Irrigation System Choice in Oklahoma Panhandle: Center Pivot versus Subsurface Drip

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Introduction

Background

This study compares the net returns from corn or sorghum, groundwater, and aquifer life from Center Pivot (CP) and Subsurface Drip (SDI) irrigation systems. The irrigation study in Oklahoma Panhandle Area (OPA) has 106,236 acres of irrigated corn, 19,457 acres of irrigated sorghum, and 64,671 acres of irrigated winter wheat. Data from Oklahoma Water Resources Board (OWRB, 2012) indicates that the annual groundwater level of the Ogallala aquifer underlying OPA has been declining at a rate of 1.0 to 2.5 feet since 1995. The annual recharge estimated to be less than 0.2 feet.

Irrigation experiments on corn and sorghum conducted at the Oklahoma Panhandle Research and Experimental Center (OPREC) to determine the yield potential and water-use efficiency (WUE) with CP and SDI is the basis of this study. The experimental applied irrigation amounts and frequencies simulated producers well capacities from 200, 400,…, 800 Gallons Per Minute (GPM). The frequencies for the CP irrigation were calculated based on the amount of time required to complete one pivot revolution for applying 1.4 acre-inches. The experiment also evaluated the performance of SDI with the above well capacities. The study verified that sorghum had higher WUE than corn, and that SDI had higher WUE than the CP. Table 1 shows the average yield and irrigation of variety trials performed at OPREC.

Table 1. OPREC variety trial average of corn and grain sorghum performed between 2005 to 2014

	Grain Yield (bu./ac)		Irrigation (inches)	
Year	Corn	Grain Sorghum	Corn	Grain Sorghum
2005	196	149	17.0	10.0
2006	183	143	20.0	5.0
2007	178	92	20.0	7.0
2008	246	115	21.0	6.3
2009	226	149	21.0	8.8
2010	179	145	18.0	7.8
2011	112	166	24.0	12.1
2012	240	152	25.5	11.3
2013	236	145	25.5	10.0
2014	228	159	18.1	8.8
Average	202	142	21.0	9.0

Objectives

a. Extend available but limited crop research on irrigated corn and sorghum yields, and water use to be more representative of long term weather conditions in the OPA.

b. Estimate the implications of recent United States Geological Survey (USGS) published Ogallala parameters on pumping cost considering pumping drawdown on various levels of pumping as the water table declines.

c. Determine the optimal irrigation level and choice between irrigated corn and grain sorghum that maximizes the net benefits from the remaining groundwater supply.

d. Determine the optimal and most profitable sequence of CP and SDI investments over the remaining life of the aquifer.

e. Determine the difference in discounted profits earned by producers who maximizes long-term Net Present Value (NPV) using CP and SDI systems from the remaining groundwater.

Methods and Procedures

The methods have two basic steps. The first step is construction of 120 acre CP and five sizes of SDI irrigated crop budgets with long-term yields for corn and sorghum supplied with well capacities of 100, …, 800 under full and deficit irrigation. The second step used the budgets in a Mixed-Integer Programming (MIP) model to determine the maximum NPV from an irrigation section (640 acre) over a 60 year period.

Environmental Policy Impact Calculator (EPIC)

To extend the irrigation studies in the OPA, the EPIC model was calibrated against available irrigated corn and sorghum experiments and variety trial results over the period from 2005-2014. The irrigation simulations for corn and grain sorghum were designed to estimate yields for a 120-acre CP and 50, 75, 100, 125, 150 acre sizes of SDI at 100, …, 800 GPM. Irrigation frequencies used in EPIC for a 120 acre CP and a 125 acre SDI are shown in Table 2. The EPIC model results were compared against corn and sorghum field experiments conducted at OPREC. Once the validation was acceptable, the EPIC model was used to generate expected corn and sorghum yields for the above well capacities and levels of deficit irrigation under 50 years of OPA daily weather from 1965 to 2014.

Table 2. Irrigation Frequency of CPS and irrigation amounts of SDI used in EPIC

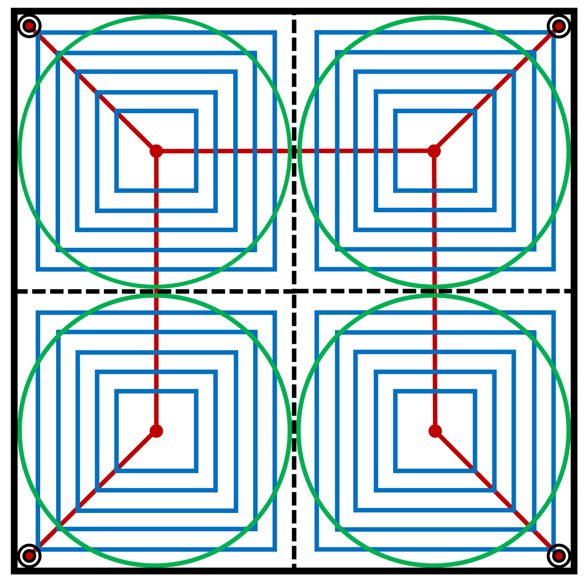
GPM	GPM/ac	CP[1] (days)	SDI[2] (ac-in)
800	6.7	4	0.35
700	5.8	5	0.31
600	5.0	6	0.28
500	4.2	7	0.20
400	3.3	8	0.16
300	2.5	11	0.12
200	1.7	16	0.08
100	0.8	32	0.04

[1]Number of days to irrigated 120 acre CP field
[2]Irrigation amount per day for 125 acre SDI field

Representative Section and Simulation Design

A representative farm is visualized for this study as shown on the right side (Figure 1). Producer's field is a 640 acre square section with four irrigation wells, the wells and irrigation systems are interconnected by underground pipe, and water table is split into six layers, and wells can produce 600 GPM at the top layer. When well capacity declines, producers can connect the existing wells to irrigate fewer acres with higher GPM. Land not irrigated is allocated for dryland grain sorghum.

Figure 1. Representative Farm



Aquifer Assumptions and Pumping Estimates

The specific yield (*S*) was 0.18 and hydraulic conductivity (*K*) was 25 feet per day (USGS, 2012). The aquifer was divided into six layers by allowing 35 feet of safety zone. The thickness of each layer was the minimum thickness that would support 90 days of pumping 100, 200,…, 600 GPM. The drawdowns (DD) are used to estimate the total head and cost of pumping acre-feet of water. The Cooper-Jacob (1946) drawdown equations were used to determine the depth of the 90-day cone of depression of each pumping rate as shown in Table 3.

Table 3. Drawdown for pumping 90 days, Saturated Layer Thickness, and Total Water Supply (WS) available at Layer

GPM	DD (ft)	Layer (ft)	WS[1] (acre-ft)
600	58.1	6	1,680
500	51.2	7	1,960
400	44.3	7	1,960
300	37.4	7	1,960
200	28.2	9	2,520
100	16.1	12	3,360

[1]Only 40 % of the total area was irrigated, and total water supply is 13,440 acre-ft

Crop Budgets

The expected net return for each possible crop activity with an irrigation treatment for corn and grain sorghum was calculated. Ten-year (2005-2014) Oklahoma average prices for corn was $4.50 per bushel and for grain sorghum was $4.20 per bushel according to data from the 2013 Oklahoma Agricultural Statistics. Drip irrigation system sizes of 50, 75, 100, 125, and 150 acres with respective costs of $43,000, $58,000, $74,300, $90,700, and $107,000 could be selected. The cost to purchase a single pivot for a 120-acre field was assumed to be $60,000.

Mixed-Integer Programming (MIP)

Optimal crop choice, net returns, and remaining water supply are estimated for a producer with 640 cultivated acres and four existing 600 GPM irrigation wells considering purchase of either a CP or SDI system. The optimal system size and crop choice over 60-year horizon was determined by MIP models for each irrigation system. Net crop returns calculated from crop budgets were the coefficients of the objective function. Irrigation purchase activities were declared as integer variables in the MIP model. Results were constrained by water supply, the irrigated area (irrigation system sizes), and the total land area of 640 acres in each year. Recharge was ignored. Irrigation system life was assumed to be 15 years.

Results

CP vs SDI: Crop Budgets

The static budgets of CP and SDI show that, irrigated sorghum becomes more profitable than irrigated corn when the well capacity to irrigate one 120-acre declines below 600 GPM. The graphs (Figure 2 & 3) compares the net returns of corn and sorghum irrigated on a 120-acre with CP and SDI, which is served by one well.

Figure 2. Center Pivot (CP) Static Budget

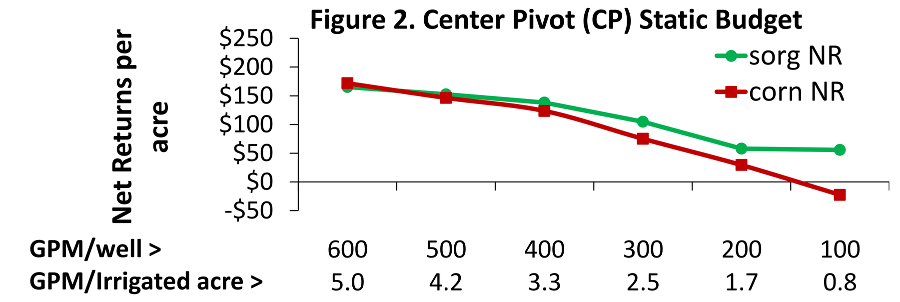
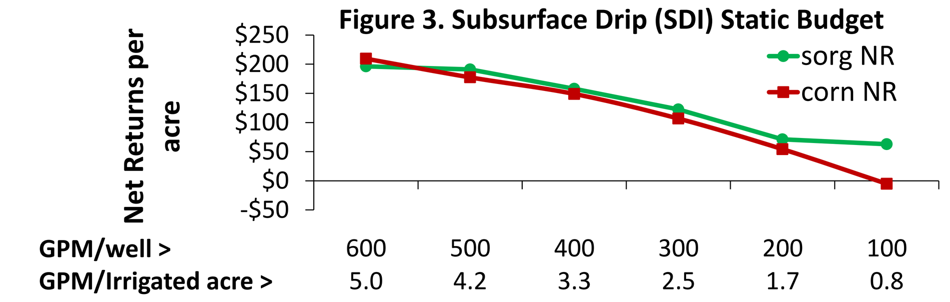


Figure 3. Subsurface Drip (SDI) Static Budget



CP vs SDI: Cropland Allocation, NPV, Water Use, and Grain Production

The number of CP and SDI system purchased, irrigated area of corn and sorghum, rate of well capacity decline, GPM per irrigated area for 60 years are shown below in Figure 6, Figure 7, and Figure 8.

With CP system, the most profitable choice for the producer with 600 GPM wells was to only purchase three 120-ac pivots and irrigate corn at 800 GPM for the first three years before switching to grain sorghum. In year 16, when the well capacity of each well had declined to 300 GPM, it was most profitable to invest in only one 120-ac pivot at 800 GPM, which increased the value of the irrigated acres to irrigate corn. However by year 33, the water level declined to well capacity of 100 GPM and it was profitable to irrigate 120 acres of sorghum by investing one pivot until the end of the project.

With higher WUE SDI system, it was most profitable to irrigate 600 acres of sorghum with four 150 acres SDI system for the first 15 years followed by 250 acres of sorghum with two 125 acres SDI system in the next 15 years. The rate of extraction using SDI was similar to the CP system but the water was distributed over more acres. It was profitable to irrigate 125 acres of corn with one SDI system for years 31-33 using four wells supplying 800 GPM. Sorghum was irrigated after year 35 until the end of the project.

The aquifer decline was similar between the CP and SDI for 60 years as shown in Figure 4, but more grain and a higher NPV (see Figure 5) was obtained from the from SDI system than from the CP. Difference in overall NPV and grain production between CP and SDI investment for 60 years are shown in Table 4 and Table 5 respectively.

Figure 4. Remaining groundwater decline rate by investing CP and SDI and maximizing 60-year NPV

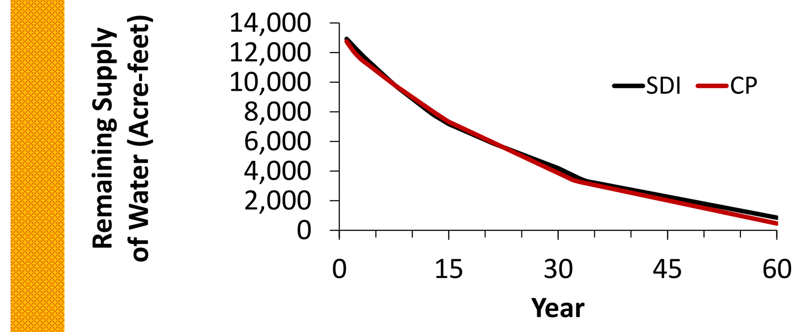


Figure 5. Cumulative NPV by investing CP and SDI and irrigate corn and sorghum for 60 years

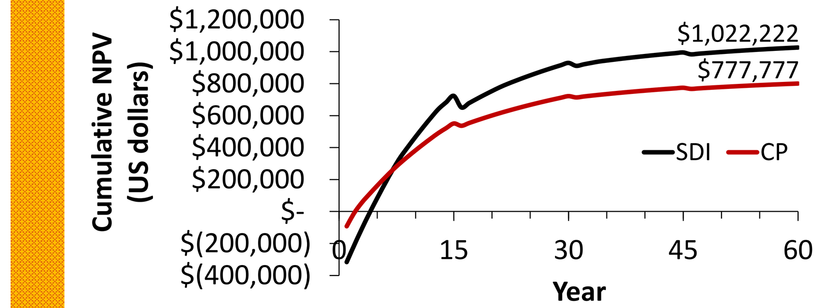


Figure 6. Optimal area of Irrigated Corn, Irrigated Sorghum

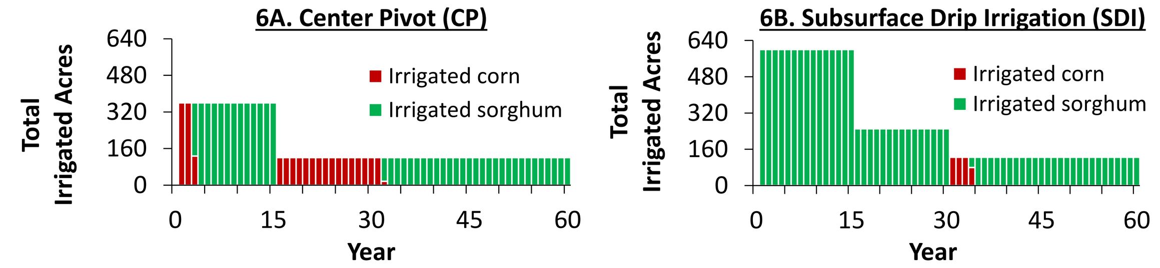


Figure 7. Well Capacity per Well

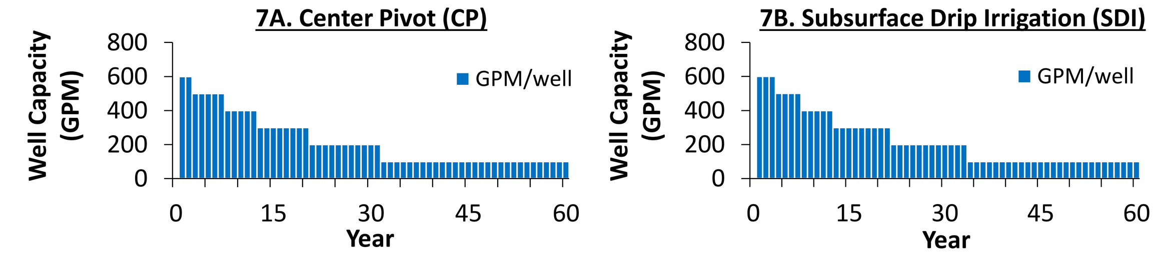


Figure 8. Well Capacity per Irrigated Acre

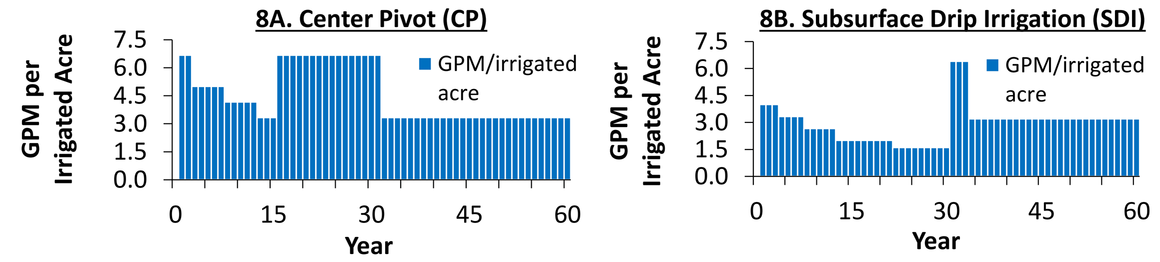


Table 4. Net Present Value (NPV) of CP and SDI Investment by Irrigating Corn and Sorghum over a Period of 60 Years

Irrigation method	Net Present Value (NPV)
CP	$777,777
SDI	$1,022,222
SDI-CP	$244,445

Table 5. Summary of Grain Production by Investing CP and SDI and Irrigating Corn and Sorghum for 60 years

Irrigation	Irrigated Crops		Dryland Crop	Total
Method	Sorghum (bu.)	Corn (bu.)	Sorghum (bu.)	Grain (bu.)
CP	1,122,865	635,601	1,730,724	3,489,191
SDI	2,308,281	81,025	1,403,281	3,792,587
SDI-CP	1,185,416	– 554,576	– 327,443	303,397

References: Ramaswamy, K., A. Stoecker, R. Jones, J. Warren, and S. Taghvaeian. 2017. "Choice of Irrigated Corn or Grain Sorghum and Center Pivot or Subsurface Drip Systems in the High Plains of Oklahoma" AAEA 2017 Annual Meeting Proceedings, July 30-August 1, Chicago, IL.

Acknowledgment: Oklahoma Water Resources Center, Oklahoma State University