Effects of Energy *and* Commodity Prices *on* Irrigation in the Kansas High Plains

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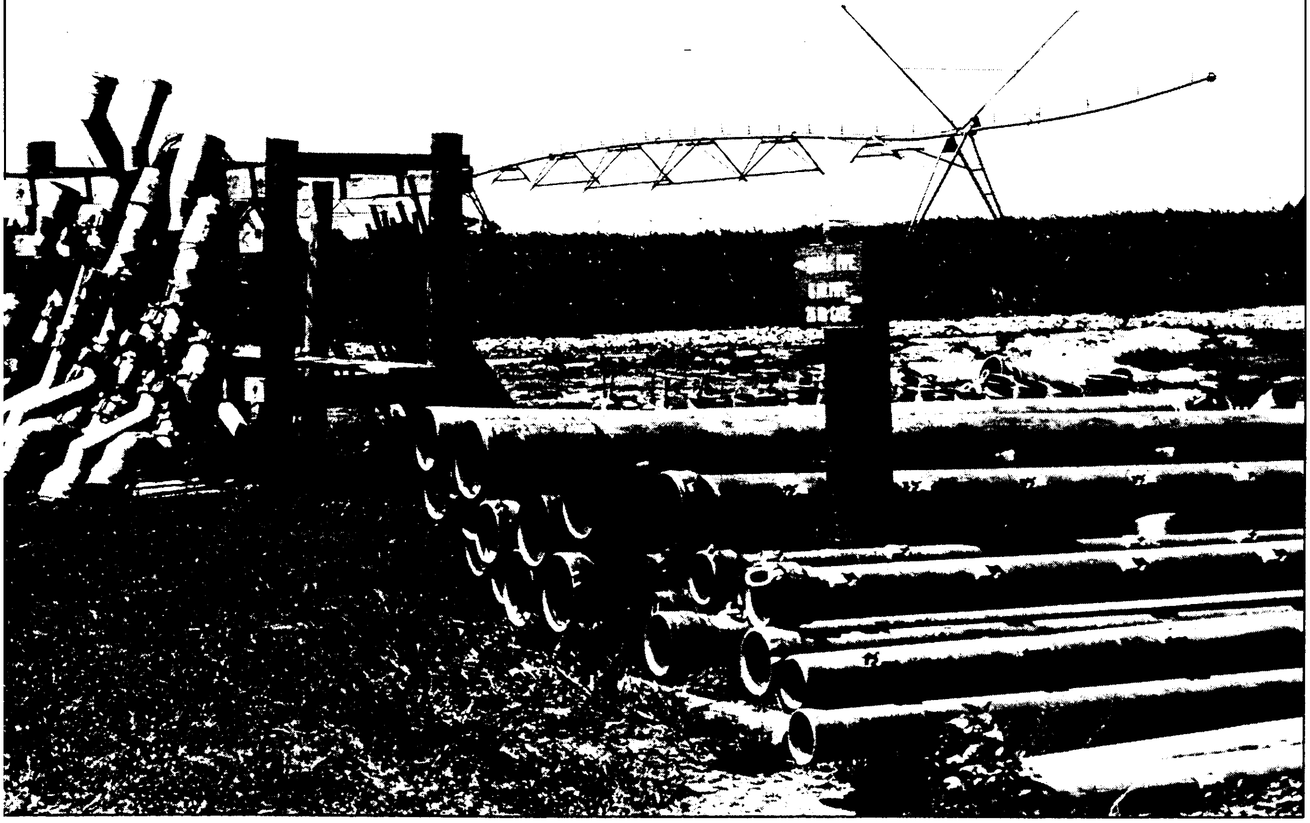

Agricultural Experiment Station, Kansas State University, Manhattan, Walter R. Woods, Director

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Effects of Energy and Commodity Prices on Irrigation in the Kansas High Plains[1]

Orlan Buller and Jeffery Williams[2]

ABSTRACT

An increase in the price of natural gas or of other energy sources can have a major impact on irrigators' net income and the economy of western Kansas. Irrigation is energy intensive, and approximately one-third of the harvested acres in western Kansas are irrigated. Some irrigation probably can be sustained for the life of wells and equipment at a natural gas price of $5.00/mcf (1990 dollars), but net income would be greatly reduced. At a price of $5.00/mcf (1990 dollars), irrigated acreage and water pumped declines sharply, and without favorable commodity prices, irrigation is unprofitable except for wells of about 150 feet deep or less. At a price above $2.00/mcf (1990 dollars), corn acreage begins to dramatically decrease and is replaced with wheat and grain sorghum plantings. Higher commodity prices (target price levels for government farm program crops) can offset an increase in the price of natural gas. Some irrigation could continue until the natural gas price rises to $7.00/mcf (1990 dollars); however, irrigation practices would be very different from present ones. No corn would be irrigated and very few acres of wheat and grain sorghum would be irrigated. Development of new wells and land preparation would not be economically feasible.

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[1] contribution no. 91-167-S from the Kansas Agricultural Experiment Station.

[2] Professors, Department of Agricultural Economics, Kansas State University, Manhattan, KS 66506-4011.

INTRODUCTION

Energy prices have a large impact on the cost and income of irrigated crops in the Great Plains because irrigation in this region is energy intensive. Many irrigators in western Kansas have experienced steadily rising prices for natural gas since the mid 1970’s resulting in higher irrigation costs. For example, the per acre cost of irrigating corn with gravity-flow irrigation has increased from 5 percent of the total variable production cost in 1978 to 11 percent in 1988. For center-pivot irrigation, the pumping cost increased from 9 percent of the total variable costs in 1978 to 19 percent in 1988. Rising energy prices have a greater effect on the cost of irrigating those crops that use larger amounts of water. Increasing energy prices can affect the number of acres irrigated, the type of crop irrigated, and the amount of water pumped.

Nearly one-third of the harvested acres of western Kansas are irrigated. The value of production historically has been much higher from an acre of irrigated crops than from nonirrigated. An increase in the price of natural gas or of another energy source can cause a reduction in irrigated acres, in the value of production, and in an irrigators’ net income. A change that diminishes the amount of irrigation also diminishes the agricultural economy of western Kansas.

Since 1975, farmers in the three crop-reporting districts of western Kansas have irrigated more than 2 million acres each year, of which approximately 80 percent was in corn, wheat, or grain sorghum (1). In 1976, when irrigated corn acreage was at an all time high, it accounted for approximately 50 percent of the total irrigated acres and was about 150 percent of the combined acreage of wheat and sorghum. After 1976, a sharp decline in irrigated corn acreage occurred. Irrigated wheat and grain sorghum acreage increased, while total irrigated acreage remained nearly constant. By 1984, irrigated corn acreage had declined to less than 20 percent of total irrigated acreage and less than half the combined acreage of irrigated wheat and grain sorghum. Since 1984, acreage shifts among the three crops have continued, but irrigated corn acreage has increased relative to irrigated wheat and grain sorghum acreage. Irrigated acreage has declined 40 percent for grain sorghum and 23 percent for wheat since 1984. Total irrigated acres for corn, wheat, and grain sorghum have declined 23 percent since then. The prices of energy and commodities, as well as changes in government programs, are believed to be major causes of the change in irrigated crop acres (2).

Objectives

The purpose of this study was to estimate the effect of an increase in the price of natural gas on the number of acres irrigated, amount of water pumped, and net income at the farm level. These relationships were studied using an economic model of a representative irrigated farm in western Kansas. This representative farm produces irrigated corn, wheat, and grain sorghum using gravity-flow and center-pivot irrigation systems on owned and rented land.

The focus of this study was on the effect of changes in the price of natural gas; however, a procedure to transform the natural gas price to that of other sources of energy was provided. Thus, the results using natural gas can be adapted to other energy types.

PROCEDURES

Representative Farm

Land and water characteristics of the representative farm were averages of the resources reported for the group of 65 irrigation farms in the southwest Kansas Farm Management Association in 1986 (3). The average crop acreage of the 65 irrigation farms was 2472 acres including fallow, of which 1554 were nonirrigated and 918 acres were irrigated. Of the 2472 crop acres, 808 acres were estimated to be owned; of the 918 acres irrigated acres, 248 were estimated to be owned and 658 acres were estimated to be irrigated with the gravity-flow system. Nonirrigated land was planted to wheat and grain sorghum.

We assumed that the representative farm has irrigation wells with a 900 gallons per minute (GPM) flow rate and 225 feet of water lift, that the gravity-flow irrigation systems have a farm irrigation efficiency of 65 percent, and that the center-pivot systems have a farm irrigation efficiency of 85 percent. A farm irrigation efficiency of 65 percent means that 65 percent of the water pumped was used by the crop to produce dry matter, including grain and 35 percent was lost by evaporation, runoff, and deep percolation. The feet of water lift and flow rate of the well for the representative farm were averages for irrigated farms and were based on the hydrology of western Kansas as reported in test well measurements. Appendix tables A-1, A-2, and A-3 report depth to water, depth to bedrock, and saturated thickness as measured in test wells in specified counties in 1988. Annual rainfall, which is highly variable in the region, influences the amount of water pumped. Average annual rainfall of 17.5 inches was assumed for the entire year. Rainfall plus irrigation provide the soil water needed for plant growth and grain production.

Economic Model

An economic model of the representative farm was developed to find the most profitable combination of irrigated crops and water use (4). The model included nine irrigation regimes for corn, nine for grain sorghum, and seven for wheat to represent an irrigator’s choices for selecting the crop and amount and schedule of water use. Irrigation regimes, water use, and yields per acre for each regime were obtained from experimental research trials (5; 6). The cost of pumping water was estimated using an irrigation variable-cost model (7). Water use and crop yield estimates were used to calculate the per acre cost and returns for each regime. The economic model, which uses a linear programming procedure, selected the alternative irrigation regimes that maximize returns to operator labor and fixed capital investment in land, irrigation wells and equipment, and other farm machinery and equipment.

The economic model allowed for the irrigation of corn, grain sorghum, and wheat on owned or rented land. Irrigated was with either the center-pivot or gravity-flow system. Variable irrigation costs were different for each crop because of differences in the amount of water pumped, irrigation system efficiency, and/or fertilizer cost.

Analysis of the impact of rising natural gas prices was conducted by changing the pumping costs in the crop budgets. The natural gas prices considered were $.50/mcf and $1.00/mcf through $9.00/mcf in $1 increments. For each natural gas price, the costs and returns of each crop and irrigation regime were calculated. The model selected the combination of crops and the irrigation regime that maximized returns.

To study the interrelationship between the effect of natural gas prices and commodity prices, two commodity price levels were considered for each natural gas price (Table 1). The low price level was the 1990 commodity loan rates. The high price level was the 1990 effective target prices. Effective target prices were the target prices adjusted for the reduced amount of production on idled cropland required by participation in the government programs.

Costs and Returns for Irrigation Regimes

Costs and returns were calculated for the nine irrigated corn regimes with center-pivot and gravity-flow systems (Table 2). The estimated water use and crop yield for each regime were based on research at the Branch Experiment Station in Tribune, Kansas (5). The nine irrigation regimes were combinations of irrigations at six stages during the crop preparation and growing season. Irrigations during the preplant (PP), 18-inch plant height (18”), pretassel (PT), silking (SK), bloom (BL), and kernel dent (DT) stages were considered. Each regime had a different amount of water pumped and/or a different irrigation schedule. One regime had one irrigation, four regimes had two irrigations, one regime had three irrigations, two regimes had four irrigations, and one regime had five irrigations. The gravity-flow had lower irrigation system efficiency and, therefore, required more water to be pumped; the center-pivot required less water to be pumped but more energy for pumping because of higher system pressure. Crop yields and fertilizer requirements were assumed to be the same for both systems.

Cost and returns for nine irrigated grain sorghum regimes with gravity-flow and center-pivot systems are reported in Table 3. The nine irrigation regimes were combinations of irrigations at five stages of the crop preparation and growing season. Irrigations during the preplant (PP), growing differentiation (GD), boot (BT), bloom (BL), and soft dough (SD) stages were considered. One regime had one irrigation, four regimes had two irrigations, three regimes had three irrigations, and one regime had four irrigations. Grain sorghum yields and irrigation regimes were from experimental data from the Tribune Branch Experiment Station.

Table 4 provides the cost and return estimates for the irrigated wheat regimes. Wheat yields for the irrigation regimes and water use estimates were from experimental plot data at the Garden City Branch Experiment Station (6).

The seven irrigation regimes were combinations of irrigations at five stages during the crop preparation and growing season. Irrigation during the preplant (PP), winter (WI), jointing (JT), boot (BT), and heading (HD) stages were considered. One regime had one irrigation, five regimes had two irrigations, and one regime had three irrigations.

Costs and returns in Tables 2, 3, and 4 are based on the owner and operator receiving full share. For tenant arrangements, which are included in the model but not in these tables, the crop share and fertilizer costs are reduced one-third. Fertilizer costs are based on the amount of fertilizer necessary to replace the nutrients removed by the crops. Other variable costs are from the Kansas State University Farm Management Guides (8).

To estimate the pumping cost for each natural gas price, a model developed by Williams et al. (7) was used. The model requires data on number of irrigated acres, system operating pressure, inches of irrigation water pumped per acre per season, pumping water level, flow rate in gallons per minute, percent pump efficiency, energy price, oil cost per gallon, pumping plant maintenance cost, annual system repair and maintenance cost, hourly wage rate, and the British Thermal Units (BTU) content of natural gas. To estimate the costs associated with the different natural gas prices only the natural gas price variable was changed.

Energy Use and Conversion

In western Kansas, 67 percent of the irrigation units are powered using natural gas, 13 percent using diesel fuel, 4 percent using liquified petroleum (LP), and 16 percent using electricity (9). In the southern half of the region, 76 percent of the irrigation units are powered using natural gas (9).

Natural gas price was used as a proxy for energy price because it was the major source of energy for irrigation in western Kansas. Results can be applied to other energy types with the appropriate conversions.

Williams et al. (7) provided a method to convert natural gas consumption per hour of pumping to electricity (kilowatts per hour), diesel (gallons per hour), and LP gas (gallons per hour). The natural gas cost equivalent multipliers are:

1 gallon per hour of LP = .1033 mcf/hr of natural gas,
1 gallon per hour of diesel = .1874 mcf/hr of natural gas,
1 KWH per hour of electricity = .0132 mcf/hr of natural gas.

For example, with a natural gas price of $4.00/mcf, the variable cost per hour of pumping with natural gas is equivalent to one hour of pumping using LP gas if the price of LP is $.41/gal ($4.00/mcf * .1033). Similar conversions can be made for diesel and electric power sources:

Diesel	$4.00 x .1874 = $.75
Electricity	$4.00 x .0132 = $.053

Appendix A-4 provides the equivalent cost prices of the four types of energy for the natural gas prices used in this study.

RESULTS

Costs and Returns for Irrigation Regime

The linear programming procedure calculated the combinations of crop acreage and irrigation regime that maximized total net return for the representative farm based on per-acre costs and returns (Tables 2, 3, and 4).

For corn, the most profitable regime used five irrigations, and the increase in per-acre income from four to five irrigations was approximately $3.00 (Table 2). The five irrigations were at preplant, 18-inch height, pretassel, bloom, and dent stages. Income was about $4.00 per acre more for the gravity-flow than for the center-pivot system. The savings from the higher irrigation efficiency of the center-pivot system were more than offset by the increased cost of pumping water at a higher pressure. These costs were based on comparing systems already in use.

Grain sorghum showed less increase than corn in per-acre crop yield or income as the number of irrigations increased (Table 3). The highest net return per acre was with two irrigations at the preplant and growing differentiation stages, but three and four irrigations were included in the model. The income advantage for gravity-flow was approximately $3.00 per acre over the center-pivot system for most irrigation regimes.

Irrigated wheat showed little yield response to the number of irrigations (Table 4). The regime with irrigations at the preplant, winter, and heading stages gave the highest per-acre net returns, with income of approximately $11.00 more than with one irrigation. A greater response came from the timing rather than from the amount of irrigation. With one irrigation, per-acre income from wheat was nearly the same as that from grain sorghum, but both were much larger than that from corn. As the number of irrigations increased, wheat yield per acre increased relatively more than income. The value of the increase in yield was largely offset by the added pumping cost of more irrigation.

Effects of Natural Gas Prices

The economic model was used to estimate income changes, acreage adjustments, and water pumped for the base representative farm for different natural gas prices. To generalize the results from the representative farm to other sized farms, results of the model are reported on a percent basis (Figure 1). Irrigated farms similar in size to the representative farm would likely have similar reductions in the percent of income, water use, and irrigated acres if natural gas price increased.

Effects on Income

Maximum income ($142,849 of gross revenue less variable production and irrigation costs) occurred with a natural gas price of $.50/mcf and the highest commodity prices. This maximum was the base used to calculate the percent of the maximum income associated with higher natural gas prices and low commodity prices. Changing either the natural gas price or commodity prices had a large, but opposite, impact on income from irrigation. An increase in the natural gas price from $.50/mcf to $6.00 reduced income 50 percent with high commodity prices and almost eliminated income from irrigation with low commodity prices. At these low prices, the profit from each crop was reduced, but less for wheat and grain sorghum than for corn. Income was about 60 percent higher with high commodity prices than with low commodity prices. An increase in natural gas price from $.50/mcf to $7.00/mcf with high commodity prices decreased income about 60 percent.

An increase in natural gas price from $.50/mcf to $7.00/mcf had about the same effect as a decrease in commodity prices from the high to the low level.

With the low commodity prices, a natural gas price of $7.00/mcf eliminated income from irrigation for the representative farm, and land use shifted to nonirrigated wheat and grain sorghum. With high commodity prices, some irrigation continued at the $9.00/mcf price.

Effects on Total Land Irrigated

The distribution of irrigated and nonirrigated crop acreage resulting from an increase in the natural gas price and a decrease in the commodity price levels was also converted to percentages with total cropland used as the base (Figures 2 and 3). The representative farm had 37.1 percent of cropland in nonirrigated crops and 62.9 percent in irrigated crops. This acreage compare to the model results of 23 percent of cropland nonirrigated and 77 percent irrigated at the natural gas price of $.50/mcf and high commodity prices.

High Commodity Prices. With high commodity prices and a natural gas price of $.50/mcf, about 77 percent of total cropland was irrigated and most of the irrigated land was in wheat (Figure 2). The percent of total cropland irrigated remained unchanged through $7.00/mcf, after which the percent of nonirrigated acreage increased to approximately 33 percent. Irrigated wheat was the predominate crop (45 percent of the irrigated acreage) until the natural gas price increased to $2.00/mcf; for prices above $2.00/mcf, wheat acreage declined to 33 percent. Above the $2.00/mcf price, irrigated corn acreage was reduced to zero. High commodity prices and low energy price are needed for corn because of its high water requirement and input costs. Corn production has higher variable costs per acre than wheat or grain sorghum, but the higher yield and high price can offset the higher costs.

The effect of an increase in the price of natural gas on irrigated grain sorghum acreage (Figure 2) was opposite that on corn. The lowest percentage occurred at the lowest natural gas price. At a $.50/mcf price, irrigated grain sorghum was about 15 percent of total cropland and about 20 percent of total irrigated acres. Irrigated sorghum acreage was at a maximum at the $4.00/mcf price, after which it declined as natural gas price increased. Maximum irrigated grain sorghum acreage was nearly 45 percent of total acreage and 58 percent of total irrigated acreage.

Wheat acreage remained at about 42 percent of total crop acreage and about 50 percent of total acres irrigated for natural gas prices of $.50/mcf to $2.00/mcf (Figure 2). Irrigated wheat acreage did fluctuate somewhat, with acreage declining until the price of $5.00/mcf, then increasing until a $7.00/mcf price, and thereafter declining again.

With a natural gas price higher then $2.00/mcf, grain sorghum and wheat were the only crops irrigated, although their combined acreage declined for prices above $7.00/mcf. Irrigated grain sorghum had the highest percent and absolute acreage when natural gas price was between $2.00 and $4.00/mcf.

At low natural gas prices, 20 percent of the irrigated acres was corn. As natural gas price increased above $2.00/mcf, the profitability of corn was reduced because it is relatively more energy- and input-intensive and, thus, was replaced by irrigated grain sorghum. Above $7.00/mcf, irrigated grain sorghum decreased more than wheat because of higher energy requirements.

Low Commodity Prices. For low commodity prices and $.50/mcf, total acres irrigated was about 78 percent of total crop acreage (Figure 3), which is nearly the same as with high commodity prices. Irrigated acreage remained about the same until a natural gas price of $2.00/mcf and, thereafter, showed a steady decrease. With a natural gas price of $7.00/mcf, very little acreage was irrigated.

Irrigated corn acreage did not occur with low commodity prices. Grain sorghum was the major irrigated crop for all natural gas prices studied. Grain sorghum had relatively high input costs and high yields. Grain sorghum acreage was 48 percent of total acreage and 62 percent of total irrigated acreage with the price of $.50/mcf but decreased as natural gas prices increased. At a $7.00/mcf price, grain sorghum acreage was nearly zero.

Irrigated wheat acreage was about 30 percent of total acres and about 38 percent of irrigated acreage at $.50/mcf, maintained this level until a natural gas price of $3.00/mcf, and then declined with higher natural gas prices. At $5.00/mcf, wheat acreage was reduced to zero.

As natural gas prices increased at low commodity prices, crop acreage shifted to nonirrigated wheat on fallow.

Effect on Water Pumped

Maximum water pumped occurred with the $.50/mcf natural gas price and high commodity prices (Figure 4). This maximum was the base used for calculating the percent of the maximum water use associated with higher natural gas price or low commodity price.

High Commodity Prices. With high commodity prices, an increase in the natural gas price immediately reduced the amount of water pumped. Although the amount of irrigated acreage was sustained, the amount of water pumped was reduced as corn acreage was eliminated. As the natural gas price increased, the amount of water pumped declined and at $4.00/mcf, the amount of water pumped was approximately two-thirds of that pumped at $.50/mcf. The reduction in water pumped was the result of fewer acres irrigated and less water per acre as irrigated acreage shifted from corn to wheat and grain sorghum.

Low Commodity Prices. At low commodity prices and $.50/mcf, the amount of water pumped was about 90 percent of that pumped at the high price level (Figure 4). At $4.00/mcf, the amount of water pumped was less than half of the maximum. Only grain sorghum was irrigated at a natural gas price above $4.00/mcf.

IMPLICATIONS

If natural gas prices continue to rise relative to the price of commodities, then irrigated agriculture will become less important in the western Kansas economy. The potential exists from improved technology for irrigation to become more efficient, thereby lowering pumping costs and conserving water. However, in the short term, there are no production or irrigation practices that can offset a sharp increase in the price of natural gas or a sharp decline in commodity prices.

If natural gas prices continue to rise with no comparable increase in commodity prices, irrigated corn in western Kansas will likely be replaced by irrigated wheat and grain sorghum, accompanied by a dramatic decline in total irrigated acreage. Increases in natural gas price affect corn acreage more than grain sorghum or wheat acreage. Corn reaches its greatest return over variable costs with four irrigations, whereas grain sorghum reaches its maximum with two irrigations. The returns from corn are higher than from grain sorghum but so is its use of natural gas and water. Thus, as natural gas price increases, production costs increase proportionately more for corn than grain sorghum. Production costs will increase even faster as more water is used for corn and the water table declines.

An increase in commodity price level favors corn production more than wheat or grain sorghum, because corn with four irrigations is a higher yielding crop. With greater per acre production from corn, an increase in commodity price levels results in return over variable costs rising faster for corn than grain sorghum or wheat.

Higher natural gas price or lower commodity prices sharply reduce the irrigator’s income, thereby reducing the amount of water pumped and the overdraft of the Ogallala aquifer.

Water lift varies from over 400 feet in some southwestern counties to less than 100 feet in northwestern Kansas (Tables A-1, A-2, and A-3). For irrigated farms with water lift greater than 225 feet, an increase in the natural gas price will decrease net income more than shown in Figure 1, decrease irrigated acreage (principally corn) more than shown in Figures 2 and 3, and reduce the amount of water pumped more than shown in Figure 4. For irrigated farms with water lift less than 225 feet, the effects of a rise in natural gas price would be less than those shown in Figures 1, 2, 3, and 4.

This study did not consider the long-term consequences that an increase in the natural gas price might have on the decision to replace irrigation wells and equipment. Consequently, the adjustments in acreage, water use, and income will probably be greater than indicated by these results. With higher natural gas prices, well or equipment repair or replacement and land development will become less feasible. If an irrigator does not see a long-term justification for the investment or reinvestment in irrigation technology, then irrigation will be discontinued.

SUMMARY

Production of irrigated crops is energy-intensive. Therefore, their levels of production and income are sensitive to changes in energy and commodity prices. Using natural gas price as a proxy for energy prices, this study showed the potential effect of an increase in the price of energy on income, acres irrigated, and water pumped. A model of a representative irrigated farm in western Kansas was used to estimate the impact of increasing energy and commodity prices.

With high commodity prices, irrigation can continue but acreage and water use probably would be greatly reduced with a natural gas price of $7.00/mcf or higher. With low commodity prices (as low as the government loan rate), irrigation in western Kansas was essentially eliminated at a natural gas price of $7.00.

An increase in the price of natural gas from $.50 to $4.00/mcf with high commodity prices was estimated to reduce net income by 35 percent because of the effect on pumping costs. As the natural gas price increased, a change in the crop mix and water use per acre could partially offset the adverse effect of that increase.

With high commodity prices, the number of irrigated acres was maintained for natural gas prices between $.50/mcf and $7.00/mcf. Thereafter, irrigated acreage decreased.

Irrigated corn acreage was adversely affected by increases in the natural gas price, more so than grain sorghum or wheat. If the natural gas price increased above $2.00/mcf, with high commodity prices, irrigated corn acreage decreased sharply.

Irrigated wheat acreage changed relatively little as the natural gas price increased with high commodity prices. Irrigated wheat acreage was almost 40 percent of total crop acres and remained at that level throughout the range of natural gas prices considered. Irrigated wheat and grain sorghum acreage replaced irrigated corn as it became unprofitable. But with a natural gas price above $7.00/mcf and with high commodity prices, irrigated grain sorghum acreage also decreased.

Some of the difference between the response in corn and wheat acreage can be explained by considering the profit potential of each. Corn production responds very well to full irrigation with relatively high yields, although input costs are high. But the combination of high commodity price and high yield provide higher profit for corn than wheat. Under a favorable price and energy cost relationship, corn is the favored crop.

Grain sorghum does not have the profit potential of corn but it is somewhat better than wheat. Thus, with high commodity prices, as natural gas price increased, the percent of irrigated acreage in grain sorghum increased, but began to decrease as the natural gas price increased above $4.00/mcf.

The amount of water pumped decreased with an increase in natural gas price for all levels studied. With an increase in the price of natural gas to $4.00/mcf, water pumped decreased about 35 percent with high commodity prices and 45 percent with low prices.

An increase in commodity price can offset an increase in the price of energy to a certain point. But as irrigation continues, the supply of water continues to diminish, which lowers well yield and increases lift. Lower well yield and increased lift exacerbate the adverse affects of an increase in energy price.

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Table 1. High and low commodity price levels

Commodity	High	Low
Wheat, $/Bu	3.86	2.44
Corn, $/Bu	2.60	1.96
Grain sorghum, $/Bu	2.45	1.86

Table 2. Per-acre corn yield, water pumped, and variable costs by irrigation regime and system

Irrigation Regime	Estimated Yield per Acre Bu.	Water Pumped Ac. In.	Fertilizer Cost $	Pumping Cost $	Other Variable Costs $	Total Variable Costs $	Income Less Total Variable Costs $
			Gravity-Flow System				
PP	50	11.12	25.08	17.34	105.39	147.81	-17.81
PP+BT	93	20.85	46.72	27.70	105.39	179.81	61.99
PP+SK	107	20.66	53.82	32.81	105.39	192.02	86.18
PP+BL	96	20.45	48.21	31.88	105.39	185.48	64.12
18+BL	118	19.95	59.28	31.11	105.39	195.78	111.02
PP+PT+BL	132	28.74	66.34	44.81	105.39	216.54	126.66
PP+PT+SK+BL	144	35.02	72.37	54.59	105.39	232.35	142.05
18+PT+BL+DT	143	32.75	71.80	52.27	105.39	229.46	142.34
PP+18+PT+BL+DT	151	42.74	75.92	66.63	105.39	247.94	144.66
			Center-Pivot System				
PP	50	8.50	25.08	19.04	105.39	149.51	-19.51
PP+PT	93	15.94	46.72	35.71	105.39	187.82	53.98
PP+SK	107	15.80	53.82	35.39	105.39	194.60	83.70
PP+BL	96	15.19	48.21	34.03	105.39	187.63	61.97
18+BL	118	15.26	59.28	34.18	105.39	198.85	107.95
PP+PT+BL	132	21.98	66.34	49.24	105.39	220.97	122.23
PP+PT+SK+BL	144	26.78	72.37	59.99	105.39	237.75	136.65
18+PT+BL+DT	143	25.64	71.80	57.43	105.39	234.62	137.18
PP+18+PT+BL+DT	151	32.68	75.92	73.20	105.39	254.51	138.09

[1] Time of irrigation is abbreviated as follows: PP=preplant, PT=pretassel, SK=silk, BL=blister, 18=18-inch plant height, and DT=dent stages.

[2] Water pumped is based on 65 percent distribution efficiency.

[3] Pumping cost is based on $2.00/mcf for natural gas, 225 feet water lift, and 900 GPM.

[4] Water pumped is based on 85 percent distribution efficiency.

[5] Income is calculated using $2.60 per bu.

Table 3. Per-acre grain sorghum yield, water pumped, and variable cost by irrigation regime and system

Irrigation Regime	Estimated Yield per Acre Bu.	Water Pumped Ac. In.	Fertilizer Cost $	Pumping Cost $	Other Variable Costs $	Total Variable Costs $	Income Less Total Variable Costs $
Gravity-Flow System							
GS Fallow	45		8.40		39.10	47.50	62.75
PP	106	10.21	53.46	16.11	76.38	145.95	113.75
PP+BT	117	18.46	59.49	29.13	76.38	164.00	122.65
PP+BL	115	18.34	57.79	28.94	76.38	163.11	118.64
PP+SD	114	18.22	57.79	28.94	76.38	162.46	116.82
PP+BT+BL	121	27.20	60.98	42.93	76.38	180.29	116.16
PP+BT+BL+SD	126	30.21	63.26	47.69	76.38	187.27	121.43
PP+BT+SD	127	27.09	63.82	42.76	76.38	182.96	128.19
PP+GD	128	18.48	64.28	29.16	76.38	169.82	143.78
PP+GD+BL	134	27.57	67.37	43.51	76.38	187.13	141.17
Center-Pivot System							
PP	106	7.74	53.46	17.34	76.38	147.18	112.52
PP+BT	117	14.12	58.49	31.62	76.38	166.49	120.16
PP+BL	115	14.02	57.79	31.41	76.38	165.58	116.17
PP+SD	114	13.93	57.33	31.20	76.38	164.91	114.59
PP+BT+BL	121	20.80	60.98	46.59	76.38	183.95	112.50
PP+BT+BL+SD	126	23.11	63.25	51.76	76.38	191.39	117.31
PP+BT+SD	127	20.71	63.82	46.41	76.38	186.61	124.54
PP+GD	128	14.13	64.28	31.65	76.38	172.31	141.29
PP+GD+BL	134	21.08	67.37	47.22	76.38	190.97	137.93

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[1] Time of irrigation is abbreviated as follows: PP=preplant, BT=boot, BL=one=half bloom, SD=soft dough, and GD=growing point differentiation stages.

[2] Water pumped is based on 65 percent distribution efficiency.

[3] Pumping cost is based on $2.00/mcf for natural gas, 225 feet water lift, and 900 GPM.

[4] Water pumped is based on 85 percent distribution efficiency.

[5] Income is calculated using $2.45 per bu.

Table 4. Per-acre wheat yield, water pumped, and variable cost by irrigation regime and system

Irrigation Regime	Estimated Yield per ac Bu.	Water Pumped $	Fertilizer Cost $	Pumping Cost $	Other Variable Costs $	Total Variable Costs $	Income Less Total Variable Costs $
				Gravity-Flow System			
Wheat on Fallow	40		8.40		37.75	41.23	113.17
PP	55	13.6	34.02	21.46	32.83	88.31	123.99
PP+WI	53	17.06	32.78	26.93	32.83	92.54	112.04
PP+MI	55	17.91	34.02	28.26	32.83	95.11	117.19
PP+HD	49	19.45	30.26	30.69	32.83	93.78	95.36
PP+BT	60	20.83	37.21	32.68	32.83	102.92	126.68
PP+JT	60	21.43	37.21	33.82	32.83	103.86	127.74
PP+WI+HD	62	20.95	38.24	33.07	32.83	104.14	135.18
				Center-Pivot System			
PP	55	10.4	34.02	23.30	32.83	90.15	122.15
PP+WI	53	13.05	32.78	29.23	32.83	94.84	109.74
PP+MI	55	13.64	34.02	30.67	32.83	97.52	139.02
PP+HD	49	14.87	30.26	33.31	32.83	105.72	125.88
PP+BT	60	15.93	37.21	35.68	32.83	105.72	125.88
PP+JT	60	16.39	37.21	36.71	32.83	106.75	124.85
PP+WI+HD	62	16.02	38.24	35.89	32.83	106.96	132.40

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[1] Time of irrigation is abbreviated as follows: PP=preplant, WI-winter, MI=milk, HD=heading, BT=boot, and JT=jointing stages.

[2] Water pumped is based on 65 percent distribution efficiency.

[3] Pumping cost is based on $2.00/mcf for natural gas, 225 feet water lift, and 900 GPM.

[4] Water pumped is based on 85 percent distribution efficiency.

[5] Income is calculated using $3.86 per bu.

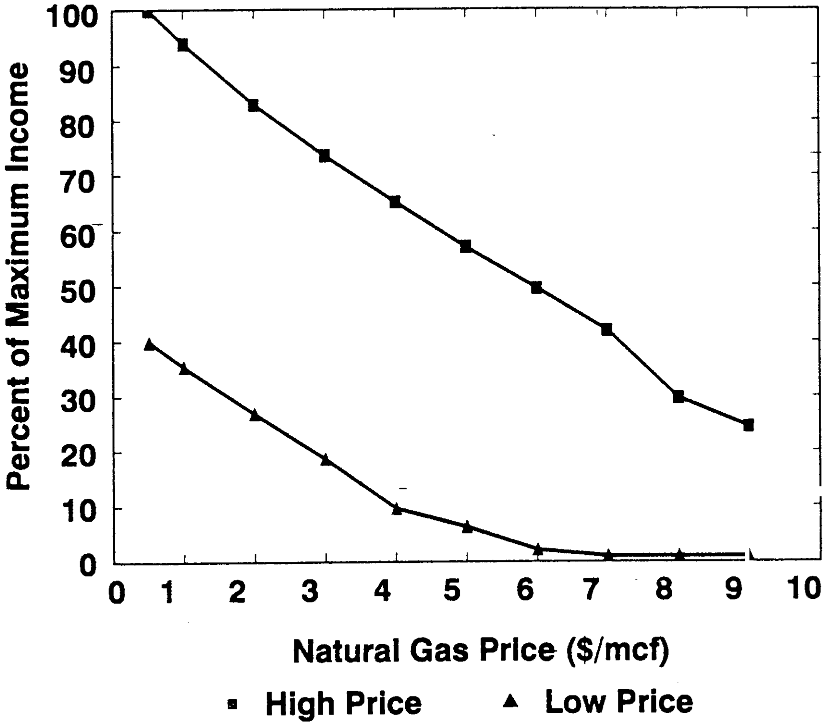


Figure 1. Changes in the percent of maximum income caused at different natural gas prices and high and low commodity prices

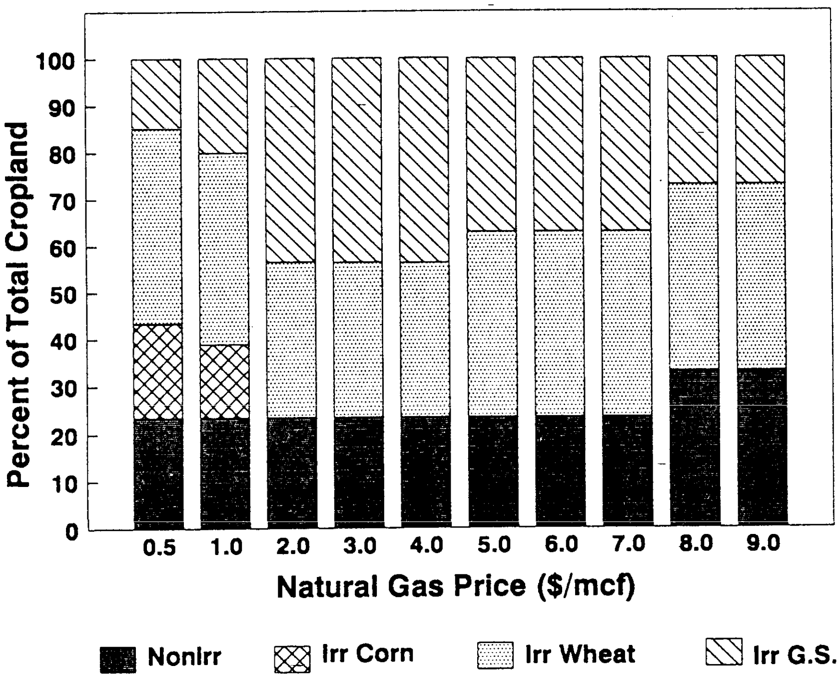


Figure 2. Distribution of total acres per crop at different natural gas prices and high commodity prices

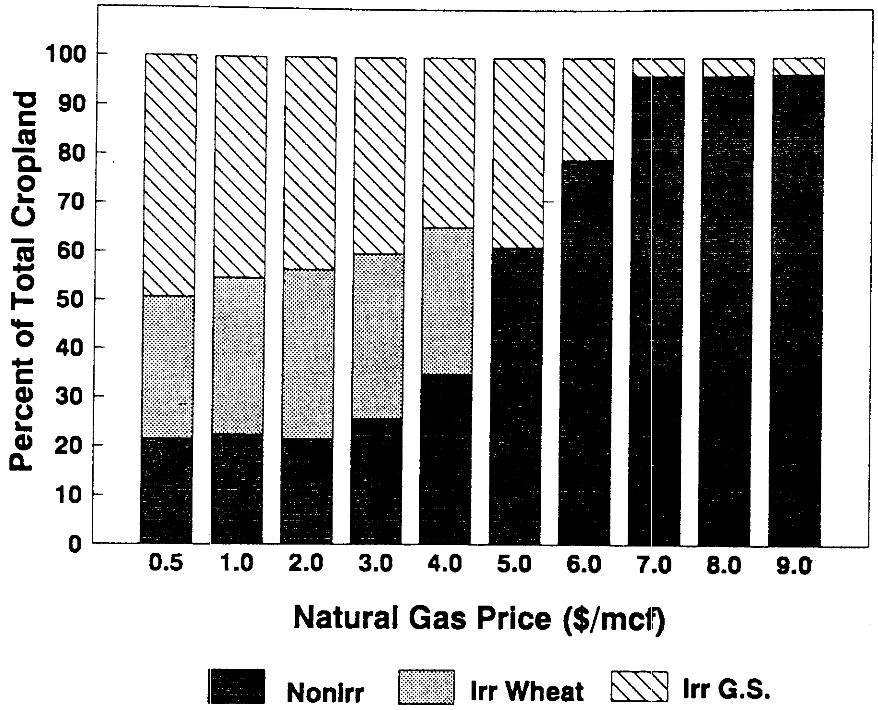
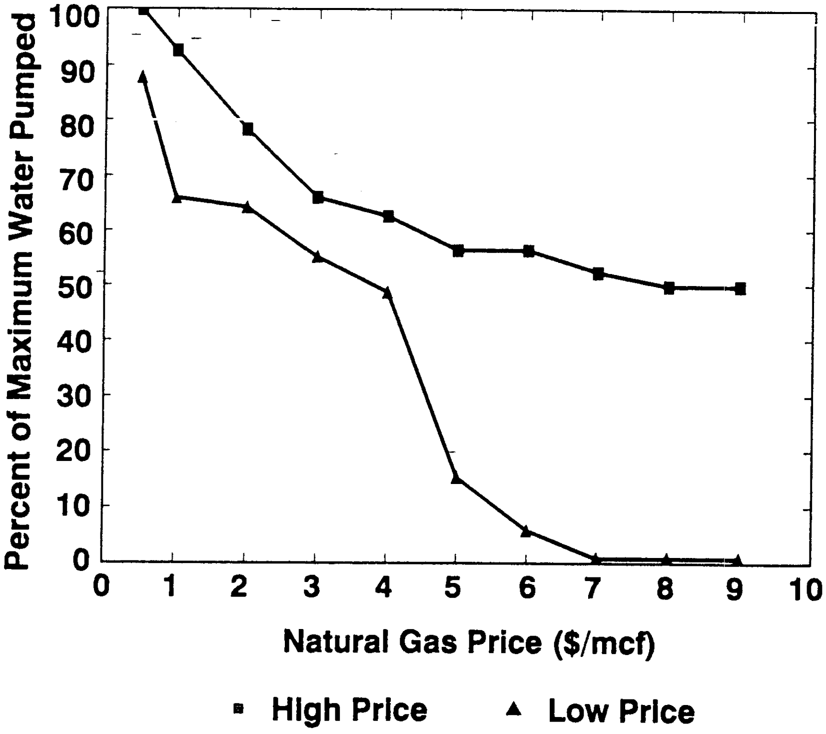


Figure 3. Distribution of total acres per crop at different natural gas prices and low commodity prices



Change in percent of maximum water pumped at different natural gas prices and high and low commodity prices

APPENDIX

Table A-1: Depth to water as reported in 1988 for some irrigation test wells and percentage accumulated by depth classification and by county

	No. Test Wells	Accumulated % of wells of less than designated depth							
County	Reporting	50ft	100ft	150ft	200ft	250ft	300ft	350ft	400ft
Southwest Region:									
Finney	73	8	39	93	100				
Ford	64	29	57	85	98	100			
Grant	41				22	63	85	100	
Gray	44	9	29	76	98	100			
Hamilton	35	54	60	74	85	94	97	100	
Haskell	31			6	19	45	64	97	100
Hodgeman	27	18	55	70	77	81	96	100	
Kearney	30	23	43	76	86	93	100		
Meade	28	28	39	64	96	100			
Morton	38	3	40	66	90	100			
Seward	35	3	9	29	63	97	100		
Stanton	36	3	14	59	92	100			
Stevens	41		10	51	88	95	100		
West Central Region:									
Gove	19	26	58	100					
Greeley	18	6	17	61	94	100			
Lane	18		61	100					
Logan	12	8	25	75	100				
Ness	12	83	100						
Scott	37		22	87	100				
Wallace	25	4	8	48	88	100			
Wichita	40	3	19	78	100				
Northwest Region:									
Cheyenne	45	18	29	51	60	100			
Decatur	33	61	79	100					
Graham	22	27	59	100					
Norton	10	30	70	100					
Rawlins	33	43	46	73	88	100			
Sheridan	50	20	26	82	100				
Sherman	64	3	9	53	97	100			
Thomas	57	7	23	74	98	100			

Source: 10

Table A-2: Depth to bedrock as reported in 1988 for some irrigation test wells and percentage accumulated by depth classification and by county

County	No. Test Wells Reporting	Accumulated % of wells of less than designated depth						
		100ft	200ft	300ft	400ft	500ft	600ft	700ft
Southwest Region:								
Finney	61	10	33	48	71	88	100	
Ford	22	5	50	95	95	100		
Grant	39		3	39	85	100		
Gray	41	2	22	83	83	100		
Hamilton	31	58	71	100				
Haskell	20				5	35	95	100
Hodgeman	4	75	100					
Kearney	29	10	31	66	83	100		
Meade	26		4	8	31	65	96	100
Morton	22	5	41	64	91	96	100	
Seward	28				7	57	82	100
Stanton	29	3	6	27	62	100		
Stevens	31			6	16	48	90	100
West Central Region:								
Gove	5	20	100					
Greeley	17	12	59	100				
Lane	19	11	100					
Logan	6	33	67	100				
Ness								
Scott	36		89	100				
Wallace	27	7	22	89	93	100		
Wichita	40		80	100				
Northwest Region:								
Cheyenne	13	46	54	69	100			
Decatur	31	61	100					
Graham	13	15	77	100				
Norton								
Rawlins	34	38	62	97	100			
Sheridan	36	17	36	97	100			
Sherman	61	2	5	69	100			
Thomas	47	4	25	69	100			

Source: 10

Table A-3: Saturated thickness reported in 1988 for some irrigation test wells and percentage accumulated depth classification and by county

Counties	No. Test Wells Reporting	Accumulated %-age of reporting wells with less than designated depth									
		25ft	75ft	125ft	175ft	225ft	275ft	325ft	375ft	425ft	475ft
Southwest Region:											
Finney	58	9	28	38	43	57	66	83	88	100	
Ford	21	5	29	85	90	95	95	95	100		
Grant	30			13	40	74	97	100			
Gray	41		20	40	84	84	94	96	100		
Hamilton	26	27	80	88	96	100					
Haskell	18					28	67	100			
Hodgeman	4	25	75	100							
Kearney	23	9	40	44	48	52	61	91	100		
Meade	22				5	10	19	59	82	95	100
Morton	16	6	25	57	63	63	94	100			
Seward	26					4	31	58	73	77	100
Stanton	20	5	15	30	50	80	100				
Stevens	28			4	11	18	25	46	57	75	100
West Central Region:											
Gove	5		80	100							
Greeley	17	6	94	100							
Lane	19	5	95	100							
Logan	5		60	100							
Ness											
Scott	33	18	88	97	100						

Table A-3 continued: Saturated thickness reported in 1988 for some irrigation test wells and percentage accumulated by depth classification and by county

Counties	No. Test Wells Reporting	Accumulated %-age of reporting wells with less than designated depth									
		25ft	75ft	125ft	175ft	225ft	275ft	325ft	375ft	425ft	475ft
West Central Region Continued:											
Wallace	23	13	61	78	87	96	100				
Wichita	37	13	97	100							
Northwest Region:											
Cheyenne	13	61	69	100							
Decatur	29	41	93	100							
Graham	12	8	58	92							
Norton	-										
Rawlins	28	14	61	100							
Sheridan	35	-	37	97	100						
Sherman	55	-	2	49	93	100					
Thomas	42	2	21	81	98	100					

Source: 10

Table A-4. Energy price conversion

Natural Gas Price $/mcf	Equivalent Price Conversion		
	Diesel $/gal	Propane $/gal	Electricity $/KW
.50	.09	.05	.007
1.00	.19	.10	.013
2.00	.37	.21	.026
3.00	.56	.31	.039
4.00	.75	.41	.052
5.00	.94	.52	.065
6.00	1.12	.62	.078
7.00	1.31	.72	.091
8.00	1.50	.82	.104
9.00	1.68	.93	.117

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Agricultural Experiment Station, Kansas State University, Manhattan 66506-4008

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