,040	$ (24,786)	11,375
5	C,.9	213	240	400	$ 63,831	$ 141,751	11,194	S,.9	155	600	40	$117,063	$ 58,678	10,901
6	C,.9	213	240	400	$ 62,880	$ 183,650	10,745	S,.9	147	600	40	$116,040	$ 136,000	10,449
7	C,.9	213	240	400	$ 62,880	$ 222,809	10,296	S,.9	147	600	40	$116,040	$ 208,264	9,997
8	C,.9	213	240	400	$ 62,880	$ 259,405	9,847	S,.9	147	600	40	$116,040	$ 275,801	9,545
9	C,.9	213	240	400	$ 62,880	$ 293,608	9,398	S,.9	147	600	40	$116,040	$ 338,919	9,093
10	C,.9	213	240	400	$ 62,867	$ 325,566	8,949	S,.9	147	600	40	$102,145	$ 390,844	8,691
11	C,.9	213	240	400	$ 62,160	$ 355,098	8,500	S,.9	135	600	40	$ 95,640	$ 436,282	8,313
12	C,.9	213	240	400	$ 62,160	$ 382,698	8,050	S,.9	135	600	40	$ 95,640	$ 478,747	7,935
13	C,.9	213	240	400	$ 62,160	$ 408,492	7,601	S,.9	135	600	40	$ 95,640	$ 518,434	7,557
14	C,.9	213	240	400	$ 62,160	$ 432,599	7,152	S,.9	135	600	40	$ 95,640	$ 555,525	7,179
15	C,.9	213	240	400	$ 61,595	$ 454,924	6,708	S,.9	135	600	40	$ 95,640	$ 590,189	6,801
16	S,.9	148	240	400	$ 41,040	$ 428,177	6,449	C,.9	215	250	390	$ 62,169	$ 549,802	6,373
17	S,.7	140	240	400	$ 39,120	$ 440,562	6,248	C,.9	202	250	390	$ 60,840	$ 569,063	5,956
18	S,.7	140	240	400	$ 39,120	$ 452,136	6,046	C,.9	202	250	390	$ 57,077	$ 585,950	5,656
19	S,.7	140	240	400	$ 39,120	$ 462,953	5,844	S,.9	161	250	390	$ 55,090	$ 601,182	5,419
20	S,.7	140	240	400	$ 39,120	$ 473,062	5,643	S,.9	161	250	390	$ 55,090	$ 615,419	5,182
21	S,.7	140	240	400	$ 39,120	$ 482,510	5,441	S,.9	161	250	390	$ 55,090	$ 628,724	4,944
22	S,.7	140	240	400	$ 39,120	$ 491,340	5,240	S,.9	161	250	390	$ 55,090	$ 641,158	4,707
23	S,.6	134	240	400	$ 37,680	$ 499,289	5,070	S,.9	161	250	390	$ 55,090	$ 652,779	4,470
24	S,.6	134	240	400	$ 37,680	$ 506,717	4,901	S,.9	147	250	390	$ 48,590	$ 662,359	4,281
25	S,.6	134	240	400	$ 37,680	$ 513,660	4,731	S,.9	147	250	390	$ 48,590	$ 671,311	4,093
26	S,.6	134	240	400	$ 37,680	$ 520,148	4,562	S,.9	147	250	390	$ 48,590	$ 679,678	3,905
27	S,.6	134	240	400	$ 35,085	$ 525,794	4,380	S,.9	147	250	390	$ 48,590	$ 687,498	3,716
28	S,.7	129	240	400	$ 32,640	$ 530,703	4,187	S,.9	147	250	390	$ 48,590	$ 694,806	3,528
29	S,.7	129	240	400	$ 31,440	$ 535,123	4,018	S,.9	147	250	390	$ 48,590	$ 701,636	3,340
30	S,.6	125	240	400	$ 31,440	$ 539,253	3,849	S,.9	147	250	390	$ 48,590	$ 708,019	3,151
31	S,.6	125	120	520	$ 33,120	$ 535,953	3,625	C,.9	215	125	515	$ 35,840	$ 701,283	2,916
32	C,.9	213	120	520	$ 33,120	$ 539,753	3,400	C,.9	215	125	515	$ 35,840	$ 705,395	2,680
33	C,.9	213	120	520	$ 33,120	$ 543,305	3,175	C,.9	215	125	515	$ 31,017	$ 708,722	2,538
34	C,.9	213	120	520	$ 33,120	$ 546,624	2,951	S,.9	167	125	515	$ 30,465	$ 711,775	2,406
35	C,.9	213	120	520	$ 33,120	$ 549,726	2,726	S,.9	167	125	515	$ 30,465	$ 714,628	2,274
36	C,.9	213	120	520	$ 33,120	$ 552,626	2,502	S,.9	167	125	515	$ 27,802	$ 717,062	2,165
37	C,.9	213	120	520	$ 30,306	$ 555,105	2,319	S,.9	147	125	515	$ 26,215	$ 719,206	2,071
38	S,.6	139	120	520	$ 23,400	$ 556,894	2,239	S,.9	147	125	515	$ 26,215	$ 721,211	1,977
39	S,.6	139	120	520	$ 18,720	$ 558,232	2,124	S,.9	147	125	515	$ 26,215	$ 723,084	1,883
40	S,.9	134	120	520	$ 18,720	$ 559,482	2,009	S,.9	147	125	515	$ 26,215	$ 724,835	1,789
41	S,.9	134	120	520	$ 18,720	$ 560,650	1,894	S,.9	147	125	515	$ 26,215	$ 726,471	1,695
42	S,.9	134	120	520	$ 18,720	$ 561,742	1,779	S,.9	147	125	515	$ 26,215	$ 728,000	1,600
43	S,.9	134	120	520	$ 18,720	$ 562,762	1,664	S,.9	147	125	515	$ 26,215	$ 729,429	1,506
44	S,.9	134	120	520	$ 18,720	$ 563,716	1,549	S,.9	147	125	515	$ 26,215	$ 730,764	1,412
45	S,.9	134	120	520	$ 18,720	$ 564,607	1,434	S,.9	147	125	515	$ 26,215	$ 732,013	1,318
46-59	S, .7	131	120	520	$ 18,360	$ 569,616	4	S, .8	145	125	515	$ 25,679	$ 738,733	49
60	S, .6	125	0	640	$ 3,840	$ 569,682	4	S ,.7	133.7	125	515	$ 22,715	$ 739,125	-

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level
GW(aft): acre feet of ground water remaining at end of year
46-59: average acres, net revenue, cumulative NPV, GW remaining in year 59

Irrigation Systems, Water Use with 640 Acres, High Water, and Five Dollar Feed Grain

CP(640a, $5, 4%, Hw) (Table 32) An increase in the feed grain price from $4 to $5 did not change the optimal CP investment pattern (2, 120 acre pivots) from the limited water situation under the lower feed grain prices in the first 15 years. Until year 15, the CP system produces corn at full irrigation (IrT.90) then it switches to grain sorghum at .7 stress during the transformation period (year 16), however, grain sorghum continues until the pivot is replaced (year 30) at IrT .6. From year 31-44, corn is grown with full irrigation on a 120-acre field, leaving the rest of the land for dryland practices. The changes between irrigated corn and sorghum are determined by the relative area of land with equipment for irrigation and the remaining groundwater supply. Corn is grown when the supply of groundwater is large relative to the land under irrigation. In Table 32 in year 30, the producer has 240 acres under two pivots. In year 31, there is only one pivot so land that can be irrigated becomes scarce relative to the supply of groundwater. However as the ground water supply becomes more depleted and limiting, it is optimal to switch back to grain sorghum. One pivot is purchased at the year 46 to irrigated sorghum till year 59 leaving 456 acre feet of water in the aquifer.

Table 32. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 13,440 Acre Feet of Groundwater in Texas County when Corn price is $5.48 and the Grain Sorghum Price is $5.09 per Bushel and the Discount Rate is Four Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yield Bus	Irrig. Acre:	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 13,440	Crop IrT	Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 13,440
1	C,.9	213	240	400	$ 138,560	$ 13,231	12,991	S,.9	155	600	40	$ 208,400	$ (227,615)	12,924
2	C,.9	213	240	400	$ 138,560	$ 141,337	12,542	S,.9	155	600	40	$ 208,400	$ (34,938)	12,407
3	C,.9	213	240	400	$ 138,560	$ 264,517	12,093	S,.9	155	600	40	$ 208,400	$ 150,329	11,891
4	C,.9	213	240	400	$ 138,560	$ 382,958	11,643	S,.9	155	600	40	$ 208,400	$ 328,470	11,375
5	C,.9	213	240	400	$ 138,551	$ 496,837	11,194	S,.9	155	600	40	$ 202,865	$ 495,210	10,901
6	C,.9	213	240	400	$ 137,600	$ 605,585	10,745	S,.9	147	600	40	$ 200,000	$ 653,273	10,449
7	C,.9	213	240	400	$ 137,600	$ 710,149	10,296	S,.9	147	600	40	$ 200,000	$ 805,257	9,997
8	C,.9	213	240	400	$ 137,600	$ 810,692	9,847	S,.9	147	600	40	$ 200,000	$ 951,395	9,545
9	C,.9	213	240	400	$ 137,600	$ 907,368	9,398	S,.9	147	600	40	$ 200,000	$ 1,091,912	9,093
10	C,.9	213	240	400	$ 137,587	$ 1,000,317	8,949	S,.9	147	600	40	$ 182,018	$ 1,214,877	8,691
11	C,.9	213	240	400	$ 136,880	$ 1,089,232	8,500	S,.9	135	600	40	$ 173,600	$ 1,327,644	8,313
12	C,.9	213	240	400	$ 136,880	$ 1,174,727	8,050	S,.9	135	600	40	$ 173,600	$ 1,436,074	7,935
13	C,.9	213	240	400	$ 136,880	$ 1,256,933	7,601	S,.9	135	600	40	$ 173,600	$ 1,540,334	7,557
14	C,.9	213	240	400	$ 136,880	$ 1,335,978	7,152	S,.9	135	600	40	$ 173,600	$ 1,640,583	7,179
15	C,.9	213	240	400	$ 135,731	$ 1,411,345	6,703	S,.9	135	600	40	$ 173,600	$ 1,736,977	6,801
16	S,.7	140	120	520	$ 93,920	$ 1,397,420	6,479	C,.9	215	250	390	$ 136,520	$ 1,713,015	6,373
17	S,.7	140	120	520	$ 93,920	$ 1,445,636	6,254	C,.9	202	250	390	$ 134,600	$ 1,782,115	5,956
18	S,.6	134	120	520	$ 91,040	$ 1,490,576	6,030	C,.9	202	250	390	$ 134,600	$ 1,848,558	5,539
19	S,.6	134	120	520	$ 91,040	$ 1,533,788	5,805	C,.9	202	250	390	$ 134,600	$ 1,912,444	5,121
20	S,.6	134	120	520	$ 91,040	$ 1,575,337	5,581	C,.9	202	250	390	$ 134,600	$ 1,973,874	4,704
21	S,.6	134	120	520	$ 91,040	$ 1,615,288	5,356	S,.9	161	250	390	$ 115,235	$ 2,024,443	4,467
22	S,.6	134	120	520	$ 91,040	$ 1,653,703	5,131	S,.9	147	250	390	$ 105,600	$ 2,069,001	4,279
23	S,.6	134	120	520	$ 91,040	$ 1,690,640	4,907	S,.9	147	250	390	$ 105,600	$ 2,111,846	4,090
24	S,.6	134	120	520	$ 91,040	$ 1,726,157	4,682	S,.9	147	250	390	$ 105,600	$ 2,153,043	3,902
25	S,.6	134	120	520	$ 91,040	$ 1,760,308	4,458	S,.9	147	250	390	$ 105,600	$ 2,192,655	3,714
26	S,.6	134	120	520	$ 91,040	$ 1,793,145	4,233	S,.9	147	250	390	$ 105,600	$ 2,230,744	3,525
27	S,.6	134	120	520	$ 91,040	$ 1,824,719	4,009	S,.9	147	250	390	$ 105,600	$ 2,267,368	3,337
28	S,.6	134	120	520	$ 88,981	$ 1,854,392	3,784	S,.9	147	250	390	$ 105,600	$ 2,302,583	3,149
29	S,.6	125	120	520	$ 82,880	$ 1,880,968	3,560	S,.9	147	250	390	$ 105,600	$ 2,336,444	2,960
30	S,.6	125	120	520	$ 82,880	$ 1,906,521	3,335	S,.9	147	250	390	$ 105,600	$ 2,369,002	2,772
31	C,.9	213	120	520	$ 89,360	$ 1,925,647	3,110	C,.9	215	125	515	$ 82,773	$ 2,366,652	2,619
32	C,.9	213	120	520	$ 89,360	$ 1,951,120	2,886	S,.9	167	125	515	$ 80,225	$ 2,389,521	2,487
33	C,.9	213	120	520	$ 89,360	$ 1,975,613	2,661	S,.9	167	125	515	$ 80,225	$ 2,411,510	2,356
34	C,.9	213	120	520	$ 89,360	$ 1,999,164	2,437	S,.9	167	125	515	$ 80,225	$ 2,432,653	2,224
35	C,.9	213	120	520	$ 89,360	$ 2,021,809	2,216	S,.9	147	125	515	$ 73,600	$ 2,451,305	2,129
36	C,.9	213	120	520	$ 89,360	$ 2,043,583	2,040	S,.9	147	125	515	$ 73,600	$ 2,469,239	2,035
37	C,.9	213	120	520	$ 89,360	$ 2,064,520	1,864	S,.9	147	125	515	$ 73,600	$ 2,486,483	1,941
38	C,.9	213	120	520	$ 89,360	$ 2,084,651	1,688	S,.9	147	125	515	$ 73,600	$ 2,503,064	1,847
39	C,.9	213	120	520	$ 74,491	$ 2,100,787	1,512	S,.9	147	125	515	$ 73,600	$ 2,519,007	1,753
40	C,.9	164	120	520	$ 68,240	$ 2,115,001	1,336	S,.9	147	125	515	$ 73,600	$ 2,534,337	1,659
41	C,.9	164	120	520	$ 68,240	$ 2,128,668	1,160	S,.9	147	125	515	$ 73,600	$ 2,549,078	1,564
42	C,.9	164	120	520	$ 68,240	$ 2,141,809	984	S,.9	147	125	515	$ 73,600	$ 2,563,251	1,470
43	C,.9	164	120	520	$ 68,240	$ 2,154,445	808	S,.9	147	125	515	$ 73,600	$ 2,576,879	1,376
44	C,.9	164	120	520	$ 63,333	$ 2,165,721	632	S,.9	147	125	515	$ 73,600	$ 2,589,984	1,282
45	S,.7	129	120	520	$ 63,320	$ 2,176,562	456	S,.9	147	125	515	$ 73,600	$ 2,602,584	1,188
46-59	-	-	-	640	$ 41,600	$ 2,287,119	456	S,.7	141	250	390	$ 71,314	$ 2,710,249	82
60	-	-	-	640	$ 41,600	$ 2,291,073	456	S,.7	134	54.17	586	$ 53,300	$ 2,722,097	-

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV, GW remaining in year 59

Table 33. Comparison of Optimal Irrigation Strategies with Center Pivot and Sub Surface Drip Irrigation on 640 Acres with 13,440 Acre Feet of Groundwater in Texas County when Corn price is $5.48 and the Grain Sorghum Price is $5.09 per Bushel and the Discount Rate is Seven Percent

	Center Pivot							Sub Surface Drip						
Year	Crop IrT	Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulat NPV	GW (aft) 13440	Crop IrT	Yield Bus	Irrig. Acres	Dry Acres	640Acre Net Rev.	Cumulative NPV	GW (aft) 13440
1	C,.9	213	240	400	138560	9495	12991	C,.8	184	600	40	$ 230,600	$ (212,486)	12640
2	C,.9	213	240	400	138560	130519	12542	S,.9	155	600	40	$ 208,400	$ (30,461)	12124
3	C,.9	213	240	400	138560	243625	12093	S,.9	155	600	40	$ 208,400	$ 139,655	11607
4	C,.9	213	240	400	138560	349332	11643	S,.9	155	600	40	$ 206,674	$ 297,326	11104
5	C,.9	213	240	400	138551	448117	11194	S,.9	147	600	40	$ 200,000	$ 439,923	10652
6	C,.9	213	240	400	137600	539806	10745	S,.9	147	600	40	$ 200,000	$ 573,192	10200
7	C,.9	213	240	400	137600	625496	10296	S,.9	147	600	40	$ 200,000	$ 697,742	9748
8	C,.9	213	240	400	137600	705581	9847	S,.9	147	600	40	$ 200,000	$ 814,143	9296
9	C,.9	213	240	400	137600	780426	9398	S,.9	147	600	40	$ 193,990	$ 919,661	8861
10	C,.9	213	240	400	137587	850368	8949	S,.9	135	600	40	$ 173,600	$ 1,007,911	8483
11	C,.9	213	240	400	136880	915399	8500	S,.9	135	600	40	$ 173,600	$ 1,090,387	8105
12	C,.9	213	240	400	136880	976175	8050	S,.9	135	600	40	$ 173,600	$ 1,167,467	7727
13	C,.9	213	240	400	136880	1032976	7601	S,.9	135	600	40	$ 173,600	$ 1,239,505	7349
14	C,.9	213	240	400	136880	1086060	7152	S,.9	135	600	40	$ 173,600	$ 1,306,830	6971
15	C,.9	213	240	400	136206	1135428	6703	S,.9	135	564	76	$ 165,635	$ 1,366,864	6616
16	C,.9	213	120	520	89840	1145535	6479	C,.9	202	250	390	$ 134,600	$ 1,351,011	6198
17	C,.9	213	120	520	89840	1173976	6254	C,.9	202	250	390	$ 134,600	$ 1,393,622	5781
18	C,.9	213	120	520	89840	1200557	6030	C,.9	202	250	390	$ 134,600	$ 1,433,446	5364
19	C,.9	213	120	520	89840	1225398	5805	C,.9	202	250	390	$ 134,600	$ 1,470,664	4946
20	C,.9	213	120	520	89840	1248615	5581	C,.9	202	250	390	$ 134,600	$ 1,505,447	4529
21	C,.9	213	120	520	89840	1270312	5356	C,.9	202	250	390	$ 118,601	$ 1,534,090	4191
22	C,.9	213	120	520	89840	1290590	5131	C,.9	179	250	390	$ 115,850	$ 1,560,239	3866
23	C,.9	213	120	520	89840	1309542	4907	C,.9	179	250	390	$ 115,850	$ 1,584,678	3541
24	C,.9	213	120	520	89840	1327253	4682	C,.9	179	250	390	$ 105,614	$ 1,605,499	3352
25	C,.9	213	120	520	89807	1343800	4458	S,.9	147	250	390	$ 105,600	$ 1,624,956	3164
26	C,.9	213	120	520	89360	1359188	4233	S,.9	147	250	390	$ 105,600	$ 1,643,139	2975
27	C,.9	213	120	520	89360	1373568	4009	S,.9	147	250	390	$ 105,600	$ 1,660,134	2787
28	C,.9	213	120	520	89360	1387008	3784	S,.9	147	250	390	$ 105,600	$ 1,676,016	2599
29	C,.9	213	120	520	89360	1399569	3560	S,.9	147	250	390	$ 105,600	$ 1,690,860	2410
30	C,.9	213	120	520	89360	1411308	3335	S,.9	147	250	390	$ 105,600	$ 1,704,732	2222
31	C,.9	213	120	520	89360	1414913	3110	C,.9	179	125	515	$ 78,725	$ 1,703,261	2059
32	C,.9	213	120	520	89360	1425166	2886	C,.9	179	125	515	$ 78,725	$ 1,712,294	1897
33	C,.9	213	120	520	89360	1434749	2661	C,.9	179	125	515	$ 78,725	$ 1,720,736	1734
34	C,.9	213	120	520	89360	1443704	2437	C,.9	179	125	515	$ 78,725	$ 1,728,626	1572
35	C,.9	213	120	520	87520	1451902	2216	C,.9	179	125	515	$ 78,725	$ 1,736,000	1409
36	C,.9	164	120	520	68240	1457875	2040	C,.9	179	125	515	$ 78,725	$ 1,742,891	1247
37	C,.9	164	120	520	68240	1463458	1864	C,.9	179	125	515	$ 78,725	$ 1,749,331	1084
38	C,.9	164	120	520	68240	1468675	1688	C,.9	179	125	515	$ 78,725	$ 1,755,350	922
39	C,.9	164	120	520	68240	1473551	1512	C,.9	179	125	515	$ 78,725	$ 1,760,976	759
40	C,.9	164	120	520	68240	1478108	1336	C,.9	179	125	515	$ 78,725	$ 1,766,233	597
41	C,.9	164	120	520	68240	1482367	1160	C,.9	179	125	515	$ 78,725	$ 1,771,146	434
42	C,.9	164	120	520	68240	1486348	984	C,.9	179	125	515	$ 78,725	$ 1,775,738	272
43	C,.9	164	120	520	68240	1490068	808	C,.9	179	125	515	$ 74,252	$ 1,779,786	169
44	C,.9	164	120	520	68240	1493544	632	S,.9	147	125	515	$ 73,600	$ 1,783,536	75
45	C,.9	164	120	520	68240	1496793	456	S,.9	147	125	515	$ 73,600	$ 1,787,040	0
46-59	-	-	-	640	41600	1514116	456	S,.9	179	-	640	$ 41,600	$ 1,800,952	-
60	-	-	-	640	41600	1514834	456	-	-	-	640	$ 41,600	$ 1,801,893	-

Irt: Irrigation trigger: An irrigation is initiated when moisture level is at or below the indicated level

GW(aft): acre feet of ground water remaining at end of year

46-59: average acres, net revenue, cumulative NPV, GW remaining in year 59

Summary and Conclusions.

The study began by using the EPIC simulation model to estimate irrigated corn and sorghum yields in Texas County under alternative irrigation well capacities and soil moisture levels (irrigation trigger) to initiate an irrigation with central pivot and subsurface drip irrigation systems. The EPIC simulation model was calibrated against the limited irrigation data available from research and variety trials at the Oklahoma Panhandle Research and Extension Center at Goodwell, Oklahoma. Data from irrigation research and variety trials from Kansas Stations at Garden City and Tribune and from the ARS station at Bushland, Texas and variety trials from the Texas Panhandle were also used as reference points for the EPIC simulated yields in Texas County, Oklahoma.

Before the simulation could begin, considerable effort was made to construct a daily weather data base covering a 50 year period from 1965 through 2014 to represent long-term weather conditions in the Oklahoma Panhandle. The fifty year daily weather series was used to estimate the mean yield for corn and grain sorghum under full and deficit irrigation.

In the center pivot simulation, the minimum irrigation frequency was determined by the number of days it would take to complete one revolution of the pivot while applying 1.2 acre inches. The 50-year daily simulation was used to estimate the mean yield, given an irrigation trigger and minimum irrigation frequency. No attempt was made to estimate a continuous response function of irrigated corn or grain sorghum to various levels of irrigation because values of water stress also changed along with the level of irrigation. Rather, the estimated yields from different irrigation levels and water stress values were used as discrete opportunities.

Enterprise budgets were constructed to determine the static profitability of the alternative irrigation levels and irrigation triggers (moisture levels to initiate an irrigation). These budgets themselves provide starting points for determining the long term use of groundwater. The net returns over variable costs and the quantity of groundwater used were used directly in developing programming models.

Several scenarios were examined to determine their effect on the optimal value and long-term use of ground water. The first scenario examined was the different producer's decision objectives. The difference in multiyear earnings between producers who followed a series of BSYC (Best Single Year Choices) or always selected the enterprise that gave the highest immediate return without considering the quantity of ground water required. This was contrasted with the producer who followed a crop selection and an irrigation level that maximized the long-term discounted profits (MNPV). This was done for a producer with a 160 acre and with a 640 acre section. Center pivot irrigation systems were used in the comparison. Returns in initial years favored the BSYC producers but after 3 to 4 years, the higher annual returns and increased groundwater levels favored the MNPV producer. This was because the MNPV producer selected grain sorghum (which used less water than corn) the resulting NPV of the planning period always favored the MNPV producer.

The main focus of the report is on a comparison between net returns from conventional center pivot (CP) systems and sub surface drip (SDI) systems. The SDI system has higher water use efficiency because it was assumed there was 10 percent less water lost to evaporation and runoff. The sensitivity of returns and water use rates to changes in feed grain prices, interest rates, holding size, and initial groundwater supplies was analyzed. The feed grain prices used were (low with $4.48 corn and $4.16 grains sorghum) and high (with $5.48/bus. corn and $5.09/bus. grain sorghum). The discount rates used were four and seven percent. The holding sizes used were 160 acres and 640 acres. In the case of the 640 acre holding, two supplies of groundwater were considered.

The optimal MNPV investment for CP and SDI systems on the 160 acre field size were analyzed with a 30-year planning horizon. The SDI was found to be more profitable than the CP systems. The 30-year MNPV values for the four cases analyzed were,

	CP		SDI	
Discount Rate	4%	7%	4%	7%
Feed Grain Price				
Low (C, $4.18; S,4.16)	$106,607	$78,286	$160,861	$115,296
High (C, $548; S, $5,09)	$344,489	$260,312	$436,103	$313,318

Adoption of the SDI system did not always extend the life of the aquifer. However, more grain was produced from the amount of groundwater used with the SDI system than with the CP system.

The 640 acre field with four existing wells offers a conservation possibility to the producer not presented by the 160 acre case. The producer may leave one or more 160 acre subfields unirrigated and increase the quantity of water supplied to the one or more 160 acre fields that are irrigated. This may also reduce the drawn down to in each pumping well. The emphasis however, was on the comparison between the CP and SDI systems. Two water supplies were considered. The low water supply considered only the water under 640 field. This amount with 60 feet of water saturated sand was estimated to be 6,280 acre feet. The larger amount was for a producer located where only 50 percent of the surrounding area was irrigated. The water supply in the second case was 13,440 acre feet. A 60-year planning horizon was used in the second case in order to determine the optimal use of the larger groundwater supply. The Cumulative NPV from CP and SDI investments for the 640 acre field were,

	CP		SDI	
Discount Rate	4%	7%	4%	7%
Limited Water				
Feed Grain Price				
Low (C, $4.18; S,4.16)	$ 618,708	$ 448,998	$ 725,405	$ 507,592
High (C, $548; S, $5,09)	$1,839,290	$1,225,076	$2,052016	$1,419,097
High Water				
Feed Grain Price				
Low (C, $4.18; S,4.16)	$ 850152	$ 569,682	$1,120,703	$ 739,125
High (C, $548; S, $5,09)	$2,291,073	$1,514,834	$2,722,097	$1,801,893

The MNPV results indicated that even with the higher feed grain prices, it was optimal for the CP producer to leave two quarter sections unirrigated and use the wells from those quarters to increase the GPM to pivots on the irrigated quarter sections. By contrast, the SDI producer would develop 600 acres (4- 150 acre SDI systems) for irrigation in the first 15 years with the five dollar feed grain prices. As shown above, the NPV from the SDI system was always more profitable than the CP for the 640 acre field.

Limitations

The study shows the advantage of MNPV from the remaining groundwater. This would be optimal if followed by all producers. We did not have the resources in this study to address the rate of groundwater flow from under one producer's field to that of another producer. If one producer follows the BSYC while the neighbor follows the MNPV strategy, there would be a difference in ground water levels which would flow toward the BSYC producer. Hopefully, the implications of this interaction can be addressed through the use of groundwater models in future studies.

The heavy reliance on simulated data is another limitation but is unavoidable. The authors have used tested simulation models and attempted to calibrate them against observed data where possible.

References

Almas, L. K. and W. A. Colette, 2008. Economic Optimization of Groundwater Resources: A Case of Texas County in the Oklahoma Panhandle. World Environmental and Water Resources Congress, 2008, Ahupua'a.

Ciriacy-Wantrup, S.V. (1963). *Resource Conservation: Economics and Policy*. Univ. Rev. Ed., Ca. Div. Ag. Sciences, Ag. Exp. Stat., Berkley, Ca.

Guru, M. V., & Horne, J. E. (2000). The Ogallala aquifer. Retrieved from. www.kerrcenter.com/publications/ogallala_aquifer.pdf.

Israelsen, O.W. and V.E. Hansen, (1962). *Irrigation Principles and Practices*, J. Wiley and Sons Inc., New York.

Karassik, I. J., J.P. Messina, P. Cooper, C. C. Heald, (2001). *Pump Handbook*, McGraw-Hill, 3'rd Ed., New York.

Luckey, R.R, N.I. Osborn, M.F. Becker, and W.J. Williams. 2000. Water flow in the High Plains Aquifer in northwestern Oklahoma. USGS Fact Sheet 081-00. Oklahoma City, Ok.: United States Geological Survey.

Dhuyvetter, K. C. and T. J. Dumler, (2011). KSU Irrigation Energy Costs: A Spreadsheet Program to Compare the Costs of Irrigation Energy Options. Agricultural Extension Service, Kansas State University,

Schwab, G. O.;Fangmeier, D. D.;Elliot, W. J.;Frevert, R. K. *Soil and water conservation engineering.* Thomas Learning, 1993 pp. xiv + 507 pp.

Qi, S.L. and Christenson, S. 2010. Assessing groundwater availability the the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, Texas and Wyoming. U.S. Geological Survey Fact Sheet 2010-3008

USDA-Natural Resources Conservation Service (2014). Geospatial Data Gateway, USDA, NRCS, https://gdg.sc.egov.usda.gov, Accessed during 2014.

Appendix A Structure of Mixed Integer Programming Model for Subsurface Drip.

The SDI offers the producers more choices than the CP on a 160 acre field in that any part of the field (given suitable soil conditions) can be developed. In the study, the possible sizes of the SDI were given in 25 acre increments from 50 to 150 acres. An outline of a mixed integer programming model where the producer considers the purchase of a 50 acre, a 75 acre, a 100 acre, a 125 acre, or a 150 acre system is shown in Figure A1 below over a 15 year planning horizon. If the producer purchases the 50 acre system unit, then the producer is allowed to grow 50 acres of irrigated sorghum for each of the 15 years over the expected life of the system. The producer has 160 acres of land available each year and 280 acre feet for ground water available in each of six aquifer layers under the 160 acres. Any irrigation water not used in year 1 in each layer is transferred to the same layer for use in the following year. When the water at the top of the aquifer (layer 6) is exhausted, the producer begins pumping from the next lower layer in the aquifer.

Figure A1. Illustration of Programming Model with Alternative Sizes and Irrigation Strategies and Non-irrigated Crop Choices for a Quarter Section and a 15 Year Planning Horizon.

		RHS	Integer Variables					Year one Crop Choices									Year 3 crop				Year 15 Crop Choices							
			IP101	IP201	IP301	IP401																						
	Year		-60000	-120000	-180000	-240000		Sf30116	..	Sf90116	..	Sa30111	..	Sa90111	Szo0100							Sf31516	..	Sf91516	..	Sa31511	..	Szo0100
Irg.Size	1	1	1	1	1	1	1																					
IP01	1	0	-50	-75	-100	-125	-150	1	..	1	..	1	..	1														
IP02	2	0	-50	-75	-100	-125	-150																					
IP03	3	0	-50	-75	-100	-125	-150										1	..	1									
IP14	14	0	-50	-75	-360	-125	-150																					
IP15	15	0	-50	-75	-360	-125	-150															1	..	1		1	..	
TA01	1	160						1	..	1	..	1	..	1	1													
W601	1	280						0.6	..	1.1	..																	
W501	1	280																										
W102	1	280										0.18	..	0.2														
TA03	3	160															1	..	1									
																	..	..	..									
TA15	15	160																				1	..	1		1	..	1
W615	15	0																				0.6	..	1	..			
W515	15	0																										
W115	15	0																								0.2	..	0

The problem is for the Producer to choose the profit maximizing size of system and also choose the crops to be grown (only sorghum is shown in Figure A1) and the irrigation intensity each year over the planning horizon.

For a producer with a 640 acre section, the acreages and the costs of the SDI systems are scaled up. For a longer planning horizon, (in 15 year increments), the system purchase costs are discounted and repeated.