TECHNICAL NOTE:

ECONOMIC COMPARISON OF SUBSURFACE DRIP AND CENTER PIVOT SPRINKLER IRRIGATION USING SPREADSHEET SOFTWARE

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ABSTRACT. *Static, single-time economic comparisons of subsurface drip irrigation and center pivot sprinkler irrigation systems for corn production are useful but do not accommodate broad changes in economic assumptions. An economic comparison decision tool was formulated in MS-Excel to allow producers and other interested parties to easily perform their own comparisons using their current individual assumptions or the latest suggestions from K-State Research and Extension. Tabular and graphical sensitivity results are provided on key economic factors including field size, SDI system cost and longevity, corn yield and selling price. The economic competitiveness of SDI systems increases with SDI longevity and overall corn yields and selling prices and also for smaller and irregular-shaped fields where center pivot sprinkler costs per unit area greatly increase.*

Keywords. *Corn, Costs, Irrigation economics, Microirrigation, Net returns, Profitability, Software.*

In much of the Great Plains, the rate of new irrigation development (land area) is slow or zero. Although the Kansas irrigated area, as reported by producers through annual irrigation water use reports, has been approximately 1.2 million ha since 1990, there has been a dramatic shift in the methods of irrigation (Rogers and Lamm, 2012). During the period since 1990, the land area irrigated by center pivot irrigation systems (CP) increased from about 50% of the total irrigated area to about 93% of the base area. In 1989, subsurface drip irrigation (SDI) research plots were established at the Kansas State University Northwest Research-Extension Center to investigate SDI as a possible additional irrigation system option (Lamm and Rogers, 2014). Although microirrigation systems, such as SDI, are considered to have some of the greatest application efficiencies of all irrigation systems (Howell, 2002), greater initial expense for SDI systems and concerns about their longevity have slowed their adoption (O'Brien et al., 1998). Nonetheless, industry and producer surveys have indicated a small but steady increase in systems throughout the Great Plains. Although Kansas SDI systems represent less than 1% of the irrigated area, the land area devoted to these systems is growing in Kansas at an estimated pace of 2000 ha/year (Evett et al., 2014). Producer interest remains high because SDI can potentially have greater application efficiency and irrigation uniformity and may better sustain crop yields at a greater level when irrigation is limited by hydrological or institutional constraints (Lamm et al., 2010). The greatest expansion of SDI in the United States is occurring in Texas with large increases since 2000. Much of this increase has been for cotton production using irrigation wells with limited capacity with nearly 3.8% of the irrigated land in Texas using SDI in 2013 (USDA-NASS, 2014). As the farming populace and irrigation systems age, there will likely be a continued momentum for conversion to modern pressurized irrigation systems. Both center pivot sprinkler irrigation (CP) and subsurface drip irrigation (SDI) are options available to the producer for much of the Great Plains landscape (low slope and deep silt loam soils). Pressurized irrigation systems in general are a costly investment and this is particularly the case with SDI. Producers need to carefully determine their best investment options. Economic comparisons of crop production for SDI and sprinkler irrigation have been developed by Bosch et al. (1992) and O'Brien et al. (1998). However, these analyses were static, and there is a need to develop a more robust, updatable, user friendly decision tool. This article will discuss the assumptions within the decision tool and its overall formulation as well as the key factors that most strongly affect the economic comparisons.

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Template Structure and Economic Assumptions

In the spring of 2002 (Lamm et al., 2002), a free Microsoft Excel spreadsheet template was introduced by K-State Research and Extension for making economic comparisons of using CP and SDI for corn production (the major irrigated crop in the region). Since that time, the template has been periodically updated (generally annually) to reflect changes in input data, particularly irrigation system and corn production costs. The template also provides sensitivity analyses for five key factors (field size, SDI system longevity, SDI system cost, crop yield, and crop price). Although the currently available template is constructed using English units which U.S. producers are more accustomed to using, the discussion in this article will be in SI units. The template is not password protected and could be easily modified to handle SI units and/or different crops.

The template has five worksheets (tabs), including the *Main, CF, Field size & SDI life, SDI Cost & Life, Yield & Price* tabs. Most of the calculations and the results are shown on the *Main* tab (fig. 1). There are 18 required input variables required to use the spreadsheet template, but if the user does not know a particular value there are suggested values for each of them. The user is responsible for entering and checking the values in the unprotected input cells. All other cells are protected on the *Main* tab. Some error checking exists on overall field size and some items (e.g., overall results and cost savings) are highlighted differently (i.e., color change) when different results are indicated. Details and rationales behind the input variables are given in the following sections.

Field and Irrigation System Assumptions and Estimates

Many of the early analyses assumed that an existing furrow-irrigated field with a working well and pumping plant was being converted to either CP or SDI, and this still may be the base condition for some producers. However, the template can also be used to consider options for a currently center pivot-irrigated field that needs a replacement irrigation system. The major change in the analysis for the replacement CP is that the cost for the new center pivot probably would not have to include buried underground pipe and electrical service in the initial investment cost. The analysis also assumes the pumping plant is located at the center of one of the field edges and is at a suitable location for the initial SDI distribution point (i.e., upslope of the field to be irrigated). However, if this is not the case, it would be easily handled by increasing the cost of SDI system to accommodate additional costs to move the irrigation distribution point. Any necessary pump modifications (flow and pressure) for the CP or SDI systems are assumed to be of equal cost and thus are not considered in the analysis. However, they can easily be handled as an increased system cost for either or both of the system types.

Land costs are assumed to be equal across systems for the overall field size with no differential values in real estate taxes or in any government farm payments. Thus, these factors "fall out" or do not economically affect the analyses.

An overall field size of 64.8 ha (i.e., typical U.S. square quarter section of 160 acres) was assumed for the base analysis. This overall field size will accommodate either a full size 50.5 ha CP system or a 62.7 ha SDI system. It was

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.

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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 $			$71,815	← $71,815	$202,617	← $202,617
Irrigation system investment cost, $/irrigated acre			$575		$1,307	
Irrigation system life, years			25	← 25	22	← 22
Interest rate for system investment, %	6.5%	← 6.5%				
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)			$649.28	← $649.28	$634.29	← $634.29
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	$4.20	← $4.20				
Net return to cropped dryland area of field ($/acre)	$40.00	← $40.00				
Advantage of Center Pivot Sprinkler over SDI *			$/total field each year			$1,290
*** Advantage in net returns to land and management**			$/acres each year			$8

Figure 1. Physical layout of the template *Main* tab showing the 18 required variables (white input cells). The template as shown here is using traditional English units for U.S. producers, but could be easily modified to use SI units for other clientele.

assumed that there would be 2 ha of non-cropped area consumed by field roads and access areas. The remaining area (approximately 12.1 ha) under the CP system are available for dryland cropping systems.

Currently, irrigation system costs are highly variable due to rapid fluctuations in material and energy costs. Cost estimates for the full-sized 50.5 ha CP system ($71,815) and the 62.7 ha SDI system ($202,617) are provided on the current version of the spreadsheet template based on 2014 discussions with dealers and O'Brien et al. (2011), but since this is the overall basis of the comparison, it is recommended that the user apply their own estimates for their conditions. In the base analysis, the life for the two systems is assumed to be 25 and 22 years for the CP and SDI systems, respectively. No salvage value was assumed for either system. This assumption of no salvage value may be inaccurate, as both systems might have a few components that may be reusable or available for resale at the end of the system life. However, with relatively long depreciation periods of 22 and 25 years and typical financial interest rates, the zero salvage value is a very minor issue in the economic analysis. The system life for the SDI system was based on the longevity of a research SDI system at the KSU Northwest Research-Extension Center that was replaced after 22 years of use. Although the Center has a system currently in use after 26 years without replacement, the authors decided to cap the assumed longevity at 22 years to remain conservative in their assumptions. The center pivot sprinkler life of 25 years is based on anecdotal results from the region. System life is a very important factor in the overall analyses. However, the life of the SDI system is of much greater economic importance in the analysis than a similar life for the CP system because of the much greater initial system costs for SDI. Increasing the system life from 22 to 25 years for SDI would have a much greater economic effect than decreasing the CP life from 25 to 22 years.

When the overall field size decreases, thus decreasing system size, there are large changes in cost per irrigated hectare between systems. SDI costs are nearly proportional to field size, while CP costs are not proportional to field size (O'Brien et al., 1998) because smaller CP systems must still have a pivot point and similar controls to a full-size CP system. Because each added sprinkler span from the pivot point irrigates proportionally more area than the last at the same unit hardware cost, longer center pivot sprinklers are less expensive per irrigated area than shorter ones. Quadratic equations to calculate irrigation system costs when less than full-size 64.8 ha fields were developed from information provided in O'Brien et al. (1998):

$$CP_c = 44.4 + (0.837 \times CP_s) - (0.00282 \times CP_s^2) \quad (1)$$

$$SDI_c = 2.9 + (1.034 \times SDI_s) - (0.0006 \times SDI_s^2) \quad (2)$$

where CP_c and CP_s, and SDI_c and SDI_s are the respective cost and size percentages in relation to the full costs and sizes of irrigation systems fitting within a square 64.8 ha block.

The annual interest rate can be entered as a variable, but the default value was set at 6.5%. The total interest costs over the life of the two systems were converted to an average annual interest cost for this analysis. Annual insurance costs were assumed to be 1.6% of the total system cost for the center pivot sprinkler and 0.6% for the SDI system, but can be changed if better information is available. The smaller value for the SDI was based on the assumption that only about 40% of the system might be insurable. Many of the SDI components are not subject to the climatic conditions that are typically insured hazards for CP systems. However, system failure risk is probably greater with SDI systems which might influence any obtainable insurance rate.

Production Cost Assumptions and Estimates

The economic analysis expresses the results as an advantage of SDI or alternatively CP systems in net returns to land and management. Thus, many fixed costs do not affect the analysis and can be ignored. Additionally, the analysis does not indicate if either system is ultimately profitable for corn production under the assumed current economic conditions.

Production costs were adapted from KSU estimates (Dhuyvetter et al., 2014) with minor adjustments representing costs on a more appropriate land area in some cases. A listing of the current costs is available on the *CF* tab which can be changed by the user to recalculate variable costs that more closely match their conditions. The sum of these costs would become the new suggested Total Variable Costs on the *Main* tab, but the user must manually change the input value on the *Main* tab (white input cell box) for the economic comparison to take effect. The user may find it easier to just change the differential production costs between the systems on the Main tab (i.e., additional SDI variable costs, positive or negative) rather than changing the baseline assumptions on the *CF* tab. This will help maintain integrity of the baseline production cost assumptions. Variable costs in the spring of 2015 were assumed to be $1604/ha and $1567/ha for the CP and SDI systems, respectively. The reduction in variable costs for SDI is attributable to an assumed 25% net water savings that is consistent with research findings by Lamm et al. (1995). This is shown in the *CF* tab as a 432 and 330 mm gross application amount for CP and SDI, respectively. The variable costs for both irrigation systems represent typical practices for western Kansas.

Yield and Revenue Stream Estimates

Corn grain yield was currently estimated at 13.8 Mg/ha in the base analysis with a corn price of $0.165/kg. Net returns for the 12.1 cropped dryland ha for the CP system (corners of field) were assumed to be approximately $100/ha which is essentially the current dryland crop cash rent estimate for western Kansas. Government payments related to irrigated crop production are assumed to be spread across the overall field size, and thus, do not affect the economic comparison of systems.

Governing Economic Equation

The net returns to land and managements for the two systems are calculated and then are compared to see which system has the competitive advantage. The results are expressed as either an annual advantage to center pivot sprinklers or SDI on both a whole-field basis and on an annual per hectare basis.

Sensitivity Analyses

Changes in the economic assumptions can drastically affect which system is most profitable and by how much. The economic comparison spreadsheet also includes three worksheet (tabs) that display tabular and individual graphical sensitivity analyses for field size and SDI system life, SDI system cost, corn yield, and selling price. The graphical and tabular sensitivity analyses that are provided by the template are shown in figures 2 through 4. These sensitivity analysis worksheets will automatically update when different assumptions are made on the *Main* worksheet. Additionally, key individual factors (field size, system costs and longevity, variable production costs, corn yields, and irrigation costs were each varied from ±10% from the baseline cost to show the sensitivity of the system economic ranking for the purposes of this article's discussion.

Results and Discussion

Using the current 2015 baseline assumptions, corn production under center pivot sprinklers would have a slight annual economic advantage ($3190/field or $20/ha) over SDI systems. However, that should not be the focus of the discussion since the economics have varied greatly in the interim since the earlier analysis (O'Brien et al., 1998) and are anticipated to continue to do so. In fact, the original purpose of the template was to allow for quick updates to the earlier analysis and to accommodate producer desires for either less or more optimistic cost and revenue

This tab determines the CP and SDI economic sensitivity to field size, shape, and SDI system life.

The elements in the table (blue) represent the CP advantage in net returns per acre.

Field size	160	127	95	64	32	**80**
CP Size	125	100	75	50	25	**64** ← Wiper 1/2 circle
CP Cost	$574.52	$670.12	$808.81	$1,053.78	$1,723.90	**$1,122.11**
CP Dry	30	24	18	12	6	**14**
SDI Size	155	124	93	62	31	78
SDI Cost	$1,307.21	$1,336.29	$1,367.77	$1,415.05	$1,525.51	$1,387.51
SDI life years		**Note: This sensitivity valid only if full-sized CP (125 acres) and SDI (155 acres) costs exist on Main worksheet (tab) !!!!!!!!**				
5	**$203.77**	**$205.49**	**$203.69**	**$195.55**	**$174.74**	**$187.51**
10	**$77.14**	**$75.01**	**$69.79**	**$58.47**	**$26.96**	**$52.23**
15	**$34.92**	**$31.52**	**$25.16**	**$12.77**	**-$22.30**	**$7.14**
20	**$13.82**	**$9.78**	**$2.84**	**-$10.07**	**-$46.93**	**-$15.41**
25	**$1.15**	**-$3.27**	**-$10.55**	**-$23.78**	**-$61.71**	**-$28.94**

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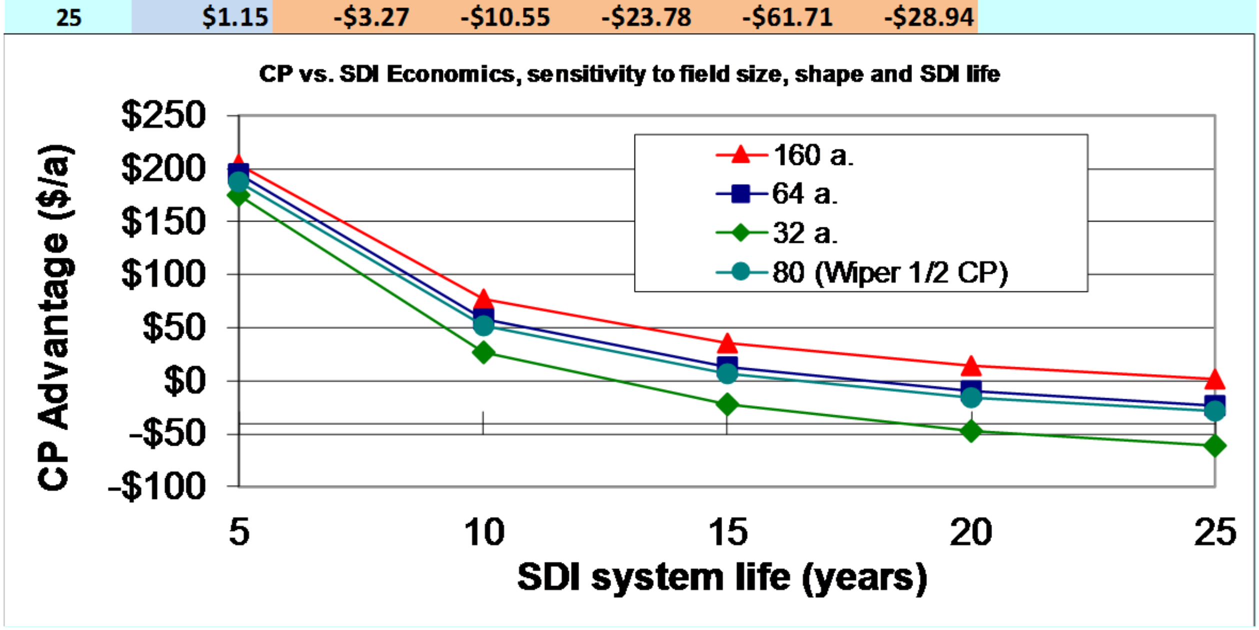

Figure 2. Sensitivity tab from the Template which illustrates the center pivot sprinkler (CP) advantage over SDI as affected by overall field size and SDI system life. The tab as shown here is using traditional English units for U.S. producers, but could be easily modified to use SI units for other clientele.

This tab determines the CP and SDI economic sensitivity to SDI system life and SDI system cost.

The elements in the table (blue) represent the CP advantage in net returns per acre.

SDI Cost	SDI system life, years					
$/acre	5	10	15	20	25	30
1000	$132.79	$35.92	$3.63	-$12.52	-$22.21	-$28.67
1100	$155.90	$49.33	$13.81	-$3.95	-$14.60	-$21.71
1200	$179.00	$62.75	$24.00	$4.63	-$7.00	-$14.75
1300	$202.11	$76.17	$34.19	$13.20	$0.61	-$7.79
1400	$225.21	$89.59	$44.38	$21.77	$8.21	-$0.83
1500	$248.32	$103.00	$54.57	$30.35	$15.82	$6.13
1600	$271.42	$116.42	$64.75	$38.92	$23.42	$13.09

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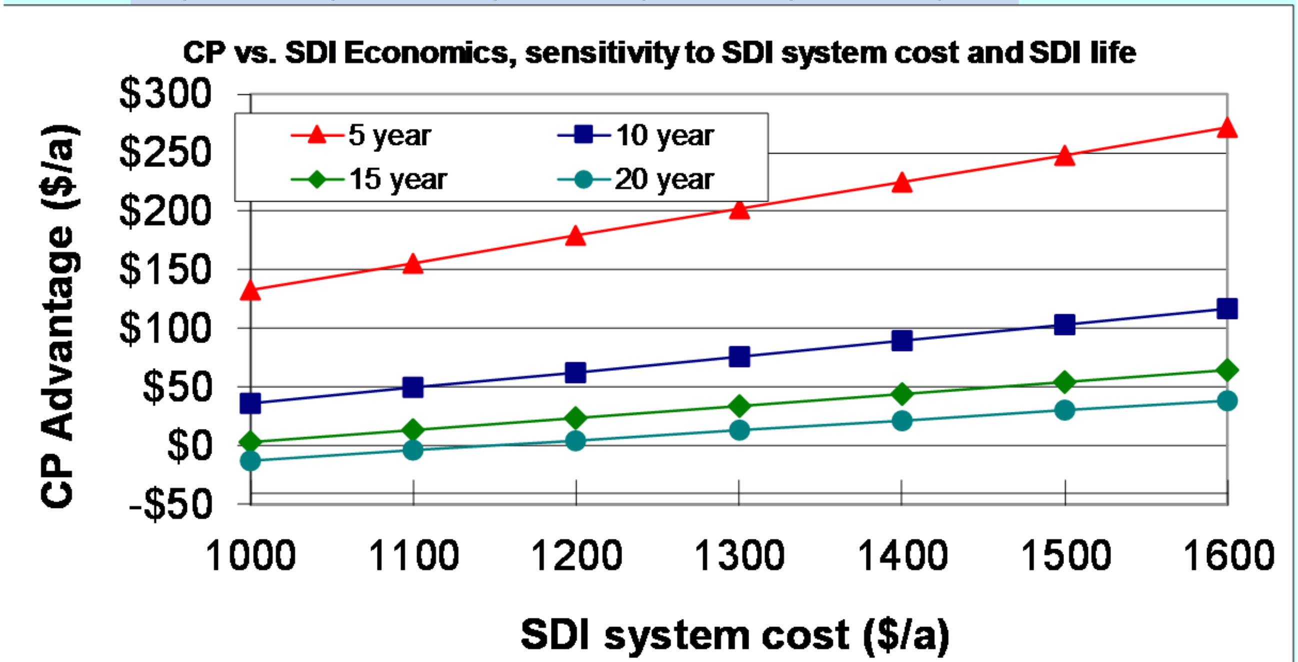

Figure 3. Sensitivity tab from the Template which illustrates the center pivot sprinkler (CP) advantage over SDI as affected by SDI system life and SDI system cost. The tab as shown here is using traditional English units for U.S. producers, but could be easily modified to use SI units for other clientele.

assumptions. Therefore, the focus of this section of the article will be on what the sensitivity analyses are indicating.

The earlier sensitivity analysis (O'Brien et al., 1998) and the subsequent analyses conducted by the authors over the years since the development of the template have shown that the system comparisons are very sensitive to assumptions about size of CP irrigation system, shape of field (i.e., whether full vs. partial circle CP system), life of SDI system and SDI system cost with advantages favoring larger CP systems and cheaper, longer life SDI systems (table 1). It should be reiterated that CP system costs per unit area increase more curvilinearly than SDI (eqs. 1 and 2), so the 20% change in field size in table 1 does not fully capture the overall response to more drastic field size changes (i.e., the CP cost per unit area is relatively stable around the 64.7 ha field size). Smaller CP systems and systems which only complete part of the circle are less competitive with SDI than full size 50.5 ha CP systems. It should also be pointed out that part of the economic competitiveness of the more expensive SDI system with a less expensive CP system occurs simply because less land area of the field is in dryland crop production. These results are presented in both tabular and graphical format in the *Field size & SDI life* and *SDI cost & life* tabs of the template (figs. 2 and 3).

The results (table 1) are also very sensitive to any changes in variable costs for SDI or CP production. However, changes in irrigation costs had no effect in the irrigation system rankings because the 25% water savings attributable to SDI were matched by the approximately 25% increase in irrigated land area with SDI. Although table 1 indicates that changes in SDI or CP variable costs can have a great effect, many of the components of the variable costs do not change appreciably between systems (e.g., seed, fertilizer, herbicides, tillage, etc.). Greater overall corn yields and greater corn prices can improve SDI economic competitiveness which can be seen on the *Yield*

This tab determines the CP and SDI economic sensitivity to corn yield and corn price assuming that corn yields are equal for both irrigation systems.

The elements in the table (blue) represent the CP advantage in net returns per acre.

	Corn cash price, $/bu						
Corn Yield	$3.00	$3.40	$3.80	$4.20	$4.60	$5.00	$5.40
160	$91.31	$79.31	$67.31	$55.31	$43.31	$31.31	$19.31
170	$85.69	$72.94	$60.19	$47.44	$34.69	$21.94	$9.19
180	$80.06	$66.56	$53.06	$39.56	$26.06	$12.56	-$0.94
190	$74.44	$60.19	$45.94	$31.69	$17.44	$3.19	-$11.06
200	$68.81	$53.81	$38.81	$23.81	$8.81	-$6.19	-$21.19
210	$63.19	$47.44	$31.69	$15.94	$0.19	-$15.56	-$31.31
220	$57.56	$41.06	$24.56	$8.06	-$8.44	-$24.94	-$41.44
230	$51.94	$34.69	$17.44	$0.19	-$17.06	-$34.31	-$51.56
240	$46.31	$28.31	$10.31	-$7.69	-$25.69	-$43.69	-$61.69
250	$40.69	$21.94	$3.19	-$15.56	-$34.31	-$53.06	-$71.81
260	$35.06	$15.56	-$3.94	-$23.44	-$42.94	-$62.44	-$81.94
270	$29.44	$9.19	-$11.06	-$31.31	-$51.56	-$71.81	-$92.06

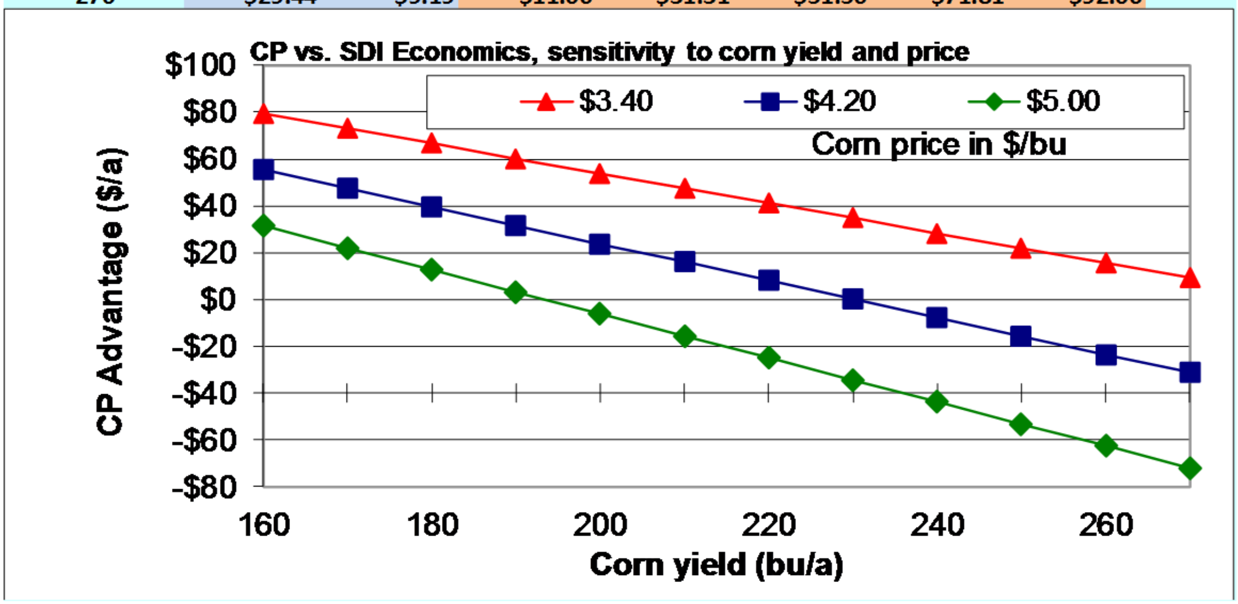

Figure 4. Sensitivity tab from the Template which illustrates the center pivot sprinkler (CP) advantage over SDI as affected by corn yield and selling price. The tab as shown here is using traditional English units for U.S. producers, but could be easily modified to use SI units for other clientele.

& Price sensitivity tab of the template (fig. 4). This result occurs because of the increased irrigated area for SDI in the given field. The importance of yield and price can be illustrated by taking one step further in the economic analysis, that being the case where there is a yield difference between irrigation systems. Combining a greater overall corn yield potential with an additional small yield advantage for SDI can allow SDI to be very competitive with CP systems.

Increased longevity for SDI systems is one of the most important factor for SDI to gain economic competitiveness with CP systems. There are a few SDI systems in the United States that have been operated for over 25 years without replacement (Lamm and Camp, 2007). However, a short SDI system life that might be caused by early failure due to clogging, indicates a huge economic disadvantage that would preclude nearly all adoption of SDI systems for lower value commodity crops such as corn. Although SDI cost is an important factor, long SDI system life can help reduce the overall negative economic effect. The CP advantage over SDI for system life between 15 and 20 years is greatly diminished as compared to the difference between a 10 and 15 year SDI system life. The sensitivity of CP system life and cost is much less because of the much smaller initial CP cost and the much longer assumed life. Changing the CP system life from 25 to 20 years will not have a major effect on the economic comparison. However, in areas where CP life might be much less than 25 years due to corrosive waters, a sensitivity analysis with shorter CP life is warranted.

The present baseline analysis already assumes a 25% water savings with SDI. There are potentially some other production cost savings for SDI such as fertilizer and herbicides that have been reported for some crops and some

Table 1. Sensitivity of SDI and center pivot sprinkler irrigation system economics to selected economic factors using values from the current 2015 template.

Economic Factor	Baseline Value	Percent Change in the CP/SDI Advantage as Affected by Changes in the Baseline Value	
		Baseline Value Minus 10%	Baseline Value Plus 10%
Overall field size	64.7 ha (160 acres)	3	12
CP costs	$1420/ha ($575/acre)	49	-49
SDI costs	$3230/ha ($1307/acre)	-68	132
CP longevity	25 years	-25	20
SDI Longevity	22 years	79	-65
Interest rate	6.5%	-33	33
CP variable costs	$1605/ha ($649/acre)	629	-629
SDI variable costs	$1567/ha ($634/acre)	-762	762
Overall corn yield	13.8 Mg/ha (220 bu/acre)	215	-215
CP corn yield	13.8 Mg/ha (220 bu/acre)	-895	895
SDI corn yield	13.8 Mg/ha (220 bu/acre)	1110	-1110
Corn selling price	$0.165/kg ($4.20/bu)	215	-215
Irrigation costs	$0.0353/kL ($3.03/acre-in.)	0	0

locales. For example, there have been reports from other regions of less broadleaf and grassy weed pressure in SDI where the soil surface remains drier and less conducive to germination of weed seeds (Lamm and Camp, 2007). Small changes in these assumptions can make a sizable difference in the economic analysis because there is more irrigated area under the SDI system. Users are encouraged to "experiment" with the input values on the *Main* worksheet (tab) to observe how small changes in economic assumptions can vary the bottom-line economic comparison of the two irrigation systems.

SUMMARY AND CONCLUSIONS

A free and easy-to-use template in MS-Excel was developed to allow economic comparison of SDI and center pivot sprinkler irrigation for corn production. Usage of the template requires input of 18 factors related to field size, estimated irrigated system investment costs, estimated irrigation system longevity, interest and insurance costs, corn production costs, corn yields and selling price, and dryland cash rent value. Current suggestions of these factors are provided as an aide to new users of the template. Users are encouraged to evaluate the economic sensitivity of the two irrigation systems by using their own estimates of key inputs to the template. Previous and current analyses with the template have consistently shown that the most important factors to increasing SDI system competitiveness with center pivot sprinkler irrigation are SDI system longevity, field size and shape, and overall corn yield levels and price. The system's economic ranking is also affected by changes in variable crop production costs between the systems, but fewer of these component costs change appreciably between systems. The template is typically updated at least once a year with new yield and cost estimates.

The most current version of the template can be accessed at http://www.ksre.ksu.edu/sdi/Software/SDISoftware.html.

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