Proceedings of the 2009 Irrigation Association Technical Conference, San Antonio, Texas, December 2-5, 2009
Available from the Irrigation Association, Falls Church, Virginia, USA.

Effect of the Changing U.S. Economy on the Relative Profitability of Center Pivot Sprinklers and SDI Systems

Daniel M. O'Brien
Extension Agricultural Economist
Northwest Research-Extension Center
Colby, Kansas
Voice: 785-462-6281 Fax 785-462-2315
Email: dobrien@oznet.ksu.edu

Freddie R. Lamm
Research Irrigation Engineer
Northwest Research-Extension Center
Colby, Kansas
Voice: 785-462-6281 Fax 785-462-2315
Email: flamm@ksu.edu

Danny H. Rogers
Extension Irrigation Engineer
Biological and Agricultural Engineering
Manhattan, Kansas
Voice: 785-532-5813 Fax 785-532-6944
Email: drogers@ksu.edu

Troy J. Dumler
Extension Agricultural Economist
Southwest Research-Extension Center
Garden City, Kansas
Voice: 620-275-9164 Fax 620-276-6028
Email: tdumler@oznet.ksu.edu

Kansas State University

In much of the Great Plains, the rate of new irrigation development is slow or zero. Since the 1970s there has been a dramatic shift in irrigation methods in the Great Plains region, as center pivot sprinkler irrigation systems have become the predominant technology, having replaced much of the furrow- irrigated base. In addition, a small yet increasing amount of subsurface drip irrigation (SDI) has been installed. Although SDI systems represent less than 1 percent of the irrigated area, producer interest still remains high because of their greater irrigation efficiency and irrigated water application uniformity. As irrigation systems need to be upgraded or replaced, available irrigated water sources become more scarce, and farm sizes become larger, there will likely be a continued interest in and momentum toward conversion to modern pressurized irrigation systems.

Irrigation system investment decisions will be affected by both the physical characteristics of the irrigation systems being considered and the economic environment that irrigated crop enterprises are operating within. Key assumptions about the physical characteristics of the irrigation systems include input-output efficiencies, life span, and system investment costs. Key economic factors include commodity prices, costs of key crop inputs, irrigation energy costs, interest rates on operating expenses, the opportunity cost of capital investments, and overall inflation in production costs. The economic factors affecting irrigation system choices can be strongly influenced by broader macroeconomic conditions and trends in the United States and world economies. To the degree that the volatile patterns in agricultural, energy and financial markets since the early 1970s continue or even become more pronounced, economic decisions about irrigation system investments will become more risk-prone and uncertain.

This paper will discuss how volatile economic conditions in key agricultural and financial markets affect expected relative profitability of center pivot sprinkler and subsurface drip irrigation systems under crop production conditions in the Great Plains. This analysis will use a K-State center pivot sprinkler (CP) and subsurface drip irrigation (SDI) comparison spreadsheet (Lamm, et al., 2009) to estimate the affect of various key economic factors upon investment decisions.

CP-SDI Comparison Spreadsheet

K-State Research and Extension introduced a free Microsoft Excel[1] spreadsheet template for making economic comparisons of CP and SDI in the spring of 2002. The spreadsheet has been periodically updated since that time to reflect changes in input data, particularly system and corn production costs. The spreadsheet also provides sensitivity analyses for key factors. Lamm, et al., (2009) explains how to use the spreadsheet and the key factors that most strongly affect the returns comparisons. The online accessible template has five worksheets (tabs), the Main, CF, Field size & SDI life, SDI cost & life, Yield & Price tabs. Most of the calculations and the result are shown on the Main tab (Figure 1.). Critical field and irrigation system assumptions are illustrated.

This template determines the economics of converting existing furrow-irrigated fields to center pivot sprinkler irrigation (CP) or subsurface drip irrigation (SDI) for corn production.

Version 09, modified by F.R. Lamm, D. M. O'Brien, D. H. Rogers, T. J. Dumler, 1-27-09

Field description and irrigation system estimates	Total	Suggested	CP	Suggested	SDI	Suggested
Field area, acres	160	← 160	125	← 125	155	← 155
Non-cropped field area (roads and access areas), acres	5	← 5				
Cropped dryland area, acres (= Field area - Non-cropped field area - Irrigated area)			30		0	
Irrigation system investment cost, total $			$73,450	← $73,450	$186,000	← $186,000
Irrigation system investment cost, $/irrigated acre			$587.60		$1,200.00	
Irrigation system life, years			25	← 25	20	← 20
Interest rate for system investment, %	7.5%	← 8.0%				
Annual insurance rate, % of total system cost			1.60%	← 1.60%	0.60%	← 0.60%
Production cost estimates			CP	Suggested	SDI	Suggested
Total variable costs, $/acre (See CF Tab for details on suggested values)			$510.25	← $510.25	$492.20	← $492.20
Additional SDI variable costs (+) or savings (-), $/acre		Additional Costs →			$0.00	← $0.00
Yield and revenue stream estimates			CP	Suggested	SDI	Suggested
Corn grain yield, bushels/acre		Suggested	220	← 220	220	← 220
Corn selling price, $/bushel	$3.87	← $4.00				
Net return to cropped dryland area of field ($/acre)	$36.00	← $36.00				
Advantage of SDI over Center Pivot Sprinkler *				$/total field each year		$1,429
* Advantage in net returns to land and management				$/acres each year		$9

You may examine sensitivity to Main worksheet (tab) assumptions on three of the tabs listed below.

Figure 1. Main worksheet (tab) of the economic comparison spreadsheet template indicating the 18 required variables (white input cells) and their suggested values when further information is lacking or uncertain.

The scenario analyzed in this research is a comparison of whether a center pivot sprinkler irrigation system (CP) is more or less profitable than a subsurface drip irrigation system on 160 acres of farmland. The CP system would irrigate 125 acres of the 160 acres of farmland, with the remaining 35 acres divided between 30 acres of non-irrigated or “dryland” cropping systems and 5 acres of non-cropped area (i.e., roads and access areas). The SDI system would irrigate 155 acres of the 160 acres of farmland, with the remaining 5 acres used for non-cropped roads and access areas. Irrigation system design and cost information is available from the authors and the K-State Research and Extension publication Irrigation Capital Requirements and Capital Costs, MF-836. Only information that is relevant to the comparison of returns for CP and SDI systems is included in this analysis. This excludes such factors as cost of irrigated cropland which will not vary for those acres that are irrigated under either irrigation system investment scenario. Non-irrigated cropland returns are included because of the inclusion of dryland acreage under the CP scenario. Average cash rental rates are included as a market-based proxy for the returns expected from farming non-irrigated cropland. For further discussion of the assumptions used in this analysis see Lamm, et al. (2009).

Actual values used in this analysis may vary from suggested values in the Main tab of the worksheet where current prices and market conditions warrant. Key information from the Main tab for the following analysis is as follows.

1. Corn selling price, $/bushel = $ 3.87 /bushel
2. Interest rate for system investment, % = 7.5%
3. Total variable costs, $/acre: CP = $510.25
4. Total variable costs, $/acre: SDI = $492.20
5. Net return to cropped dryland area of field ($/acre) = $ 36.00

Production cost estimates and assumptions represented in the CF tab are based on K-State Research and Extension crop enterprise budget estimates for irrigated corn in western Kansas (Figure 2.).

Factors for Variable Costs			CP	Suggested	SDI	Suggested	Version 09, modified by F.R. Lamm, D. M. O'Brien, D. H. Rogers, T. J. Dun
Seeding rate, seeds/acre	$/1000 S	Suggested	34000	← 34000	34000	← 34000	
Seed, $/acre	$2.24	← $2.24	$76.16		$76.16		
Herbicide, $/acre			$28.68	← $28.68	$28.68	← $28.68	
Insecticide, $/acre			$35.30	← $35.30	$35.30	← $35.30	
Nitrogen fertilizer, lb/acre	$/lb	Suggested	242	← 242	242	← 242	
Nitrogen fertilizer, $/acre	$0.24	← $0.40	$58.08		$58.08		
Phosphorus fertilizer, lb/acre	$/lb	Suggested	50	← 50	50	← 50	
Phosphorus fertilizer, $/acre	$0.39	← $0.35	$19.50		$19.50		
Crop consulting, $/acre			$6.50	← $6.50	$6.50	← $6.50	
Crop insurance, $/acre			$37.00	← $37.00	$37.00	← $37.00	
Drying cost, $/acre			$0.00	← $0.00	$0.00	← $0.00	
Miscellaneous costs, $/acre			$0.00	← $0.00	$0.00	← $0.00	
Custom hire/machinery expenses, $/acre			$150.14	← $150.14	$150.14	← $150.14	Assumes all tillage, cultural and harvesting operations.
Other non-fieldwork labor, $/acre			$0.00	← $0.00	$0.00	← $0.00	Assumed covered by custom hire.
Irrigation labor, $/acre			$6.50	← $6.50	$6.50	← $6.50	
Irrigation amounts, inches			17	← 17	13	← 13	Assumes approximately 25% savings with SDI.
Fuel and oil for pumping, $/inch			$3.75	← $5.80	$3.75	← $5.80	Assumes equal operating pressures at pump site.
Fuel and oil for pumping, $acre			$63.75		$48.75		
Irrigation maintenance and repairs, $/inch			$0.60	← $0.60	$0.60	← $0.60	
Irrigation maintenance and repairs, $/acre		Suggested	$10.20		$7.80		
1/2 yr. interest on variable costs, rate	7.5%	← 8.0%	$18.44		$17.79		
Total Variable Costs			**$510.25**		**$492.20**	These values are *suggesred* values on Main tab.	

Figure 2. CF worksheet (tab) of the economic comparison spreadsheet template and the current production cost variables. Sums at the bottom of the CF worksheet are the suggested values for total variable costs on the Main worksheet (tab).

Corn enterprise cost of production information is available from the authors and the K-State Research and Extension publication Center Pivot Irrigated Corn Cost Return Budget in Western Kansas, MF-585. Actual values may vary from suggested values in the worksheet where current prices and market conditions warrant.

Key assumptions represented on the CF tab that are relevant to this economic analysis are listed below.

1.	Nitrogen fertilizer, $/pound of 82-0-0	= $ 0.24 /pound
2.	Phosphorus fertilizer, $/pound of 18-46-0	= $ 0.39 /pound
3.	Fuel and oil for pumping, $/acre inch	= $ 3.75 /acre inch
4.	½ yr. Interest on variable costs, rate	= 7.5% interest
5.	Total variable costs, $/acre: CP	= $510.25
6.	Total variable costs, $/acre: SDI	= $492.20

Lamm, et al. (2009) provides a further explanation of sensitivity analysis of physical production factors critical to the CP versus SDI investment decision in spreadsheet tabs on a) Field size & SDI life, b) SDI cost & life, and c) Yield & Price tabs.

Economic Factors Affecting CP versus SDI Investments

The key economic factors in this decision framework which are hypothesized to have an impact upon CP versus SDI investments include commodity prices, costs of key crop inputs, irrigation energy costs, interest rates on operating expenses, the opportunity cost of capital investments, and overall inflation in production costs.

Economic analysis typically relies upon “ceteris paribus” assumptions to determine the marginal impact of any particular factor in isolation (i.e., with "all other things being equal or held constant"). The following analysis will first focus on the impacts of variability of key factors separately (i.e., “ceteris paribus”). A final broader analysis will be conducted in which “low” versus “high” market product price and production cost regimes are examined to understand the systematic impact of these key factors. This systematic perspective reflects the integrated, interdependent nature of agricultural, energy and financial markets.

Corn Price Variability Impact

Over the July 2000-September 2009 period U.S. corn prices have exhibited great variability, with corn upfront corn futures contract prices ranging from approximately $1.90 to $7.50 per bushel (Figure 3.). In this analysis, CP versus SDI investment returns will be analyzed for the base budget corn price ($3.87 per bushel), a low price ($1.95) and a high price ($6.00). The low price of $1.95 per bushel represents the current U.S. average commodity marketing loan program price for corn. The high price of $6.00 per bushel represents a basis-adjusted estimate of cash prices that would be typically available to crop producers at the high end of the 2000-2009 corn futures trading range.

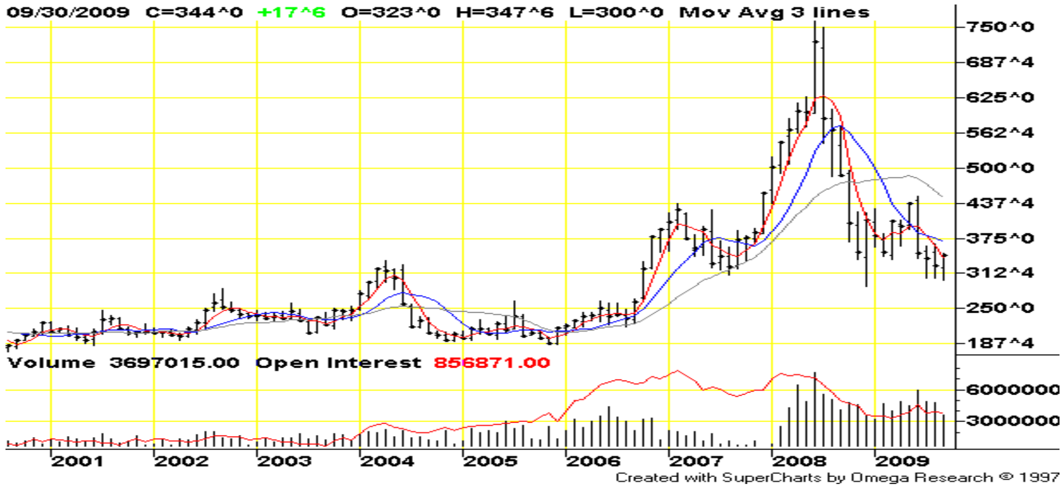

Figure 3. CBOT Corn Futures Continuation Chart: July 2000-September 2009. Online source: www.futures.tradingcharts.com

In this analysis, lower corn prices tended to favor CP systems, while higher corn prices tended to favor SDI systems (Table 1). These results can also be derived from the Yield and Price tab of the K-State spreadsheet.

Table 1. Corn Price Variation Impact on SDI versus CP Returns

Corn Price Scenarios	CP Variable Cost ($ per acre)	SDI Variable Cost ($ per acre)	SDI Less CP Returns ($ per 160 acres)	SDI Less CP Returns ($ per acre)
Base: $3.87 per bu.	$510.25	$492.20	$1,429	$9
Low: $1.95 per bu.	$510.25	$492.20	**-$11,243**	**-$70**
High: $6.00 per bu.	$510.25	$492.20	$15,487	$97

Natural Gas – Pumping Cost Variability Impact

Just as for other agricultural and energy-related commodities, over the July 2000-September 2009 period U.S. natural gas prices have exhibited great variability. Lead contract natural gas futures contract prices have ranged from approximately $2.00 to nearly $16.00 per mcf. (Figure 4.).

In the irrigated crop enterprise budgets developed by K-State Research and Extension, natural gas is the energy source used to calculate irrigation pumping costs. Center pivot sprinkler versus SDI investment returns will be analyzed for a base budget natural gas price of $5.53 per mcf., leading to a cost of $3.75 per acre inch of water applied for pumping-related fuel and oil. The low natural gas price to be considered is $2.00 per mcf., leading to a cost of $1.55 per acre inch of water applied for pumping-related fuel and oil. The high natural gas price is $12.00 per mcf., leading to a cost of $7.78 per acre inch of water applied for pumping-related fuel and oil.

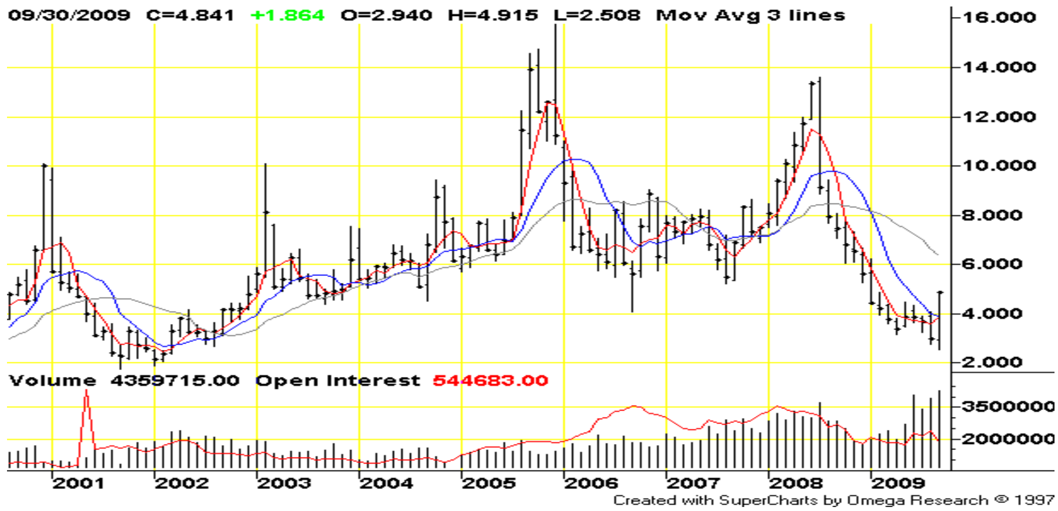

Figure 4. NYMEX Natural Gas Futures Continuation Chart: July 2000-September 2009. Online source: www.futures.tradingcharts.com

Natural gas price variation does not have a large impact on net returns in this analysis, causing a variation of $2 to $3 per acre in the advantage of SDI over CP systems from the base scenario (Table 2.).

Table 2. Natural Gas Price Variation Impact on SDI versus CP Returns

Natural Gas Price Scenarios	CP Variable Cost ($ per acre)	SDI Variable Cost ($ per acre)	SDI Less CP Returns ($ per 160 acres)	SDI Less CP Returns ($ per acre)
Base: $5.53 per mcf. 3.75 per acre inch	$510.25	$492.20	$1,429	$9
Low: $2.00 per mcf. 1.55 per acre inch	$471.45	$462.53	$1,178	$7
High: $12.00 / mcf. 7.78 per acre inch	$581.33	$546.56	$1,888	$12

Nitrogen and Phosphorous Fertilizer Cost Variability Impact

Fertilizer prices for anhydrous ammonia or NH3 (82-0-0 N-P-K) and di-ammonium phosphate or DAP (18-46-0 N-P-K) have also been extremely variable in the most recent decade. Over the 1999-2008 period U.S. fertilizer prices have trended higher, with 82-0-0 prices ranging from $211 to $755 per ton of nitrogen on average per year. During the summer of 2008 anhydrous ammonia prices reached over $1,050 per ton of nitrogen. During 1999-2008 di-ammonium phosphate prices ranged from $227 to $850 per ton, reaching up to $1,200 per ton in the summer months of 2008.

Although the prices for these two fertilizer products are not perfectly correlated, the low and high price scenarios for anhydrous ammonia and di-ammonium phosphate will be analyzed together. The base 82-0-0 price is $400 per ton or $0.24 per pound of nitrogen, and the base price for 18-46-0 is $0.39 per pound. The low 82-0-0 price is $211 per ton or $0.13 per pound of nitrogen, and $0.11 per pound for 18-46-0. The high 82-0-0 price is $950 per ton or $0.57 per pound of nitrogen, and $0.85 per pound for 18-46-0.

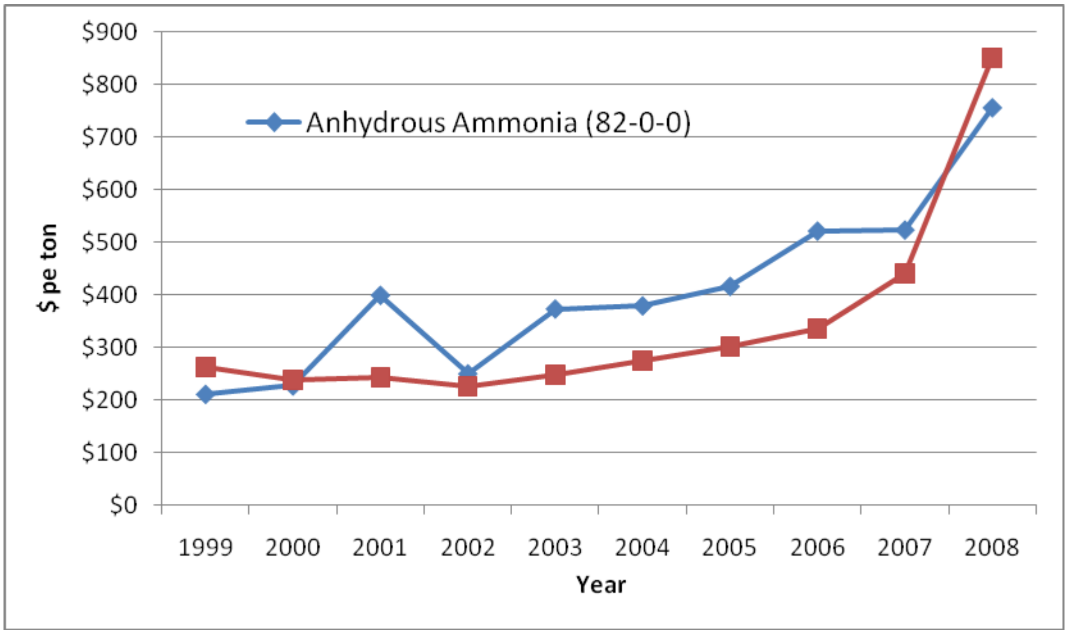

Figure 5. United States Annual Average Fertilizer Prices: 1999-2008. Source: USDA Economic Research Service

Fertilizer price variation does not have a large impact on net returns in this analysis, causing a variation of only $2 to $8 per acre in the advantage of SDI over CP systems from the base scenario (Table 3.).

Table 3. Fertilizer Price Variation Impact on SDI versus CP Returns

Fertilizer Price Scenarios	CP Variable Cost ($ per acre)	SDI Variable Cost ($ per acre)	SDI Less CP Returns ($ per 160 acres)	SDI Less CP Returns ($ per acre)
Base: $0.24 / lb 82-0-0 $0.39 / lb 18-46-0	$510.25	$492.20	$1,429	$9
Low: $0.13 / lb 82-0-0 $0.11 / lb 18-46-0	$467.93	$449.88	$2.698	$17
High: $0.37 / lb 82-0-0 $0.85 / lb 18-46-0	$616.97	$598.92	$1,773	$11

Interest Rate Variability Impact

Interest rates in the United States have varied from almost 0% up to 20% since 1950 (Figure 6.). Large swings in interest rates can have sizable impacts on the cost of borrowing money. In this analysis interest rates affect variable operating costs and the cost of borrowing money for irrigation system investments. Even if irrigation investments are paid for without credit and associated interest expenses on borrowed money, the opportunity cost of having capital invested in one enterprise as opposed to another are relevant to an investor's decision.

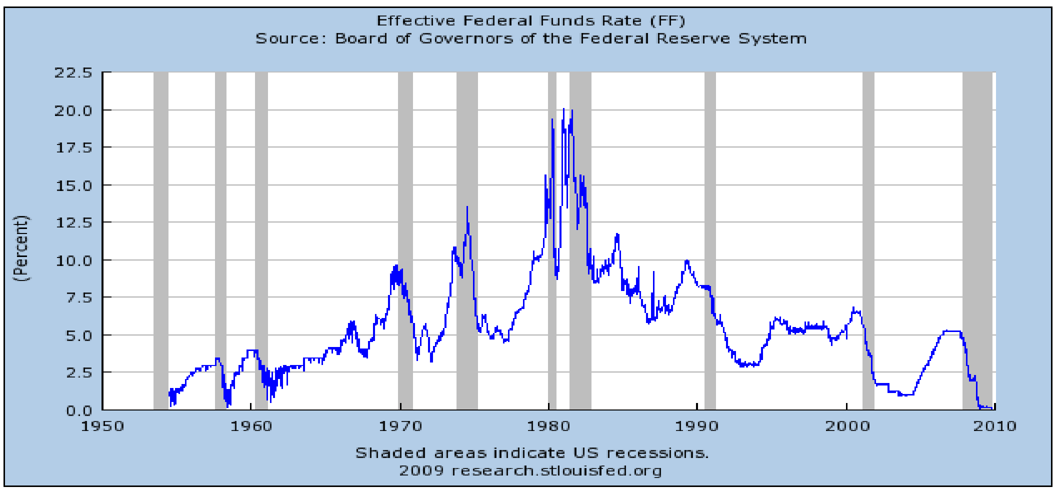

Figure 6. United States Interest Rates: 1950-2009. Source: St. Louis Federal Reserve Bank.

In this analysis the base interest rate used is 7.5%. The low interest rate scenario is calculated using a 5% rate on operating funds and capital investments. The high interest rate was set equal to the top rate charged during the period of the late 1980s – early 1990s, i.e., 20%.

Interest variation does have a large impact on relative returns in this analysis. Low interest rates near 5% benefit SDI over CP systems by $10 per acre, while historically high 20% interest rates cause CP systems to become more profitable than SDI systems by approximately $40 per acre (Table 4.).

Table 4. Interest Rate Variation Impact on SDI versus CP Returns

Interest Rate Scenarios	CP Variable Cost ($ per acre)	SDI Variable Cost ($ per acre)	SDI Less CP Returns ($ per 160 acres)	SDI Less CP Returns ($ per acre)
Base: 7.5% Interest	$510.25	$492.20	$1,429	$9
Low: 5.0% Interest	$504.11	$486.27	$2,987	$19
High: 20.0% Interest	$540.99	$521.85	**-$6,359)**	**-$40**

Cost Inflation Variability Impact

Since the early 1900s, inflation rates in the United States have varied from a negative 1.94% (i.e., deflation) during 1920-29 to a positive 8.7% during the 1913-1919 period (Figure 7.). Since World War II, the decade of the 1970s had the highest annual average rate of inflation at 7.09% per year. Periods of high inflation in the cost of consumer goods raise consumer's cost of living and tend to diminish their real inflation-adjusted buying power and personal wealth. In the same way, inflation in agricultural production costs tend to increase cost of production and diminish crop enterprise profitability if not accompanied by increases in agricultural product prices.

In this analysis, the impacts of one time inflations of 3% and 9% in the level of crop production costs are analyzed in comparison to the base scenario of no differential cost inflation. For this scenario, the impact of inflation in seed, herbicide, insecticide, crop consulting, crop insurance, custom hire / machinery expenses, labor costs, irrigation maintenance and repair, and non-irrigated cropland rental rates are examined. A more thorough multi-period analysis of inflation impacts over time is called for in future research.

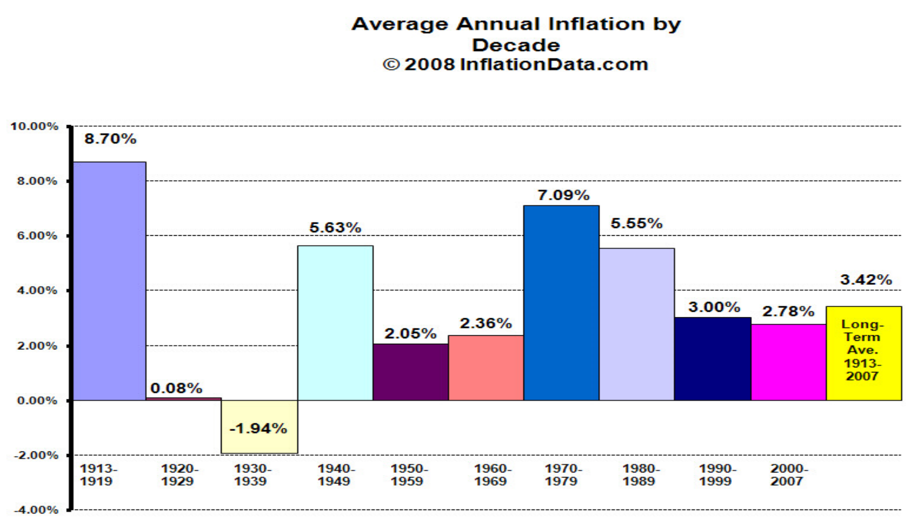

Figure 7. United States Inflation Rates by Decade: 1913-2007. Source: www.InflationData.com.

Inflation variation does not have a large impact on net returns in this analysis, causing declines of $2 to $7 per acre in the advantage of SDI over CP systems from the base scenario (Table 6.).

Table 6. Interest Rate Variation Impact on SDI versus CP Returns

Inflation Rate Scenarios	CP Variable Cost ($ per acre)	SDI Variable Cost ($ per acre)	SDI Less CP Returns ($ per 160 acres)	SDI Less CP Returns ($ per acre)
Base: 0% Inflation	$510.25	$492.20	$1,429	$9
Low: 3% Inflation	$521.30	$503.17	$1,077	$7
High: 9% Inflation	$542.98	$524.70	$385	$2

Broader "Low versus High" Price Cost Scenario Impact

Given the interrelated nature of agricultural and financial markets, it is judicious to examine the impact of broader "low price-low cost" and "high price-high cost" scenarios upon the profitability of SDI versus CP systems. The various inputs into these two scenarios are given in Table 7.

Table 7. "Low" and "High" Price-Cost Scenario Inputs

Key Crop Inputs	"Low" Price-Cost Scenario	"High" Price-Cost Scenario
1. Corn Price, $/ bu.	$1.95	$6.00
2a. Natural Gas $, $/mcf.	$2.00	$12.00
2b. Pumping Cost, $/acre in.	$1.55	$7.78
3. Fertilizer Cost		
NH3 (82-0-0), $/lb. N.	$0.13	$0.37
DAP (18-46-0), $/lb.	$0.11	$0.85
4. Interest Rates	5.0%	20.0%
5. Inflation Rate in Crop Production Costs	3.0%	9.0%

Whether the “low” price – cost or the “high” price – cost regime is in effect has a large impact on the relative returns of an subsurface drip irrigation as opposed to a center pivot sprinkler irrigation system. “Low” prices and costs strongly favor CP systems while “high” price – cost scenarios strongly favor SDI systems (Table 8.).

Table 8. Interest Rate Variation Impact on SDI versus CP Returns

Inflation Rate Scenarios	CP Variable Cost ($ per acre)	SDI Variable Cost ($ per acre)	SDI Less CP Returns ($ per 160 acres)	SDI Less CP Returns ($ per acre)
“Low” Price - Cost Scenario	$434.88	$425.98	**-$9,026**	**-$56**
“High” Price - Cost Scenario	$764.20	$727.09	$3,691	$23

Summary and Conclusions

Variability in United States’ agricultural and financial markets impacts irrigation investment decisions in general, and the decision to purchase a center pivot sprinkler or subsurface drip irrigation system in particular. The levels of economic variability observed in U.S. grain, energy, crop input and financial markets have been particularly heightened in recent years. If the recent past is a reasonable predictor of the future, then volatility in these markets is likely to add risk and uncertainty to irrigation investment decisions for the foreseeable future.

This analysis was based on a decision tool developed by Kansas State University to assist farmers in their irrigation system investment decisions – particularly as they consider whether to invest in center pivot sprinkler or subsurface drip irrigation systems. This analysis focused on the impact of broader economic factors whereas earlier efforts (Lamm, et al, 2009) focused more so on system physical efficiencies, design and life span in determining the most profitable system investment.

These results indicate that economic factors and forces that tend to either increase irrigated crop income or that tend to increase costs equally between the irrigation system alternatives tend to either favor subsurface drip irrigation or are neutral to the investment decision between the two options. Higher corn prices distinctly favor subsurface drip irrigation system returns, while lower corn prices favor center pivot irrigation systems. Changes in fertilizer prices, natural gas prices and associated irrigation pumping costs, and inflation in crop production costs tend to have neutral or small impacts upon the relative returns to each irrigation system.

Because of the higher investment cost required for subsurface drip irrigation systems, increases in interest rates on either borrowed capital or the on the opportunity cost of invested capital in irrigation systems tend to favor investment in center pivot sprinkler irrigation systems with their lower costs of initial investment.

When grouping economic factors into “low price – cost” and “high price – cost” scenarios, it turns out that “low price – cost” scenarios tend to favor center pivot sprinkler irrigation cost investments. Conversely, “high price – cost” scenarios of economic factors favors subsurface drip irrigation investments.

Future analysis should focus on the multi-period impacts of inflation, interest, and variability in product revenues and crop input costs. If farmers believe the hypothesis that higher levels of volatility will continue to exist in agricultural, energy and financial markets in the future, then their irrigation investment decisions will need to be all that much more informed in regards to the physical and economic uncertainties they are dealing with.

This is a contribution of the Kansas State University, Manhattan, Kansas.
Contribution No. 10-113-A from the Kansas Agricultural Experiment Station.

This paper is also part of a year-long SDI technology transfer effort in 2009 involving Kansas State University, Texas A&M University and the USDA-ARS and is funded by the Ogallala Aquifer Project. To follow other activities of this educational effort, point your web browser to http://www.ksre.ksu.edu/sdi/. Watch for this logo.

REFERENCES

Dumler, T. J., D. M. O’Brien, and B. L. S. Olson. 2008. Center-pivot-irrigated corn cost-return budget in Western Kansas. KSU Farm Management Guide, MF-585. Manhattan, Kansas. 4 pp. Also available at http://www.oznet.ksu.edu/library/agec2/MF585.pdf

Dumler, T. J., D. M. O’Brien, and D. H. Rogers. 2007. Irrigation capital requirements and energy costs. KSU Farm Management Guide, MF-836. Manhattan, Kansas. 4 pp. Also available at http://www.oznet.ksu.edu/library/agec2/mf836.pdf

Lamm, F. R. and C. R. Camp. 2007. Subsurface drip irrigation. Chapter 13 in Microirrigation for Crop Production - Design, Operation and Management. F.R. Lamm, J.E. Ayars, and F.S. Nakayama (Eds.), Elsevier Publications. pp. 473-551.

Lamm, F. R., H. L. Manges, L. R. Stone, A. H. Khan, and D. H. Rogers. 1995. Water requirement of subsurface drip-irrigated corn in northwest Kansas. Trans. ASAE, 38(2):441-448. Also available at http://www.oznet.ksu.edu/sdi/Reports/1995/WaterReq.pdf

Lamm, F. R., D. M. O'Brien, D. H. Rogers, and T. J. Dumler. 2009. Using the K-State center pivot sprinkler and SDI economic comparison worksheet. *Proceedings of the Central Plains Irrigation Conference, Colby, Kansas, February 24-25, 2009.* Also available at http://www.ksre.ksu.edu/pr_irrigate/OOW/CPIC09.htm

O'Brien, D. M., D. H. Rogers, F. R. Lamm, and G. A. Clark. 1998. An economic comparison of subsurface drip and center pivot sprinkler irrigation systems. App. Engr. in Agr. 14(4):391-398. Also available at http://www.oznet.ksu.edu/sdi/Reports/1998/EconSDICP.pdf