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Can Subsurface Drip Irrigation (SDI) be a Competitive Irrigation System in the Great Plains Region for Commodity Crops?

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Abstract. *Subsurface drip irrigation (SDI) as with all microirrigation systems is typically only used on crops with greater value. In the US Great Plains region, the typical irrigated crops are the cereal and oil seed crops and cotton. These crops have less economic revenue than typical microirrigated crops. This paper will present a case for how SDI can be economically competitive for the lesser value crops of the Great Plains. The case will have 5 sections: 1) How do Great Plains crops respond to SDI? 2) Are there special uses for SDI in the Great Plains? 3) How can SDI system costs be minimized without causing operational and maintenance problems? 4) Can SDI systems have a long life? 5) How does SDI compare economically to alternative irrigation systems?*

Keywords. Microirrigation, subsurface drip irrigation, irrigation design, irrigation management.

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Introduction

Subsurface drip irrigation has been part of modern agriculture since the early 1960s with some of the earliest research in this era beginning in 1959 with comparisons of SDI and surface drip irrigation (DI) for production of citrus crops and potatoes (Davis, 1974; Hall, 1985). Early efforts with SDI were often hampered by emitter clogging and poor distribution uniformity. However, at the 4th Decennial National Irrigation Symposium, Camp et al. (2000) indicated there had been a resurgence of both research and commercial activities beginning in about the 1980s because of improvements in plastic materials, manufacturing processes, and emitter designs that reduced some of the earlier problems. Analysis of data from the latest USDA Farm and Ranch Irrigation Survey (USDA-NASS, 2009) indicates that nationally, SDI comprises only about 27% of the land area devoted to SDI and DI. However, in the Great Plains region where typically lower value cereal and oil seed crops and cotton dominate the irrigated landscape, SDI is used on between 80 and 90% of the microirrigated area. When growing the lesser-value commodity crops with microirrigation, a deeper, multiple-year SDI system that can be amortized over many years is often the only economical option for a producer. Currently, microirrigation represents only about 1.5% of the total pressurized irrigation systems in the Great Plains with center pivot sprinkler systems being predominant. The microirrigated areas in Texas and New Mexico, where the saturated thickness of the Ogallala is generally small are 4 and 6% of the total pressurized irrigation system area, respectively (USDA-NASS, 2009). In Texas alone, the estimated SDI land area increased from 8800 ha in 2000 to over 100,000 ha by 2004 primarily for cotton production (Bordovsky and Porter, 2008; Colaizzi et al., 2009).

This paper will present a case for how SDI can be economically competitive for the lesser value crops of the Great Plains. The case will have 5 sections: 1) How do Great Plains crops respond to SDI? 2) Are there special uses for SDI in the Great Plains? 3) How can SDI system costs be minimized without causing operational and maintenance problems? 4) Can SDI systems have a long life? and 5) How does SDI compare economically to alternative irrigation systems? The paper will present a positive, but realistic case for use of SDI in the Great Plains. This is not to say there are not significant challenges to adoption of SDI. For discussions of some of the SDI challenges and disadvantages, readers are referred to Lamm and Camp (2007), Lamm, (2009), and Lamm et al., (2010).

How do Great Plains crops respond to SDI?

Although multiple crops are grown with SDI in the Great Plains, this discussion will be limited to the irrigated cereal, oil, forage, and fiber crops which are predominantly corn, grain sorghum, soybean, sunflower, alfalfa, and cotton. The largest SDI area in the Great Plains region is devoted to cotton.

Cotton

Cotton production has been compared under three types of sprinkler irrigation (MESA, mid elevation spray application, LESA, low elevation spray application, LEPA, low energy precision application) and SDI in three studies from Texas (Bordovsky and Lyle, 1998; Bordovsky and Porter, 2003, Colaizzi et al., 2010). SDI provided consistently greater cotton lint yields than mechanical move sprinkler irrigation and in most cases it was a statistically significant increase (Table 1). Water productivity (yield per unit of water use) was also generally greater for SDI than with sprinkler irrigation methods in these studies (data not shown), but was not significantly different in the study by Bordovsky and Porter, 2003. Seasonal water use of the cotton was not appreciably different in the two studies where data were reported (Bordovsky and Lyle, 1998;

Colaizzi et al, 2010). These overall results might be partially attributed greater to partitioning of total water use to transpiration with SDI and less evaporative losses (possibly both soil water evaporative losses and sprinkler application losses). However, there is growing evidence (Colaizzi et al., 2010) that SDI, by not wetting up the soil surface, is providing a more favorable thermal environment (warmer) for irrigated cotton which is important, particularly as cotton production moves further northward in the Texas Panhandle, Oklahoma and southern Kansas.

Table 1. Cotton lint yield as affected by irrigation method in three research studies in Texas.

Irrigation Method	Location and Data Source		
	Halfway, Texas, 1995-1997 Data from Bordovsky and Lyle, 1998	Halfway, Texas 1999-2001 Data from Bordovsky and Porter, 2003	Bushland, Texas 2003, 2004, 2006 & 2007 Data from Colaizzi et al., 2005 and Colaizzi et al., 2010
	Lint yield, Mg/ha		
MESA (Sprinkler)			0.67 b
LESA (Sprinkler)		0.89 c	0.67 b
LEPA (Sprinkler)	1.21 b	1.00 b	0.79 a
SDI	1.36 a	1.16 a	0.88 a
Average SDI increase over all sprinkler, %	12.4%	22.8%	24.2%

Cotton lint yield means within the same column followed by the same letter are not statistically different at the 0.05 probability level.

Corn

Field corn (maize) has been compared under SDI and simulated LEPA sprinkler irrigation for twelve years in northwest Kansas. An earlier study conducted by Lamm (2004) for 7 years indicated differential corn yield response between irrigation systems depending on the prevailing weather conditions (Figure 1). Analysis of the yield components in this earlier study has indicated that in normal to wetter years, SDI and LEPA have nearly similar numbers of kernels/ear for comparable irrigation levels, but SDI has greater kernel mass at harvest (data not shown) resulting in a corn grain yield increase for SDI averaging 0.9 Mg/ha. In extreme drought years, LEPA had greater numbers of kernels/ear and although SDI still had greater kernel mass at harvest, LEPA corn grain yields averaged 0.9 Mg/ha greater than SDI. A follow-up study that is currently underway is attempting to determine the reason for these differences by planting the corn later in the growing season in hopes of eliciting a more consistent change in the kernel numbers and by applying both SDI and DI with different frequencies. Weather conditions during these subsequent years have not been conducive to providing new insights but have extended the data set for comparison of SDI and LEPA sprinkler irrigation (Table 2). Corn grain yields for the greatest irrigation capacity (25 mm/4 days for LEPA or 6.4 mm daily for SDI) were greater for SDI in eight of twelve years and for the smaller irrigation capacity (25 mm/8days for LEPA or 3.3 mm/d with SDI) each system type had six years with greater corn yields. Within a given year, yield differences were sometimes quite large, but there were no appreciable differences when averaged over the entire period. Further effort is justified to determine the rationale for why these yield differences are occurring.

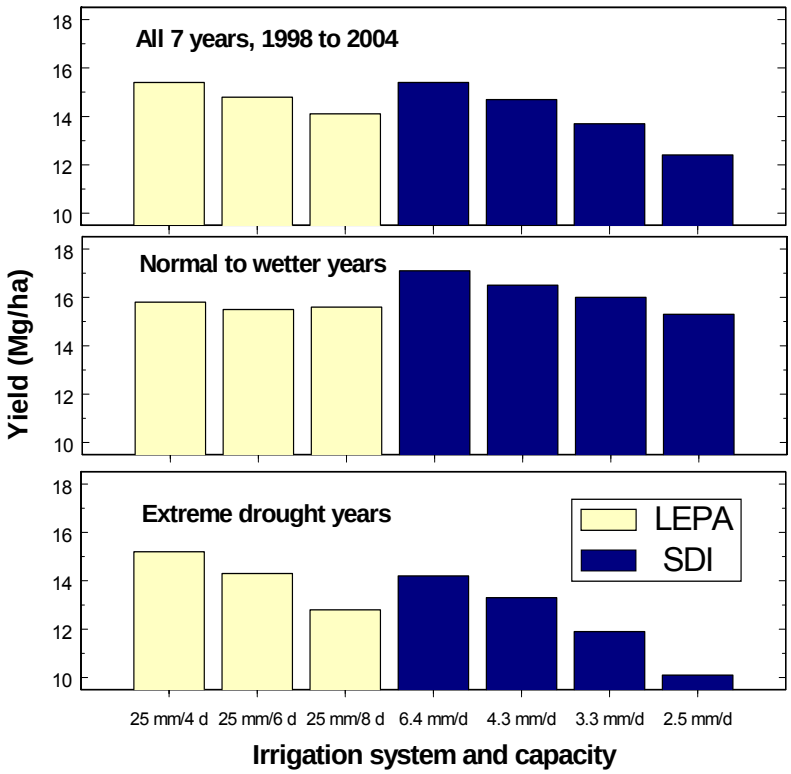

Figure 1. Variation in corn yields across years and weather conditions as affected by irrigation system type and capacity, KSU Northwest Research-Extension Center, Colby, Kansas.

Table 2. Corn grain yields (Mg/ha) as affected by irrigation system type at Colby, Kansas. Data from Lamm (2004) for 1998 through 2004 and from unpublished data (F. R. Lamm) from a study currently underway for 2005 through 2009.

Year	LEPA 25 mm/4 d	LEPA 25 mm/6 d	LEPA 25 mm/8 d	SDI 6.4 mm/d	SDI 4.2 mm/d	SDI 3.2 mm/d	SDI 2.5 mm/d
1998	15.5	15.7	15.8	17.5	16.4	16.8	17.0
1999	16.3	15.8	15.9	16.5	16.5	16.1	14.5
2000	15.0	14.4	13.0	15.2	13.8	12.9	11.5
2001	17.3	15.6	14.8	15.6	14.7	13.0	11.9
2002	14.7	13.7	12.2	13.9	12.4	11.0	8.8
2003	13.8	13.5	11.4	12.3	12.2	10.8	8.3
2004	15.4	15.0	15.2	17.2	16.6	15.0	14.4
2005	13.7	14.1	-	14.2	13.0	-	-
2006	16.4	16.0	-	15.8	16.2	-	-
2007	15.9	16.4	-	17.1	14.9	-	-
2008	15.7	14.6	-	16.6	17.3	-	-
2009	16.0	14.6	-	16.2	15.3	-	-
Average	15.5	15.0	14.0	15.7	14.9	13.7	12.3

Soybean

Soybean production has been compared under different irrigation system types and irrigation levels in two studies conducted in 2005, one in Texas (Colaizzi et al., 2010) and one in Kansas (F. R. Lamm, unpublished data). In Texas, soybean yields were numerically greater for all irrigation levels for SDI except for the full irrigation level and were significantly greater at the 25 and 50% irrigation levels (Figure 2). In Kansas, soybean had greater yields with SDI only at the 60% irrigation level but yields were similar at the 80 and 100% irrigation levels. Additional years of data are needed, but it appears that under deficit irrigation, soybean production may benefit from SDI.

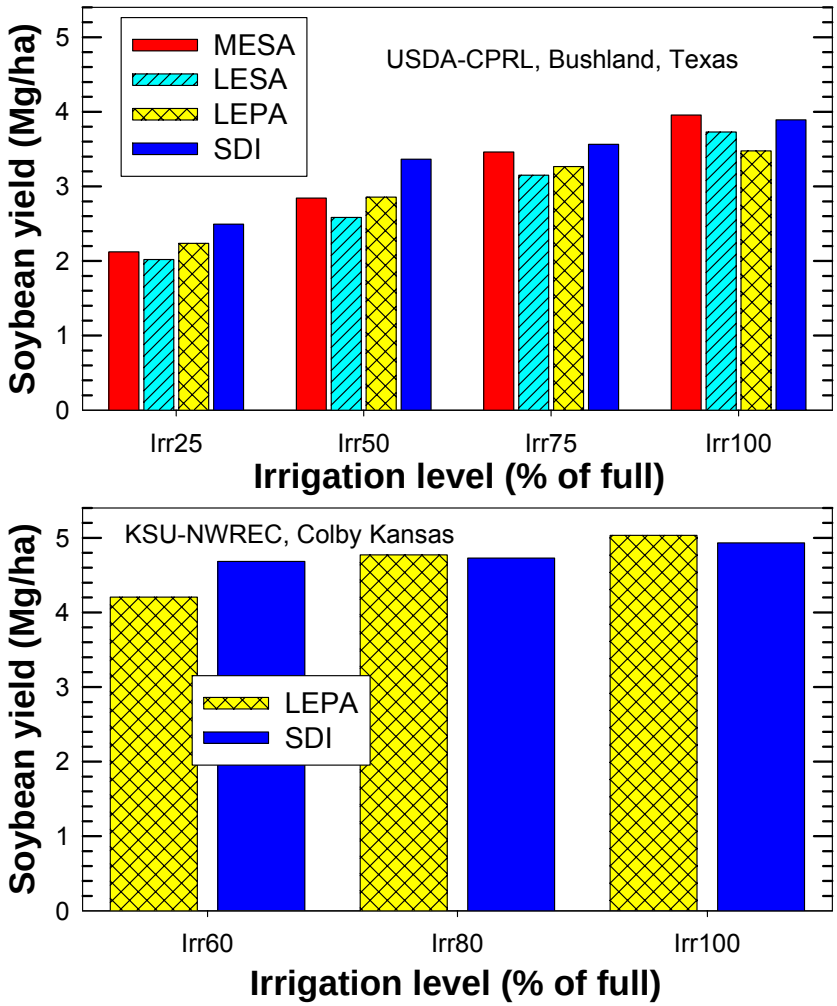

Figure 2. Soybean production as affected by irrigation system and irrigation level at the USDA-CPRL, Bushland Texas and at the KSU-NWREC, Colby Kansas in 2005.

Grain Sorghum

Grain sorghum production has been studied at both Bushland, Texas (2000 through 2002) and Colby Kansas (2006 and 2008) under different irrigation system types and irrigation levels (Colaizzi et al., 2004, F. R, Lamm, unpublished data). Grain sorghum yields were greater with

SDI than with sprinkler irrigation at the 25 and 50% irrigation levels in Texas but not for the 75% and 100% or any irrigation levels (60, 80 or 100%) in Kansas (Figure 3). The reason for the reduced grain sorghum yields for SDI at the greater irrigation levels is not know but Colaizzi et al., (2004) hypothesize it may be related to poor soil aeration and nutrient leaching. Grain sorghum is much less responsive to irrigation than corn and perhaps its root system is less tolerant of excess water.

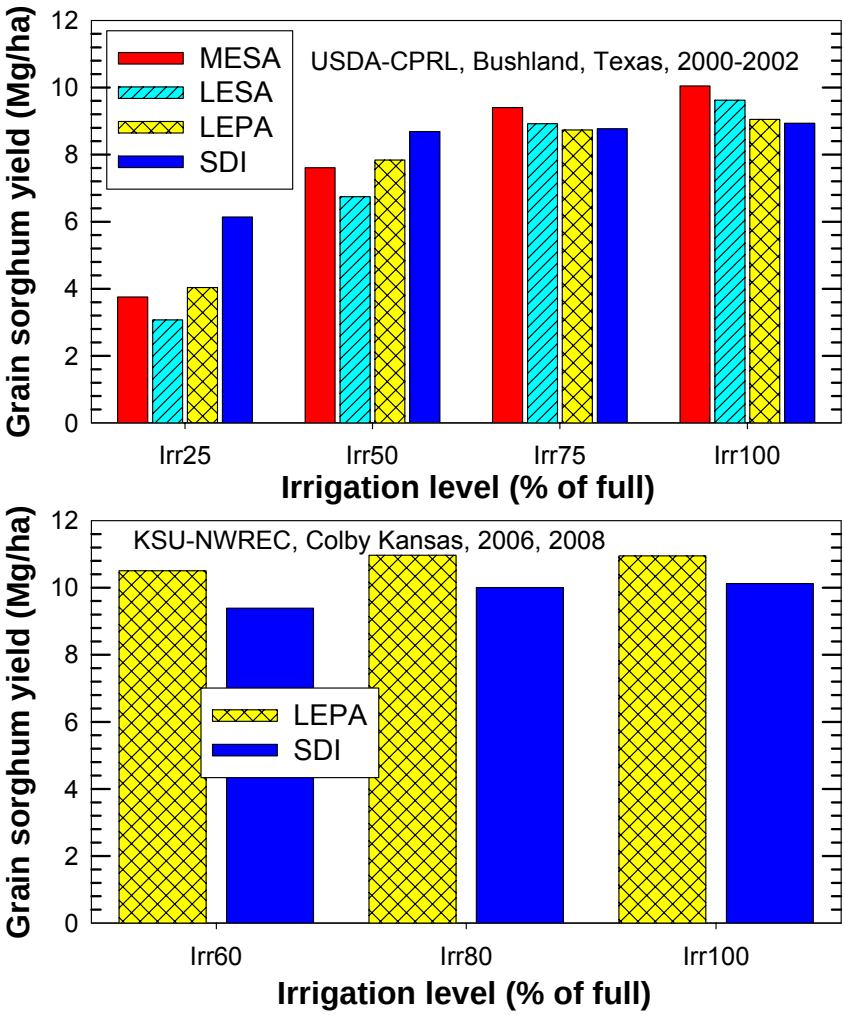

Figure 3. Grain sorghum production as affected by irrigation system and irrigation level at the USDA-CPRL, Bushland Texas and at the KSU-NWREC, Colby Kansas.

Sunflower

Sunflower was grown at the KSU-NWREC at Colby, Kansas in 2004 and 2007 under simulated LEPA sprinkler and SDI at irrigation levels of 60, 80 and 100% of full irrigation (F. R. Lamm, unpublished data). Sunflower yields were greater with SDI than with LEPA sprinkler at the 60 and 80% irrigation levels but not at the 100% irrigation level (Figure 4). It can be further noted that SDI yields at the 60 and 80% irrigation levels were greater than that obtained at the 100% irrigation level. Further analysis of the sunflower study results is warranted, particularly the soil water data throughout the season.

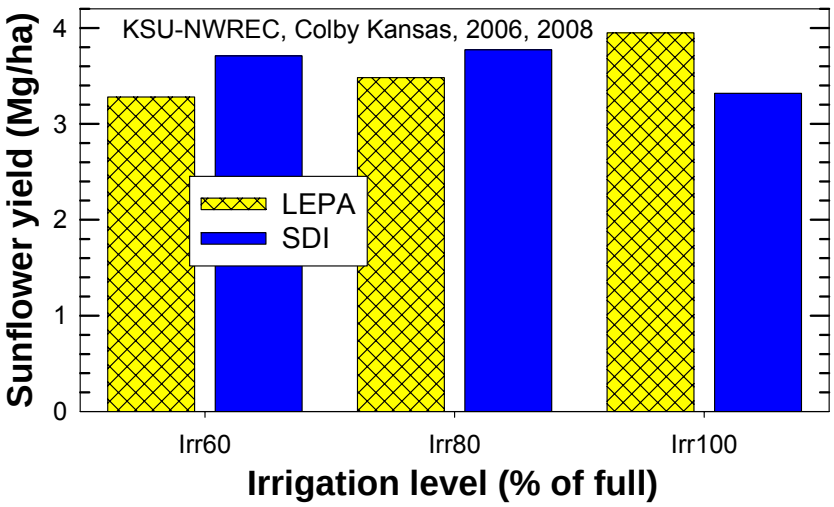

Figure 4. Sunflower as affected by irrigation system and irrigation level at the KSU-NWREC, Colby Kansas.

Alfalfa

Studies comparing SDI with other irrigation system types have not been conducted in the Great Plains, but unpublished studies of alfalfa production under SDI have been conducted at the KSU-NWREC since 2004. Alfalfa, a forage crop, has high crop water needs and thus can benefit from highly efficient irrigation systems such as SDI. In some regions, the water allocation is limited by physical or institutional constraints, so SDI can effectively increase alfalfa production by increasing the crop transpiration while reducing or eliminating soil evaporation. Since alfalfa is such a high-water user and has a very long growing season, irrigation labor requirements with SDI can be reduced relative to less efficient alternative irrigation systems that would require more irrigation events (Henggeler, 1995). A major advantage of SDI for alfalfa is the ability to continue irrigating immediately prior, during, and immediately after the multiple seasonal harvests. Continuation of irrigation reduces the amount of water stress on the alfalfa and thus can increase forage production which is generally linearly related to transpiration.

In the study at Colby, alfalfa production and quality were evaluated with respect to three irrigation levels (treatments designed to replace 70, 85 and 100% of ETc) and at three perpendicular horizontal distances from the dripline (0, 0.38, and 0.76 m). There were not large differences in annual yield between irrigation levels but over the course of each season there would tend to be a slight reduction in alfalfa yield with increasing distance from the dripline. This reduction was greater for the 70% ETc treatment and resulted in reduced overall annual yields (Figure 5). The annual yields also compared well with the maximum yields from several western U.S. states summarized by Grismer (2001) which ranged from approximately 17 to 22 Mg/ha. However, crude protein (a measure of alfalfa quality) and digestibility were greater at the greater distances and reduced ETc. This economically would help compensate for the yield reduction.

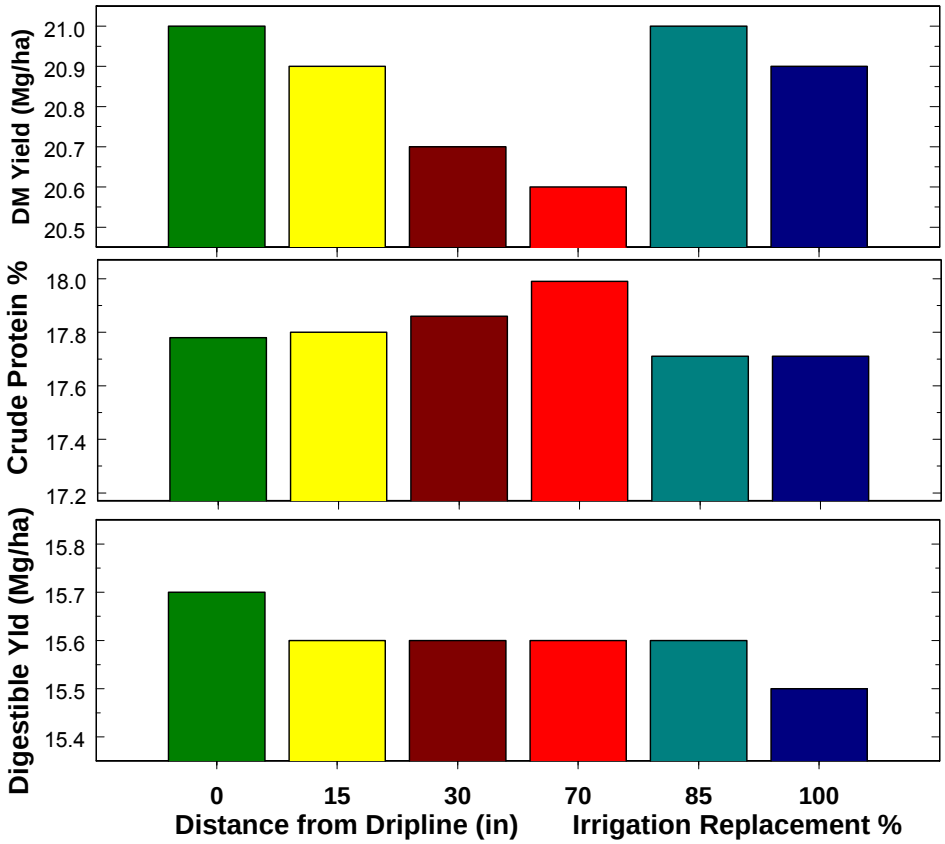

Figure 5. Alfalfa dry matter yield, crude protein and digestible yield in an SDI study at Colby, Kansas, 2005-2007.

Summary of Crop Response to SDI

SDI generally outperformed sprinkler irrigation methods under most deficit irrigation conditions for all field crops except grain sorghum at Colby Kansas. This is important because, with declines continuing to occur in the Ogallala aquifer, there will an increasing number of producers considering deficit irrigation for either hydrological (e.g., pumping rate) or institutional constraints (governmental limitations). Alfalfa is a very profitable irrigated crop in the region and an important crop for the growing number of dairies in the Great Plains region. It is highly productive under SDI, and relatively high annual yields were obtained even with deficit irrigation in a three-year study at Colby, Kansas.

Are there special uses for SDI in the Great Plains?

The Great Plains has a large portion of the concentrated animal feeding operations (CAFO) in the United States, and these large operations generate biological effluents that are typically applied with center pivot sprinkler irrigation to cropped land. However, research conducted in Kansas has indicated it is feasible from both engineering (Trooien et al., 2000, Lamm et al., 2002b) and agronomic (Lamm et al., 2007) standpoints to apply these CAFO effluents with SDI. Primary advantages of applying the effluent with SDI are reduction of human exposure, reduction of odors from the application system, and elimination of runoff of irrigation water/effluent that contains nutrients and other constituents. Additional advantages are listed by Trooien and Hills, (2007). In the agronomic study (Lamm et al., 2007), corn yields were greater with SDI than with simulated sprinkler irrigation and were greater with application of swine biological effluent as compared to commercial nitrogen fertilizer application of 225 kg/ha (Figure

6). Water productivity was significantly greater with SDI when averaged over the two years of the study (2000 and 2001), and SDI produced approximately 3 kg more grain for each mm of water use. This is probably a combination of better nutrient retention in the root zone and the resultant nutrient utilization and less crop water stress for SDI. This special use of SDI is likely to grow in the Great Plains and elsewhere as freshwater sources for irrigation become increasingly stretched.

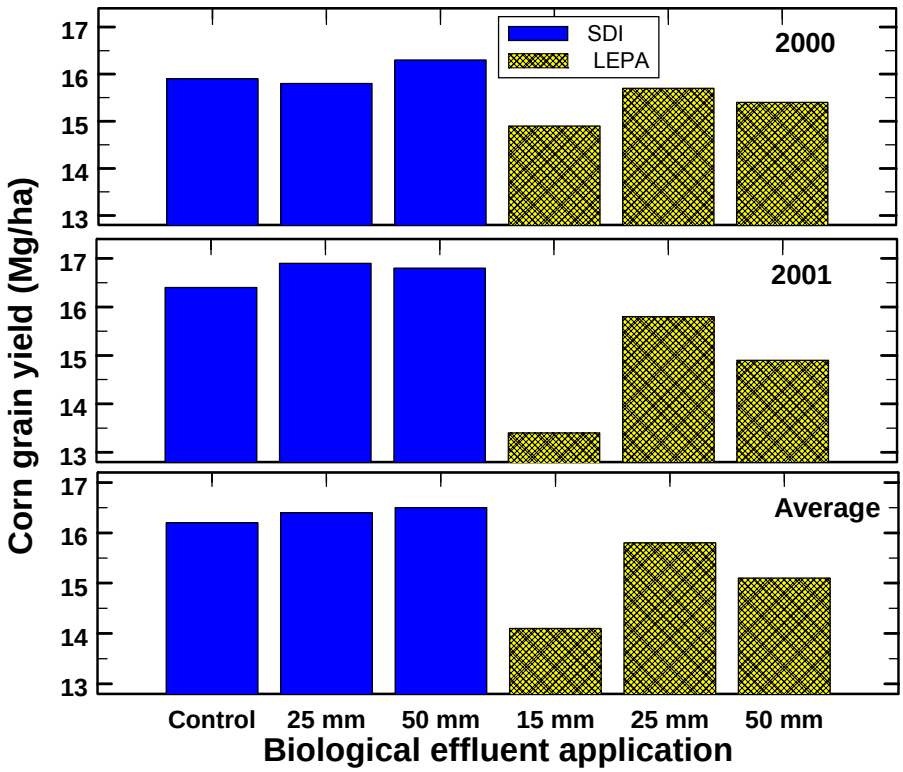

Figure 6. Corn grain yield as affected by SDI and LEPA sprinkler irrigation and swine effluent application at the KSU-NWREC, Colby Kansas. Control treatment is 255 kg/ha of commercial nitrogen fertilizer.

How can SDI system costs be minimized without causing operational and maintenance problems?

It is common for crop production fields in the U.S. Great Plains to be square with a size of approximately 65 ha and a field slope of less than 1%. When the SDI system flowrate is sufficient, these factors allow for longer dripline lengths and larger zone sizes. This helps reduce initial system and installation costs, as well as reducing the number of control components that must be operated and maintained. To sustain high distribution uniformity with longer driplines and larger SDI zones, manufacturers have provided driplines with larger diameters (as great as 35 mm ID) with relatively small emitter discharge (≈ 0.5 L/h) for use on larger SDI systems.

Flushlines are subsurface manifold pipelines installed at the distal end of SDI zones that allow for convenient and economical flushing of a group of driplines. Hydraulically, it would be more effective to flush a single dripline, but to reduce costs, flushlines are recommended for the systems growing commodity crops on the U.S. Great Plains (Lamm and Camp, 2007).

Although it is often assumed that short intervals between SDI events are necessary and a desirable practice, a literature review (Camp, 1998) indicated that SDI frequency is often only critical for shallow-rooted crops on shallow or sandy soils. In many areas of the Great Plains, relatively deep silt loam and clay loam soils with relatively good water holding capacity are the predominant soil type. Studies with field corn production in the Great Plains indicate SDI application intervals of one to seven days have very little effect on corn grain yields, provided soil water is managed within acceptable stress ranges (Caldwell et al., 1994; Howell et al., 1997; Lamm and Aiken, 2005). Similarly, frequency of SDI under deficit irrigation was not an important factor in cotton production on a silty clay loam in Texas (Enciso-Medina et al., 2003). There were no differences in cotton yield, quality, or gross returns related to SDI frequency. The implications of these research studies is that longer periods between SDI events can allow irrigators to use less-expensive, manually operated SDI systems.

Cotton production was examined under SDI systems of varying uniformity (system flowrate variation, ≈ 5%, 15%, or 27%) for both moderate and near full irrigation levels for five years (2001-2006) at Halfway, Texas (Bordovsky and Porter, 2008). Yield variations along the driplines did not always correspond to the anticipated emitter discharge reductions due to changes in uniformity. Although cotton lint yield varied within the field, the total cotton lint yield within a zone was not affected by the range of system uniformities. Economic analysis of the results of this study was provided by Wilde et al. (2009). They reported that when irrigation is limited, it may be economically advantageous to accept a less costly and less uniform SDI design. However, at the full irrigation level, sometimes it is more profitable to install a more uniform SDI distribution system. The fact that greater SDI system uniformity does not always lead to greater profitability is important and needs to be considered carefully when designing and planning economical systems for commodity crop production in the Great Plains. A discussion of the minimum components for SDI systems is provided by Rogers and Lamm (2009).

Summary of techniques often used to reduce SDI system costs

Large and relatively flat field sizes allow the use of longer driplines and larger zone sizes which helps to reduce system investment, installation, and operational costs. The soil and crop types do not require that SDI application intervals to be frequent which allows producers to install less expensive manually-operated systems. The choice of microirrigation itself often leads to an improvement in irrigation uniformity, but sometimes acceptance of small uniformity decreases for SDI system designs may result in cost savings and more profitable system operation. However, minimizing SDI system costs through cheaper designs can be a double-edged sword, as a cheaper system may increase operating costs and/or possibly increase the chance of system failure. The SDI system must be properly designed and maintained to ensure system longevity.

Can SDI systems have a long life?

SDI installations can have a long economic life when properly designed and managed. Long system life allows for amortizing investment costs over many years, thus allowing lower-valued commodity crops to be grown economically with SDI.

A 76-ha block of SDI installed in 1983 at Sundance Farms in Coolidge, Arizona was still being used in 2005 to grow grains and cotton (Wuertz, 2005). Although this block has sustained clogging of about 25 to 30%, Wuertz indicates it produces equivalent crop yields and 30 to 40% water savings compared with furrow-irrigated fields. A commercial SDI system installed in 1984 near Fort Collins, Colorado was still in operation for irrigated pasture in 2006 (Larson and

Peterson, 2006), although the owner admitted some reduction in SDI system uniformity due to clogging.

The performance of eighteen older SDI systems (longevity between 6 and 20 years) in Texas was evaluated by Enciso-Medina et al., (2009) in 2008 and 2009. System uniformity was more closely associated with system design, water quality, and the maintenance regimen than to the years of service. Similar results were reported for a large number of microirrigation systems evaluated in California (Hanson et al.,1995; Pitts et al., 1996). System uniformity was poorly correlated with microirrigation system age ranging from 0 to 30 years, with irrigated land area up to 230 ha, and with emitter discharge rates as great as 200 L/h (Hanson et al., 1995).

An SDI system used for research at the KSU-NWREC at Colby Kansas that has been operated for over 21 years without replacement is showing few signs of degradation (Lamm et al., 2009). Flowrates for 22 of 23 research plots were within ± 5% of the initial first season flowrate at the end of 22 crop seasons. This benchmark study area has received shock chlorination approximately 2-3 times each season, but has not received any other chemical amendments, such as acid. The water source at this site has a TDS of 279, hardness of 189.1, and pH of 7.8. This water source would be considered a moderate chemical clogging hazard according to traditional classifications (Nakayama and Bucks, 1986).

SDI system life must be at least 10-15 years to reasonably approach economic competitiveness with full sized center pivot sprinkler irrigation systems that typically last 20-25 years (O'Brien et al., 1998). Using careful and consistent maintenance, a 20 year or longer SDI system life appears obtainable when high quality water from the Ogallala aquifer is used.

How does SDI compare economically to alternative irrigation systems?

In an economic comparison of furrow irrigation and SDI for cotton production in West Texas, Thompson et al. (2002) reported that breakeven costs for SDI were approximately 15% lower than for furrow irrigation. Although variable and fixed costs of production were 30% greater for the SDI system, the cotton lint yield and gross revenue increase was nearly 50% greater with SDI. Water productivity, in the region with low capacity irrigation systems, was increased nearly 60% with SDI as compared to furrow irrigation.

Typically, SDI has much higher investment costs as compared to other pressurized irrigation systems such as full size center pivot sprinklers. However, there are realistic scenarios where SDI can directly compete with center pivot sprinklers for corn production in the Central Great Plains. As field size decreases, SDI can more directly compete with center pivot sprinklers because of increasing higher ratio of center pivot sprinkler (CP) costs to irrigated area (Figure 7). Small and irregular shaped fields may be ideal candidates for SDI.

Economic comparisons of CP and SDI systems are sensitive to the underlying assumptions used in the analysis (Lamm et. al., 2002a). The results show that these comparisons are very sensitive to size of CP irrigation system, shape of field (full vs. partial circle CP system) and life of SDI system (Figure 8). The results are moderately sensitive to corn yield, corn harvest price, yield/price combinations and very sensitive to higher potential yields with SDI with advantages favoring SDI as corn yields and price increase. A Microsoft Excel spreadsheet template has been developed for comparing CP and SDI economics and is available for free downloading from the internet at http://www.ksre.ksu.edu/sdi/Software/SDISoftware.htm

These results suggest that SDI systems can compete economically with alternative irrigation systems. Government cost-share programs that are sometimes available to provide incentives

for irrigation efficiency improvements can further increase the economic competitiveness of SDI systems.

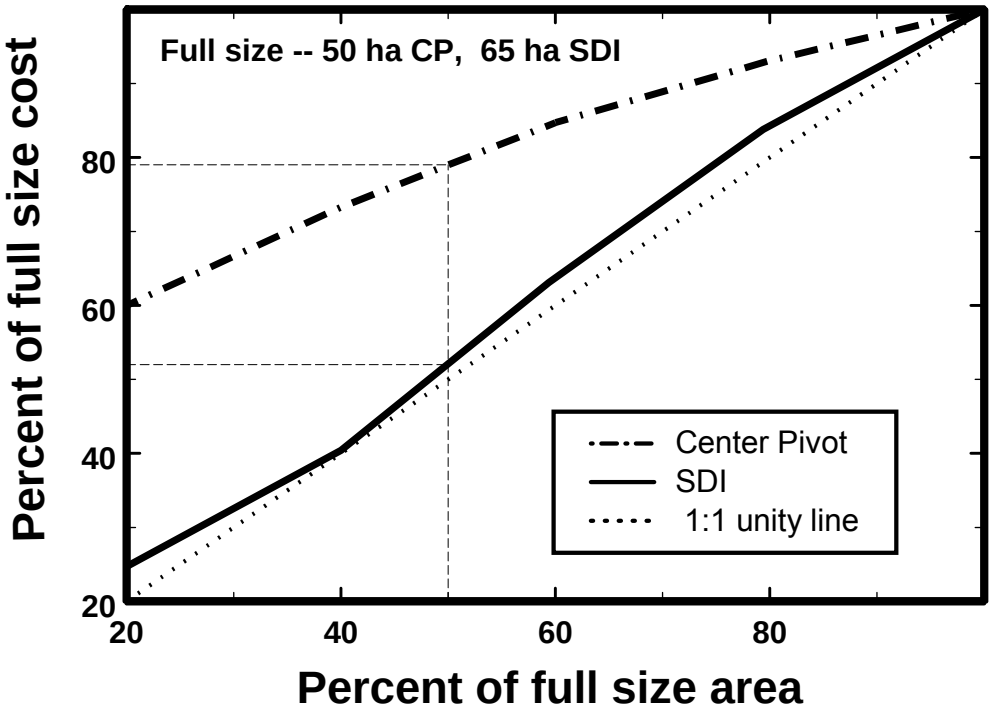

Figure 7. Center pivot sprinkler (CP) and SDI system costs as related to field size. (after O'Brien et al., 1998)

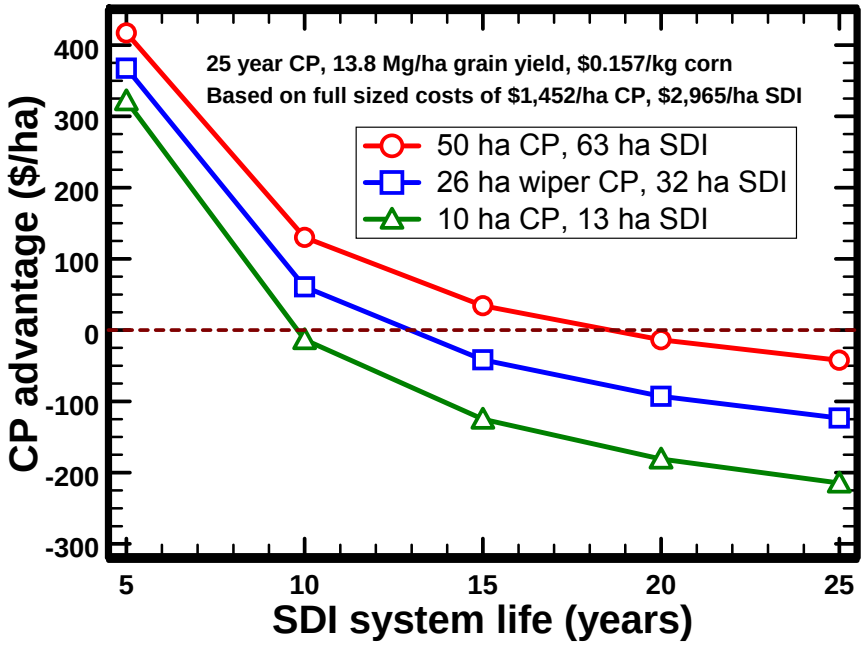

Figure 8. Economic advantage of center pivot sprinkler systems over SDI systems for various field sizes and shapes (e.g., wiper CP is a full sized center pivot that is only able to cover one-half circle on a 32 ha rectangular field) and SDI system lifespans.

Conclusions

A case has been made that SDI can be a competitive irrigation system in the Great Plains region for commodity crops. Although center pivot sprinkler systems are the predominant irrigation system in the region, there are realistic scenarios where an SDI system can be a better choice. Each irrigation system economic plan can have different results depending on the goals and constraints, but decisions should be based on the informational inputs and assumptions, not just traditions and experiences.

Acknowledgements

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

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