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# **Irrigation Technology Upgrade and Water Savings on the Kansas High Plains Aquifer**

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## **Background**

Depleting water resources is a widespread problem across the High Plains aquifer. Irrigation is a major water use in Kansas, accounting for 3 million acre-feet or about 85% of annual withdrawals (U.S. Geological Survey, 2013). Irrigation of water-intensive crops is a major cause for the decline in the saturated thickness of the aquifer. In western Kansas, the value of irrigation is accentuated due to the lack of surface water and low precipitation. In the post-World War II era, irrigated acreage on the High Plains aquifer in Kansas expanded extensively, owing in part to the developments in irrigation technology. The increase in irrigation using groundwater has led to withdrawals exceeding recharge rates, thereby causing a decline in water levels in the aquifer.

A common policy recommended to encourage water conservation and improve the recharge of the aquifer is to subsidize irrigation technology upgrades. The state of Kansas administered cost-share programs for irrigation technology upgrades in the 1990s, a typical switch being from a conventional center-pivot to a center-pivot with drop nozzles irrigation system. While newer irrigation technologies are understood to have improved producer's net returns and reduced production risk, whether they reduce consumptive water use is a question of controversy (Peterson and Ding 2005). Several studies found evidence that under certain conditions, producers with modern irrigation systems have an incentive to increase consumptive use by expanding irrigation acreage or increase net irrigation per acre with a more water-intensive crop (Huffaker and Whittlesey 2003).

In this paper, we analyze a series of simulations of irrigated crop production in the Kansas High plains aquifer to identify the risk-efficient conditions under which a producer will have an incentive to upgrade an irrigation technology and whether more efficient technologies

have a water conserving effect. The simulations account for timing of irrigation and variability in observed weather conditions across 42 years in the study region. The crop production scenarios differ by irrigation water applied, crop choice and well capacities to highlight the effect of these factors on consumptive water use and water savings.

### **Conceptual Framework**

The paper is structured to incorporate agronomic features of irrigation scheduling, yield-evapotranspiration relationships, water-use measures, and engineering relationships of irrigation costs into an economic model of risks, choices and net returns of irrigation technology and crops.

The production function of irrigated cropping can be stated as:

$$y = f(e * w + z; q) \quad (1)$$

with the properties of  $f'(\cdot) > 0$  and  $f''(\cdot) < 0$ . Let  $w$  denote gross water applied,  $e$  irrigation application efficiency with value between 0 and 1,  $z$  effective rainfall and  $q$  well capacity. The effective rainfall ( $z$ ) is a random variable with distribution  $F(z)$ .

Not all of the water applied to the field would be beneficial to the crop. The amount of water that reaches the crop root zone is dependent on the irrigation system. Irrigation application efficiency ( $e$ ) is the proportion of water delivered using a particular irrigation technology (conventional center-pivot irrigation system or center-pivot with drop nozzles irrigation system). Effective rainfall ( $z$ ) denotes the amount of rainwater that reaches the plant canopy. The source of irrigation water losses is including evaporation losses, transpiration losses, runoff and deep percolation (Rogers et al, 1997).

Water used by crop's root system consists of effective irrigation water applied ( $e * w$ ) and effective rainfall( $z$ ). The gross water applied ( $w$ ) on the field depends on the well capacity ( $q$ ). For example, without supplemental rainfall, a 190 gallon per minute (gpm) well takes 15

days for a center-pivot irrigation system to completely irrigate a 160-acre crop circle, whereas, a 285 gpm takes 10 days and a 570 gpm well takes 5 days. The gross water applied ( $w$ ) considers the time lag between irrigating the first portion of the field and the last portion of the field in center-pivot irrigation system since the water is delivered to different parts of the field as the tower gradually pivots around the field. The producers are assumed to schedule irrigation based on soil moisture and optimally allocate the quantity and timing of irrigation events to maintain adequate soil moisture levels for crop growth. An irrigation event is triggered whenever the soil moisture level falls below a threshold level called the management allowed deficit (MAD). MAD is the deficit level of soil moisture below the field capacity of the soil. In other words, the soil moisture level and MAD level add up to the field capacity of the soil.

A producer faces the decisions of irrigation technology, crop, and an MAD level for irrigation scheduling at the start of a season. In order to choose the appropriate irrigation technology, the producer considers the net returns, irrigation efficiency, costs and risk associated with each irrigation system. In choosing an irrigated crop, the producer will choose the irrigated crop and allocate irrigated land across crops based on the availability of water, costs, returns to capital, crop prices and irrigation efficiency. A producer can make better choices if presented with risk-efficient crop choices. A producer can strategically choose the crop, irrigation system and MAD with the aim of maximizing net returns while ensuring the efficient use of available groundwater.

Total cost of farming is comprised of irrigation cost and non-irrigation production cost. Irrigation cost is a variable cost of water applied to the field associated with a particular technology or irrigation system. Irrigation cost equation can be written as:

$$c(w, pe, d) = k * pe * d * w \quad (2)$$

where  $pe$  denotes energy price,  $d$  is the depth to water table,  $k$  is a coefficient of energy requirement to extract the water for each feet, and  $w$  is the total water applied to the field. The energy required to extract the water is associated with irrigation system technology. The variable cost per acre-foot is assumed to be independent of land quality. Non-irrigation production costs ( $v$ ) include seed, herbicide, pesticide, fertilizer, crop consulting, non-machinery labor, interest on non-land cost and other miscellaneous cost. For the purpose of analysis, as equipment cost and the cost of irrigation system installation are not included in the analysis. The total cost can be written as:

$$TC = c(w, pe, d) + v. \quad (3)$$

The optimization problem will be producer's choice of crop, MAD and irrigation technology. The optimization can be solved in three stages. First, the producer chooses optimal MAD for each crop and irrigation system. Second, the most preferred crop is determined by comparing net return distributions of corn and sorghum. Third, field level water inflows, outflows, and efficiency measures were compared for conventional center-pivot and center pivot with drop nozzles irrigation system across crops. For the most preferred MAD level and most preferred crops, the irrigation system that maximizes net returns subject to limited water use was determined to be the most preferred irrigation technology. Let  $\pi_{ij}$  denote a profit function for each irrigation technology ( $i$ ) and crop ( $j$ ), then  $\pi_{ij} = p_j * f_{ij}(e * w + z; q) - c_i(w, pe, d) - v_{ij}$ .

In the first stage, a producer chooses the MAD level to maximize utility based on his risk preference so that:

$$\text{Max}_{\{MAD\}} E[U(\pi_{ij})] \quad (4)$$

$$s.t. \ w = h(MAD, z)$$

$$w \leq q$$

Water applied to the field will depend on MAD level chosen and effective rainfall. Water applied also cannot exceed the well capacity for each field. The solution of the optimization problem is  $MAD(p_j, e, pe, d, q, v_{ij}; F(z); r_a)$ ,

Where  $r_a$  is the coefficient of absolute risk aversion. In the second stage, the profit for each crop, irrigation technology and specific MAD level chosen from first stage is denoted as:

$$\pi_{ijm} = p_j * f_{ij}(e * w + z; q; MAD) - c_i(w, pe, d; MAD) - v_{ij} \quad (5)$$

For a chosen MAD level, crop will be chosen by comparing its expected utility maximum and risk preference. Expected utility is then:

$$E[u(\pi_{ijm})] = \int u(\pi_{ijm}) dF(\pi_{ijm}) \quad (6)$$

The probability distribution of profit depends on probability distribution of rainfall, so that  $F(\pi_{ijm}) = F(z)$ . We can rewrite the expected utility maximum:

$$E[u(\pi_{ijm})] = \int u(\pi_{ijm}) dF(z) \quad (7)$$

Our analysis assumes that utility takes the form of negative exponential  $u(\pi_{ijm}) = 1 - e^{-r*\pi_{ijm}}$  where  $r$  is a constant risk coefficient. Let  $EU(r)$  denoted the expected utility of the observed distribution,  $(\pi_{ijm})$ , assuming a negative exponential utility function with a risk aversion coefficient of  $r$ . The producer can chose crop that maximize the expected utility computed as:

$$\max_{crop_i} EU[(r)] = \int [1 - e^{-r*\pi_{ijm}}] dF(z) \quad (8)$$

At the third stage, the producer will choose the irrigation system that maximizes expected utility for the most preferred MAD level and crop choice (i). The irrigation system that maximizes expected utility subject to limited water use was determined to be the most preferred technology. The profit for irrigation technology choosing can be written as

$$\pi_{ijm} = p_j * f_{ij}(e * w + z; q, MAD, crop_i) - c_i(w, pe, d; MAD, crop_i) - v_{ij} \quad (9)$$

The technology question is evaluated by comparing conventional center-pivot and center-pivot with drop nozzle irrigation systems in terms of water consumption. Risk-efficient crop choices are compared under conventional center-pivot and center-pivot with drop nozzle irrigation systems for corn and sorghum, providing information that a producer could use to choose irrigated crops to most efficiently use the available water. To accomplish the objectives, we developed a model that combines an irrigation scheduling program called *KanSched* (Clark and Rogers, 2000), a crop yield simulating program called Kansas Water Budget model (Stone *et al.*, 1995) and Stochastic Efficiency with respect to a function risk analysis using SIMETAR.

### **Data and Model Assumption**

The simulation considers four scenarios, which include combinations of corn and sorghum irrigated with conventional center-pivot and center-pivot with drop nozzle. Both irrigation systems irrigate a 126-acre crop circle within a 160-acre plot, leaving 34 acres of non-irrigated land. The pre-evaporation loss for the conventional center-pivot irrigation system was assumed to be 15% and that of center-pivot with drop nozzles was assumed to be 5% (Rogers *et al.*, 1997). The gross amount of water applied per irrigation event was set so at 1.2 inches, with the amount of irrigation water reaching the soil profile after evaporation losses being 1.02 inches (85% of 1.2 inches) for conventional center-pivot and 1.14 inches (95% of 1.2 inches) for center-pivot with drop nozzles.



Irrigation events are constrained by well capacity and other factors, which limit and affect irrigation frequency. Irrigation schedules corresponds to three well capacities (190, 285 and 570 gallons per minute) with four Soil Water Availability (0.40, 0.60, 0.80) and five MAD values (0, 0.15, 0.3, 0.45 and 0.6). The number of irrigations during the crop season cannot exceed 18 due to a limitation inherent to the KWB model and the total amount irrigation cannot exceed to 24 inches during crop season due to water regulations in western Kansas. The irrigation scheduling also consider the time lag between irrigating the first portion of the field and the last portion of the field in center-pivot irrigation system since the water is delivered to different parts of the field as the tower gradually pivots around the field. The time that is taken to irrigate the entire field before the occurrence of water stress is referred to as the irrigation frequency or cycle time. The irrigation frequencies for a 190, 285 and 570 gpm well are 15, 10 and 5 days, respectively. The optimal irrigation schedules are devised using a strategy to select the irrigation dates based on the well capacity and the soil moisture level. The soil moisture level is updated every day based on rainfall and evapotranspiration data using a water balance equation. *KanSched* model is used to determine when and how much irrigation water to apply. An irrigation event is triggered if the soil moisture falls below a predetermined deficit level.

The irrigation schedules for each scenario were then entered into the Kansas Water Budget (KWB) model to estimate crop yields based on accumulated ET corresponding to crop growth stages. We are estimating the economic net return per acre using the simulated yield from KWB model and Kansas State Extension projected crop budget for specified MAD and specified Well capacity. The optimal MAD is determined for corn and sorghum based on the irrigation schedules and net returns for a given well capacity.

The next step is to choose the crop and irrigation system. The simulated net returns across all weather conditions under a fixed combination of MAD, crop-technology scheme, and well capacity were gathered together to form a probability distribution. The following step is to compare this distribution using the risk efficiency criteria in SIMETAR to choose the crop based on the water availability and the risk preference of the producer. The final step is to compare the irrigation systems based on ET, consumptive use, non-beneficial use season long irrigation efficiency, and reduction in irrigation water for each well capacity. The purpose of comparing the irrigation systems was to evaluate the effect of an irrigation technology upgrade on the aquifer and determine the best alternative irrigation strategy given the well capacity.

We use long run weather data from Kansas Weather Data Library for Tribune, Kansas includes daily observation of temperature, rainfall, and solar radiation over 42-years from 1971 to 2012. These data along with irrigation technology, MAD level, well capacity and crop characteristic were used to calculate the daily reference ET, maximum crop ET and soil water balance which will determine irrigation scheduling using the *KanSched* model and simulate the yield of corn and sorghum using KWB model.

Various parameters assumptions are required for our base specification to run the *KanSched* Model adjusted with soil type in Tribune, Kansas. The soil water holding capacity was set to 0.15 inches of water/inch of soil depth, and the permanent wilting point to 0.13 inches of water/inch of soil depth representing the Ulysses silty loam soil type in Tribune, Kansas. The emergence date, water budget dates were set in accordance with typical irrigated and dryland crops in western Kansas. The depth of the roots on the start date was set at 6 inches and the maximum root zone depth that would be able to pull water from the soil profile was set at 60 inches. The crop growth dates correspond to irrigated crops in western Kansas. The crop

coefficients were adjusted to fit the crop coefficients from the KWB model as closely as possible.

The irrigation cost was measured with the assumption that most of the acreage irrigation systems in Kansas are using natural gas as source of energy to pump water from groundwater. The price of natural gas was obtained from the United States Department of Energy Outlook and is used to compute irrigation cost with several assumptions. The operating pressures of the conventional center pivot and center pivot with drop nozzle systems were assumed to be 75 and 20 pounds per square inch and the conversion factor that translates pressures (in pounds per square inch) to an equivalent distance of vertical lift is 2.31. The irrigation cost also includes the repair cost which is assumed \$ 0.30 for estimated cost of repair per irrigation and \$ 12.00 for maintenance of the irrigation pump. The average cost of irrigation per inch for conventional center-pivot irrigation and center-pivot with drop nozzles irrigation system was \$5.94 and \$4.17, respectively.

The farm net return was calculated using the farm return and production cost. The production costs for irrigated corn and irrigated sorghum in western Kansas were computed based on the K-State Research and Extension Crop Budgets (Dhuvyvetter 2012). Farm return was calculated using yield estimation from KWB model and crop prices obtained from United States Department of Agriculture (USDA) in agriculture outlook for the year 2012.

## Risk Analysis Simulations

The simulated yield and K-State Extension projected crop budgets were used to compute net returns for each year in the weather dataset, the specified MAD, and the specified well capacity. Finally, the simulated net returns across all weather conditions under a fixed combination of MAD, crop-technology scheme, and well capacity were gathered together to form a probability distribution. Depending on the optimization objective, several distributions were selected for analysis and compared using SERF (stochastic efficiency with respect to a function) in *SIMETAR*.

SERF belongs to a larger family of criteria for ranking probability distributions of risky alternatives (e.g., choices with uncertain net returns) known as stochastic dominance rules. Stochastic dominance rules were introduced to economic decision problem (Hadar and Russell 1969; Hanoch and Levy 1969) and are based on the preferences, or utility functions, of decision makers under specified conditions. The utility function  $u(x)$  is assumed to be increasing, continuous and twice differentiable, where  $x$  represents the decision-maker's wealth. More assumptions on the utility function result in a more refined and discerning criteria to select between risky alternatives. The absolute risk aversion coefficient (ARAC), denoted  $r_a(x)$ , is defined as:

$$r_a(x) = \frac{-u''(x)}{u'(x)} . \quad (10)$$

Stochastic dominance orders alternatives for decision makers facing uncertain outcomes by setting lower bounds ( $r_L$ ) and upper bounds ( $r_U$ ) on the absolute risk aversion coefficient

$$r_L \leq r_a \leq r_U . \quad (11)$$

The SERF method, developed by Hardaker *et al.* (2004) identifies utility efficient sets by ordering alternative sets in terms of certainty equivalents<sup>1</sup> (CE) over a range of risk aversion coefficients. Suppose there are  $p$  states of nature, each occurring with probability  $1/p$ , and that the wealth level if state  $i$  occurs is  $x_i$ . Expected utility is then:

$$E[u(x)] = \int u(x) dF(x) = \sum_{i=1}^p u(x_i) \frac{1}{p} \quad (12)$$

If utility takes the form of a negative exponential ( $u(x) = 1 - e^{-rx}$ ), then the risk aversion coefficient is constant and equal to  $r$ . Let  $EU(r)$  denote the expected utility of the observed distribution,  $\{x_i\}$ , assuming a negative exponential utility function with a risk aversion coefficient of  $r$ . Expected utility can then be computed as:

$$EU(r) = \sum_{i=1}^p \left( \frac{1}{p} \right) [1 - e^{-rx_i}] \quad (13)$$

The certainty equivalent of income at this ARAC level,  $CE(r)$ , can be found by setting the computed value of  $EU(r)$  equal to the utility function evaluated at  $CE(r)$ :

$$EU(r) = 1 - e^{-r \cdot CE(r)} \quad (14)$$

Solving for  $CE(r)$  yields

$$CE(r) = \ln(1 - EU(r))^{-1/r} \quad (15)$$

For a risk-averse decision maker, the certainty equivalent is always less than expected income. For example, an alternative A will be preferred to an alternative B by the SERF criterion, for a range of absolute risk aversion coefficients,  $[r_L, r_U]$ , if  $CE(r)$  under distribution A is greater than  $CE(r)$  under distribution B for all  $r \in [r_L, r_U]$ . Hardaker *et al.* (2004) established

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<sup>1</sup> The certainty equivalent is an income level that a decision maker is indifferent between receiving versus the (uncertain) income generated by taking the risky decision.

that if the above condition holds, then the expected utility of A will exceed that of B for any utility function with an absolute risk aversion coefficient in the range  $[r_L, r_U]$ . Since the conditions are derived with a negative exponential utility function, the SERF method assumes that the decision makers' utility is of that form.

To illustrate, consider one of the comparisons in identifying the most risk-efficient cropping scheme under an irrigation system. For a given well capacity, four distributions of income were generated, corresponding to the four scenarios from table 1 below. One of these was arbitrarily selected as the base alternative and a range of risk aversion coefficients from 0 to 0.10 was chosen. The most risk-efficient cropping alternative was then identified as the one with the largest  $CE(r)$  value over the chosen RAC range. This process was then repeated for all three well capacities – 280 gpm, 400 gpm and 699 gpm – to determine the most risk-efficient alternative in each case.

Table 1. Crop-technology Scenarios

Scenario	Irrigation System	Irrigated Corn (Acres)	Irrigated Sorghum (Acres)
1	Conventional Center-Pivot	126	0
2	Conventional Center-Pivot	0	126
3	Center-Pivot with Drop Nozzles	126	0
4	Center-Pivot with Drop Nozzles	0	126

## Results

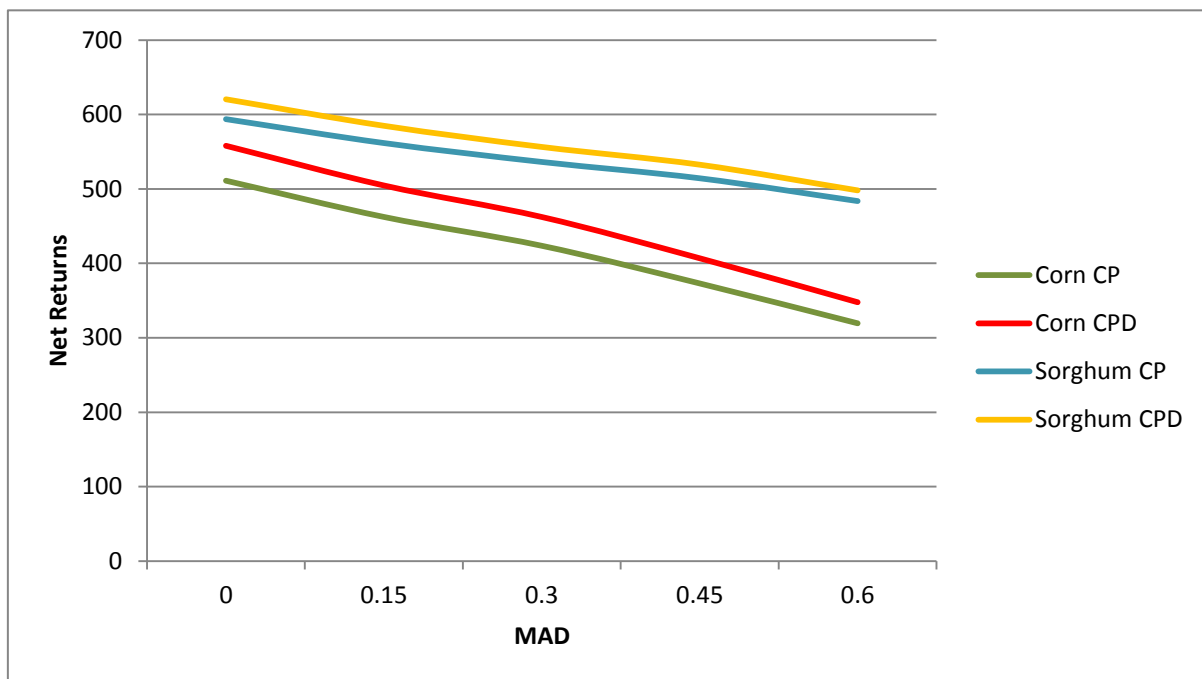
### Choice of Optimal Irrigation

A risk-neutral producer with a small well (190 gpm) is likely to grow sorghum, but might shift to corn if a producer has a medium (285 gpm) or a faster well (570 gpm). It is reasonable to speculate that risk-neutral producers are responsible for the decline of groundwater resources, more so by producers with medium or faster wells as they are likely to plant water intensive crops. At the same time, producers with medium wells are very sensitive to precipitation. They

may switch from corn to sorghum if they perceive a slightly unfavorable shift in the distribution of precipitation.

For a risk-neutral producer, center pivot with drop-nozzle irrigation system is the optimum choice for irrigation technologies as it provides higher average net returns and lower variation in net returns compared to a conventional center-pivot irrigation system, besides being more efficient. Producers with faster wells are limited by a Kansas regulation to a maximum irrigation of 24 inches per crop season. Consequently, the regulations and well capacity limitation will justify the center pivot drop-nozzle system as the most beneficial irrigation technology for a producer.

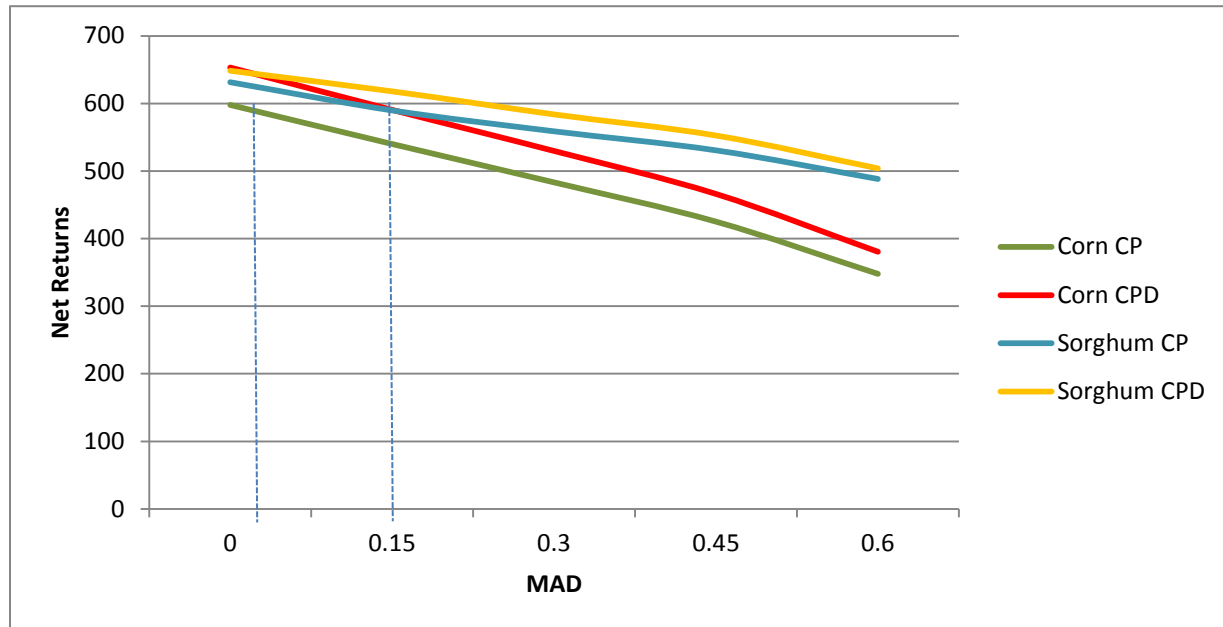
**Figure 1. Comparison of Net Returns for Crops across MAD levels with a 190gpm well**



As seen in figure 1, the 0 MAD is the most profitable choice for a producer with a 190 gpm well. The average net returns are steadily decreasing as MAD level increases. The figure

also indicates that sorghum provides higher average net returns compared to corn under both irrigation systems, and that the CPD system provides higher average returns than the CP system.

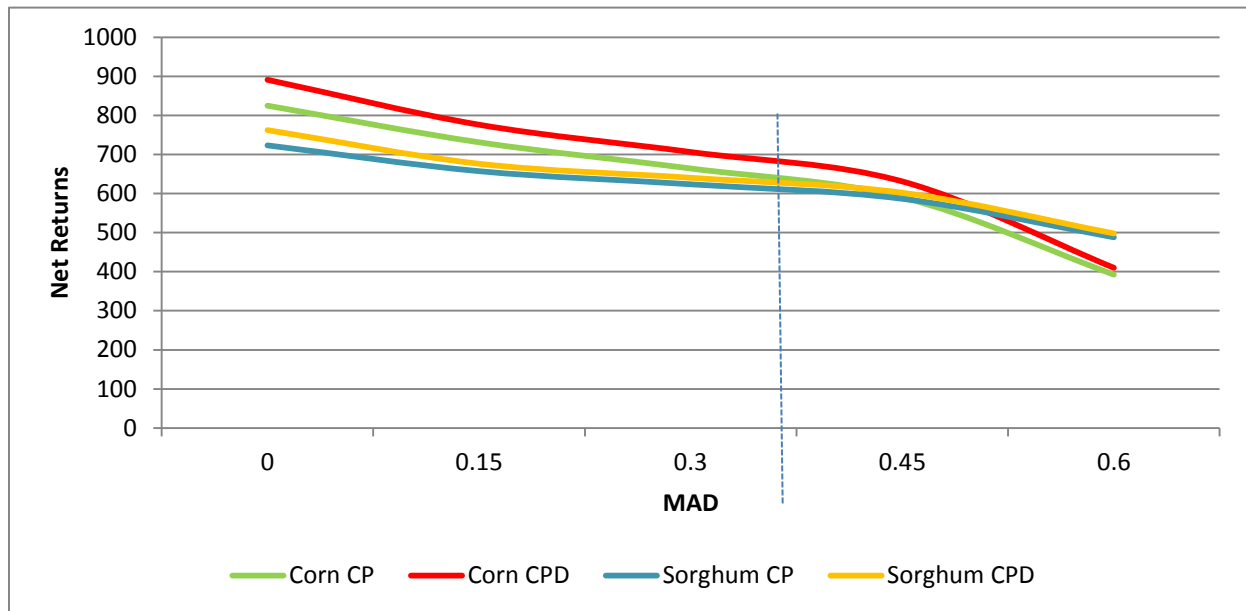
**Figure 2. Comparison of Net Returns for Crops across MAD levels with a 285 gpm well**



The average net returns for all crops with different irrigation technologies system are steadily declining when the MAD level increases as seen in figure 2. Similar to 190 gpm well, the 0 MAD level is the most profitable choices for a producer with a 285 gpm well. At the starting point of 0 MAD level, corn with center pivot dripping irrigation system was the most advantageous choice for the producer.



**Figure 3. Comparison of Net Returns for Crops across MAD levels with a 570 gpm well**



The average net returns for all crops are steadily decreasing as MAD level increases for both irrigation system technologies as seen in figure 3. The highest average net return with a 570 gpm well is achieved if a producer chooses 0 MAD.

In summary, based on the comparison of net returns for crops across MAD levels for the three wells, it is deemed that the 0 MAD is the optimal level to generate the highest net returns for a 190, 285 or 570 gpm well, irrespective of the crop choice or irrigation system. In the next section, the producer's response to an irrigation technology upgrade is evaluated at the 0 MAD level to identify the optimal irrigation system and the crop choice.

The descriptive statistics for corn and sorghum net returns for the three wells under both conventional center-pivot (CP) and center-pivot with drop nozzles (CPD) are presented in table 2 below. While a smaller well (190 gpm) resulted in negative net returns under some cases (corn with CP or CPD), an increase in water available generated higher net returns. The net returns increase with the well capacity while the standard deviation in net returns declines with a faster

well. A slower well generates higher net returns for sorghum, a relatively less water intensive crop but a faster well favors corn, a more water-intensive crop. This is an interesting result because if the water applied is controlled by the producer there could be possibilities that generate water savings while maximizing net returns with a faster well. The following section makes generalized statements based on the descriptive statistics, assuming a producer is risk-neutral.

Table 2. Average, standard deviation, minimum and maximum net returns of sorghum and corn for 190 gpm, 285 gpm and 570 gpm well

Capacity well		190 gpm well	285 gpm well	570 gpm well
CP	Corn	Average	511.02	597.81
		Stdev	230.29	190.12
		Max	898.52	921.41
		Min	-149.54	53.96
	Sorghum	Average	593.70	631.43
		Stdev	113.43	93.91
		Max	780.39	783.65
		Min	262.43	368.05
CPD	Corn	Average	557.94	653.16
		Stdev	218.90	177.98
		Max	927.36	956.82
		Min	-70.28	145.51
	Sorghum	Average	620.42	648.41
		Stdev	107.65	92.50
		Max	797.57	795.24
		Min	309.26	388.12

With a 190 gpm well, sorghum generates net returns with a higher average and lower standard deviation than corn under either irrigation system. Sorghum is likely to be the chosen crop as it provides higher and more stable income to the producer. Technology upgrade in irrigation system will benefit a risk-neutral producer who plants sorghum by providing a higher profit.

The most advantageous choice for a risk-neutral producer with a 285gpm well and a CPD system is to plant corn, while sorghum is a more profitable choice with a CP system. The risk neutral producer has an incentive to switch to a relatively less water-intensive crop after switching to a more efficient irrigation system. Also, there is only a small difference of average net return between corn and sorghum, implying that an increase in precipitation will likely affect a producer's decision on crop choice. With either irrigation system, sorghum provides less variable net returns. Thus, farmers who are very risk averse may prefer sorghum even with a CP system. If the farmer were to plant the same crop with either system, the technology upgrade would reduce variability somewhat.

Corn provides higher but less stable net returns than sorghum with a 570gpm well under both irrigation systems. A risk-neutral producer will likely grow corn before and after a switch in the irrigation technologies. However, corn is a more risky option as it has not only more variability in net returns but also the possibility of a lower net return, so risk averse farmers may choose sorghum. Compared to the CP system, the CPD system provides producer who plants corn with higher net return and lower variation in net return. A risk neutral producer who plants corn will have higher average net returns, if he operates a center pivot with drop-nozzle irrigation system rather than a conventional center-pivot irrigation system.

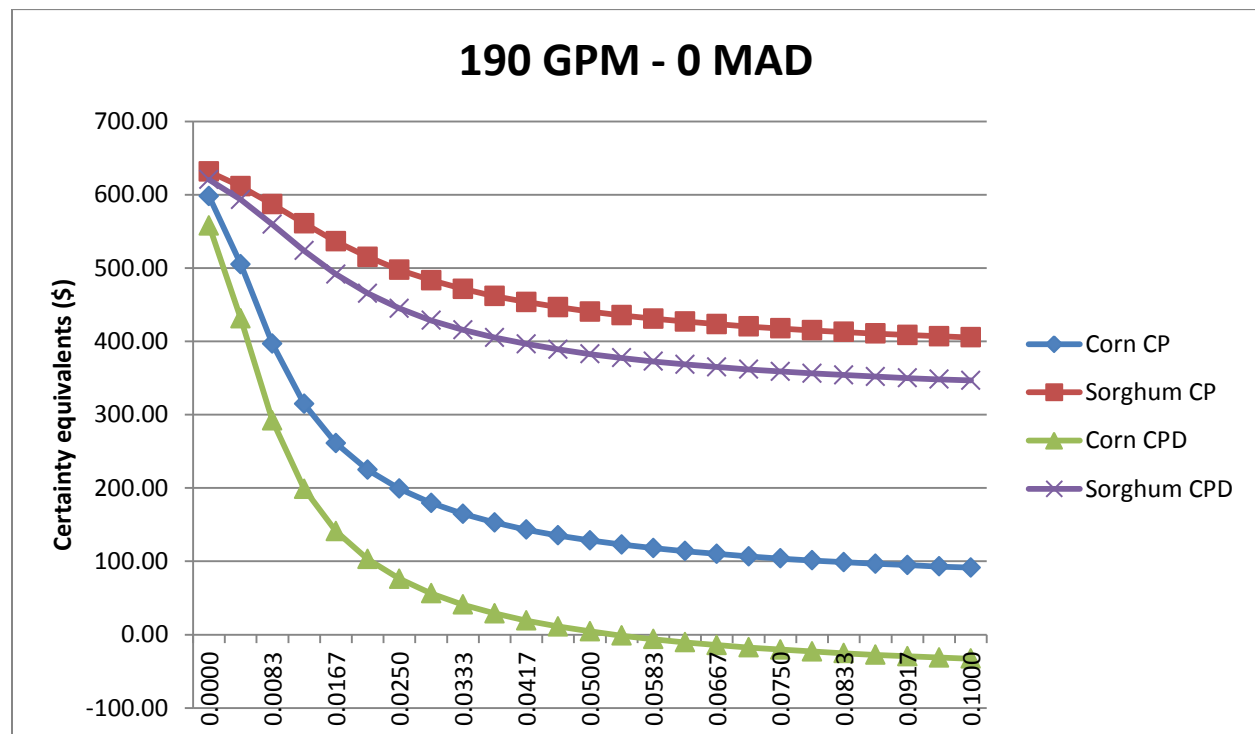
### **Producer's Response to an Irrigation Technology Upgrade**

The following graphs compare the certainty equivalents for three well capacities – 190gpm, 285 and 570 gpm at the 0 MAD level. For the purpose of analysis, the certainty equivalents of corn and sorghum for both the irrigation systems are presented below for a range of risk aversion coefficients from 0 to 0.10, 0 being risk-neutral and 0.10 being slightly risk

averse. For a given well capacity (190 gpm) and a given MAD level (0), a producer's likely response can be deduced from the certainty equivalents graphs below.

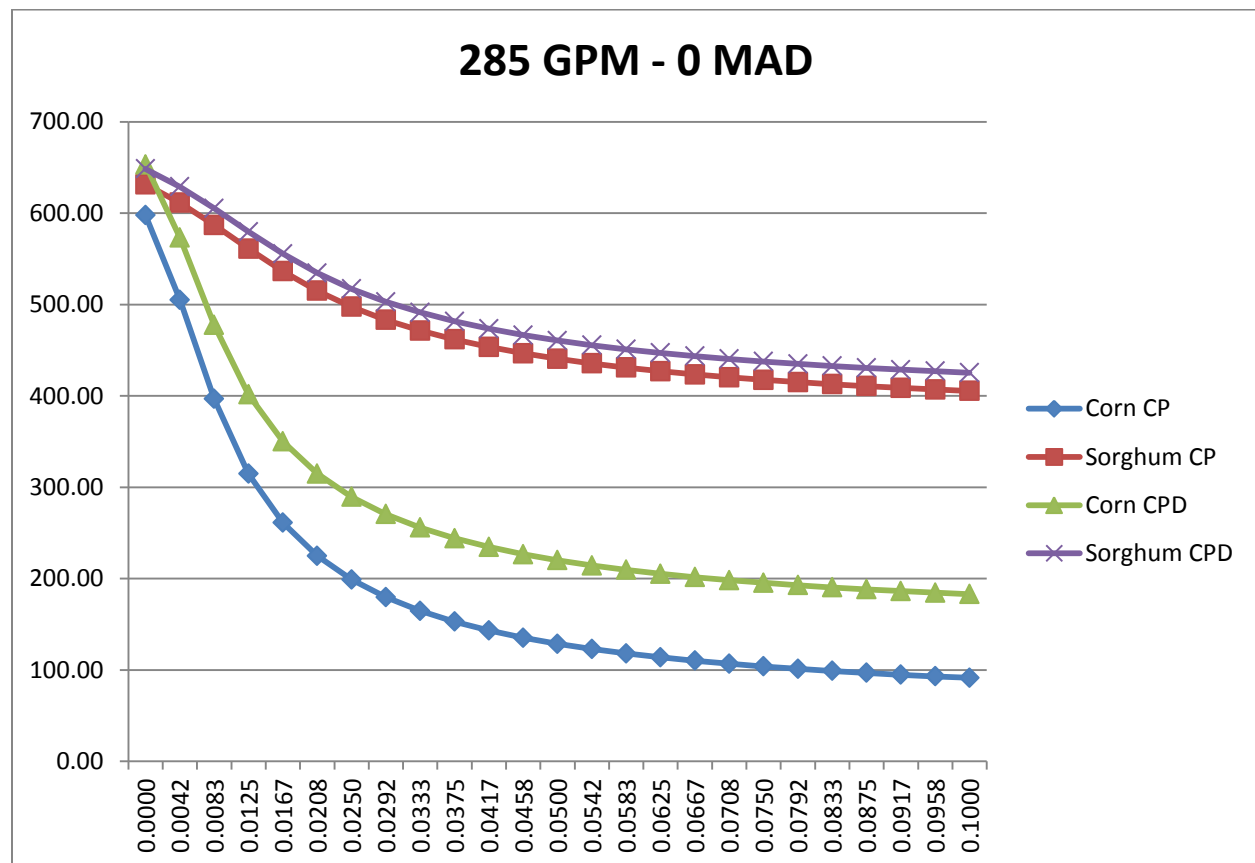
For a 190gpm well, figure 4 reveals that for all levels of risk aversion sorghum is preferred to corn with either a CP or a CPD irrigation system. This is consistent with the mean-variance results in table 2. By growing sorghum instead of corn with the CP system, the producer gains \$33.62, if the producer is risk-neutral ( $ARAC=0$ ) and the gains increase with increase in risk aversion to \$314, if the producer is relatively risk-averse ( $ARAC=0.10$ ). Similarly, by growing sorghum instead of corn with a CPD system, the producer gains \$62.47, if he is risk-neutral ( $ARAC=0$ ) and the gains increase with increase in risk aversion to \$379.50, if he is relatively risk-averse ( $ARAC=0.10$ ). With a CPD system and an absolute risk aversion coefficient above 0.05, the certainty equivalent earnings from corn production is negative.

**Figure 4. Certainty Equivalents for 190 gpm well and 0 MAD – Corn and Sorghum**



For a gpm well, producers with a CP system likely to grow sorghum regardless of their risk attitude (figure 5). After a technology upgrade to a CPD system, farmers who are risk neutral are likely to grow corn but those with risk-aversion coefficients above 0.0042 would prefer sorghum. The choice to grow corn instead of sorghum after the technology upgrade would result in a net gain of \$4.75 per acre for risk neutral producers. So, producers with an absolute risk aversion coefficient in the range of 0 to 0.0042, may have taken advantage of the cost-share grants to upgrade irrigation systems and switch to a more water-intensive crop (corn).

**Figure 5. Certainty Equivalents for 285 gpm well and 0 MAD – Corn and Sorghum**



By growing sorghum instead of corn with a CP system, the producer gains \$33.62, if he is risk-neutral (ARAC=0) and the gains increase with increase in risk aversion to \$314, if he is

relatively risk-averse (ARAC=0.10). Beyond an absolute risk aversion coefficient of 0.0042, a producer by growing sorghum instead of corn with a CPD system, the producer gains \$55.72, and the gains increase with increase in risk aversion to \$242.52, if he is relatively risk-averse (ARAC=0.10). With a 285 gpm well and 0 MAD, a producer would be better off growing sorghum with a conventional center-pivot irrigation system. After the technology upgrade, if the producer is risk-neutral, he would grow corn or if he is slightly risk averse (ARAC in the range of 0.0042 to 0.10), he would grow sorghum.

**Figure 6. Certainty Equivalents for 570 gpm well and 0 MAD – Corn and Sorghum**

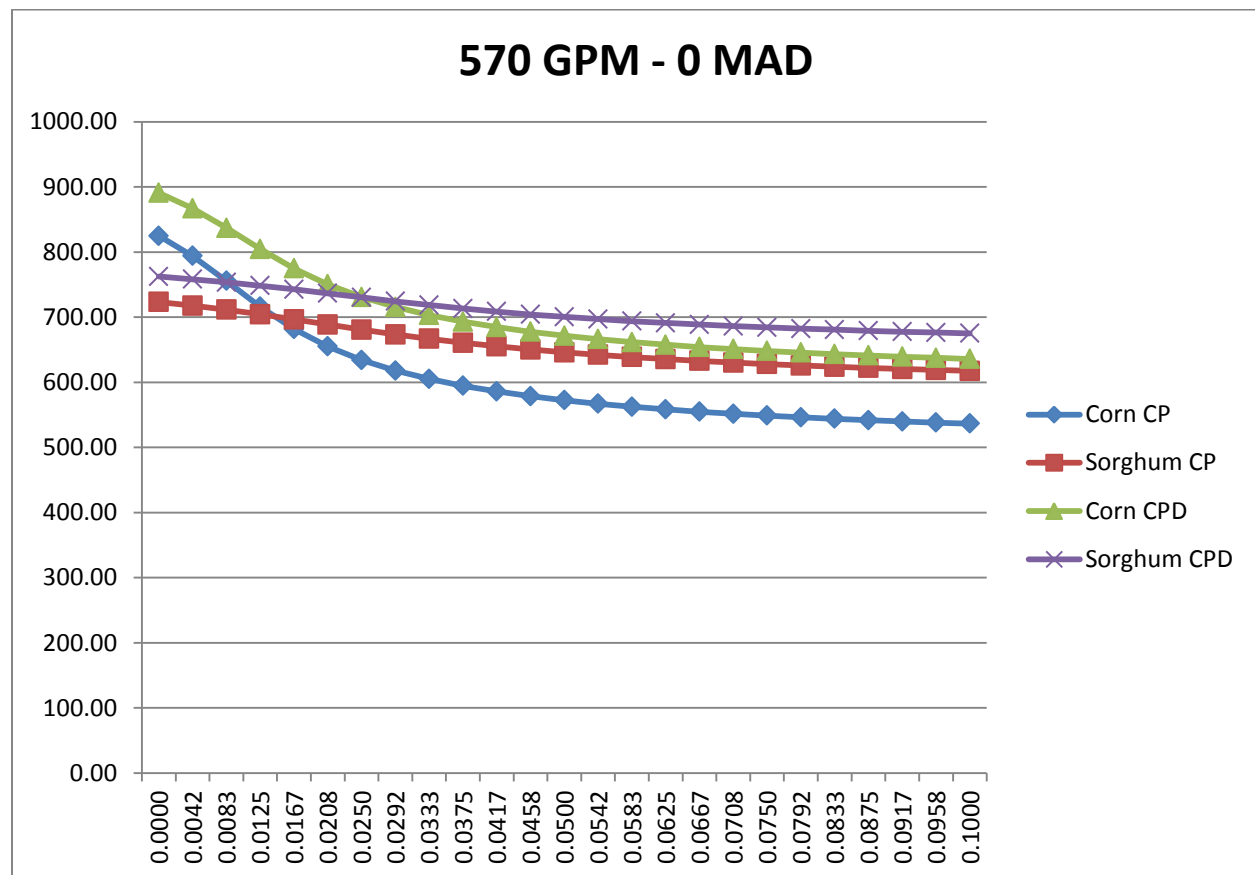


Figure 6 shows the results for a 570 gpm well. Producers with a CP system will likely choose corn if they are risk-neutral or a slightly risk averse (ARAC below 0.0125), but more risk

averse individuals (ARAC from 0.0125 to 0.10) will prefer sorghum. However, if a producer chooses to upgrade to the CPD irrigation system, corn is the preferred choice of crop for a somewhat wider range of risk attitudes (ARAC up to 0.0205). Producers with an ARAC in the range of 0.0125 to 0.0205 would prefer sorghum before the technology upgrade and choose corn after the technology conversion, thereby increasing consumptive water use. For a producer with an ARAC in the range of 0.0205 to 0.10, sorghum, a relatively less water-intensive crop is the preferred choice both before and after an irrigation technology upgrade, thereby resulting in water savings. It is interesting to note that with a faster well while producers who are risk-neutral exhibit profit maximizing behavior without regard to water savings, a relatively risk-averse producer, would in fact contribute towards water savings. This reveals that farmers with the same resource setting may respond differently to technology upgrades and that irrigation technology subsidies lead to water savings in some cases but not in others.

## **Conclusions**

This paper evaluated the relationship of an irrigation technology upgrade on crop choice and water consumption under risk-neutral or slightly risk-averse attitudes. The results show that 0 MAD or imposing no restrictions on irrigation yields the highest net returns irrespective of crop choice or irrigation system. Adoption of an efficient irrigation system can result in either more or less water consumption, the direction of the impact depends on the crop choice and the risk attitude of the producer.

Based on the simulations modeled, we find that producers are likely to have an incentive to switch crops from sorghum to corn after upgrading their irrigation system, resulting in an increase in consumptive water use. Producers who took advantage of cost-share grants and

adopted water-intensive crops after adoption of an efficient irrigation system are likely more risk-averse and profit-maximizing in their behavior.

It is also plausible that producers grow corn before the technology upgrade and switch to sorghum after the technology upgrade, resulting in water savings. Producers displaying this response are likely risk-neutral or very slightly risk-averse and are altruistic in extending the life of the aquifer to other producers or future generations.

In summary, our findings emphasize the importance of risk in evaluating the impacts of irrigation technological upgrades and the consequences of these upgrades on consumptive water use. A significant finding of this paper is that producer's heterogeneity has a bearing on the response to a technology subsidy. The differences in risk attitudes of producers helped explain the conflicting findings in the literature. While some producers who took advantage of cost-share grants increased water consumption, others improved their irrigation systems and conserved water.



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