

A LOOK AT TWENTY YEARS OF SDI RESEARCH IN KANSAS

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BRIEF HISTORY

Subsurface drip irrigation (SDI) technologies have been a part of irrigated agriculture since the 1960s, but have advanced at a more rapid pace during the last 20 years (Camp et al. 2000). In the summer of 1988, K-State Research and Extension issued an in-house request for proposals for new directions in research activity. A proposal entitled Sustaining Irrigated Agriculture in Kansas with Drip Irrigation was submitted by irrigation engineers Freddie Lamm, Harry Manges and Dan Rogers and agricultural economist Mark Nelson. This project led by principal investigator Freddie Lamm, KSU Northwest Research-Extension Center (NWREC), Colby, was funded for the total sum of \$89,260. This project financed the initial development of the NWREC SDI system that was expressly designed for research. In March of 1989, the first driplines were installed on a 3 acre study site which has 23 separately controlled plots. This site has been in continuous use in SDI corn production since that time, being initially used for a 3-year study of SDI water requirements for corn. In addition, it is considered to be a benchmark area that is also being monitored annually for system performance to determine SDI longevity. In the summer of 1989, an additional 3 acres was developed to determine the optimum dripline spacing for corn production. A small dripline spacing study site was also developed at the KSU Southwest Research-Extension Center (SWREC) at Garden City in the spring of 1989.

In the summer of 1989, further funding was obtained through a special grant from the US Department of Agriculture (USDA). This funding led to expansion of the NWREC SDI research site to a total of 13 acres and 121 different research plots. This same funding provided for a 10 acre SDI research site at Holcomb, Kansas administered by the SWREC. By June of 1990, K-State Research and Extension had established 25 acres of SDI research facilities and nearly 220 separately controlled plot areas.

Over the course of the past 20 years, additional significant funding has been obtained to conduct SDI research from the USDA, the Kansas Water Resources Research Institute, special funding from the Kansas legislature, the Kansas Corn Commission, Pioneer Hi-Bred Inc., and the Mazzei Injector Corporation. Funding provided by the Kansas legislature through the Western Kansas Irrigation Research Project (WKIRP) allowed for the expansion of the NWREC site by an

additional 5.5 acres and 46 additional research plots in 1999. An additional 22 plots were added in 2000 to examine swine wastewater use through SDI and 12 plots were added in 2005 to examine emitter spacing. Two research block areas originally used in a 1989 dripline spacing study have been refurbished with new 5 ft spaced driplines to examine alfalfa production and emitter flowrate effects on soil water redistribution. The NWREC SDI research site comprising 19.5 acres and 201 different research plots is the largest facility devoted expressly to small-plot row crop research in the Great Plains and is probably one of the largest such facilities in the world.

Since its beginning in 1989, K-State SDI research has had three purposes: 1) to enhance water conservation; 2) to protect water quality, and 3) to develop appropriate SDI technologies for Great Plains conditions. The vast majority of the research studies have been conducted with field corn because it is the primary irrigated crop in the Central Great Plains. Although field corn has a relatively high water use efficiency, it generally requires a large amount of irrigation because of its long growing season and its sensitivity to water stress over a great portion of the growing period. Of the typical commodity-type field crops grown in the Central Great Plains, only alfalfa and similar forages would require more irrigation than field corn. Any significant effort to reduce the overdraft of the Ogallala aquifer, the primary water source in the Central Great Plains, must address the issue of irrigation water use by field corn. Additional crops that have been studied at the NWREC SDI site are soybean, sunflower, grain sorghum, alfalfa and demonstration trials of melons and vegetables.

GENERAL STUDY PROCEDURES

This report summarizes several studies conducted at the KSU Northwest and Southwest Research-Extension Centers at Colby and Garden City, Kansas, respectively. A complete discussion of all the employed procedures lies beyond the scope of this paper. For further information about the procedures for a particular study the reader is referred to the accompanying reference papers when so listed. These procedures apply to all studies unless otherwise stated.

The two study sites were located on deep, well-drained, loessial silt loam soils. These medium-textured soils, typical of many western Kansas soils, hold approximately 18.9 inches of plant available soil water in the 8 ft profile at field capacity. Study areas were nearly level with land slope less than 0.5% at Colby and 0.15% at Garden City. The climate is semi-arid, with an average annual precipitation of 17 inches. Daily climatic data used in the studies were obtained from weather stations operated at each of the Centers.

Most of the studies have utilized SDI systems installed in 1989-90 (Lamm et al., 1990). The systems have dual-chamber drip tape installed at a depth of approximately 16-18 inches with a 5-ft spacing between dripline laterals. Emitter spacing was 12 inches and the dripline flowrate was 0.25 gpm/100 ft. The corn was planted so each dripline lateral is centered between two corn rows (Fig. 1).

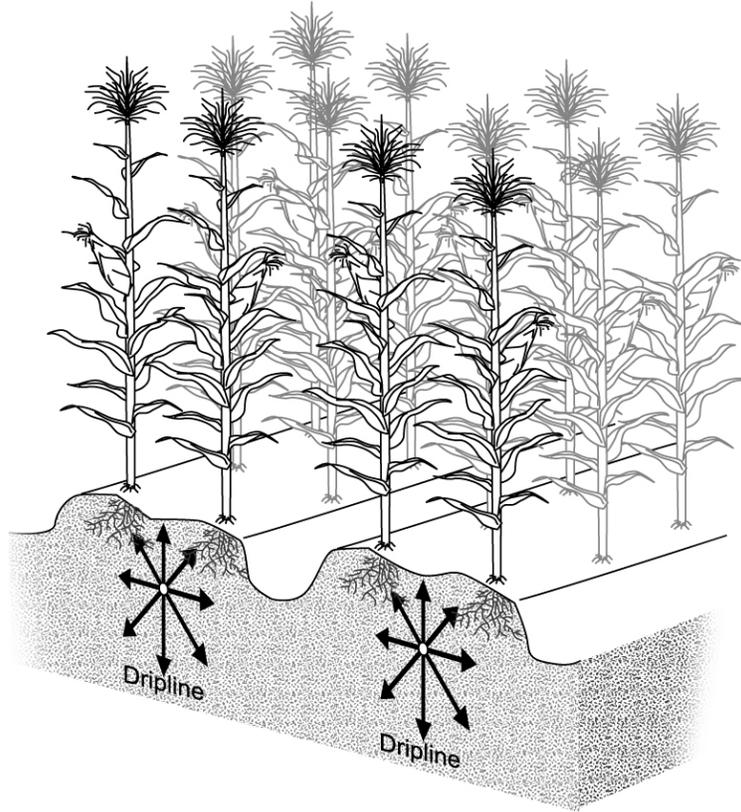


Figure 1. Physical arrangement of the subsurface dripline in relation to the corn rows.

A modified ridge-till system was used in corn production with two corn rows, 30 inches apart, grown on a 5-ft wide bed. Flat planting was used for the dripline spacing studies conducted at both locations. In these dripline spacing studies, it was not practical to match bed spacing to dripline spacing with the available tillage and harvesting equipment. Additionally at Garden City, corn rows were planted perpendicular to the driplines in the dripline spacing study. All corn was grown with conventional production practices for each location. Wheel traffic was confined to the furrows.

Reference evapotranspiration and actual evapotranspiration (AET) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heerman (1974). The specifics of the calculations are fully described by Lamm et al. (1995).

Irrigation was scheduled using a water budget to calculate the root zone depletion with precipitation and irrigation water amounts as deposits and calculated daily corn water use (AET) as a withdrawal. If the root-zone depletion became negative, it was reset to zero. Root zone depletion was assumed to be zero at crop emergence. Irrigation was metered separately onto each plot. Soil water amounts were monitored weekly in each plot with a neutron probe in 12 inch increments to a depth of 8 ft.

WATER REQUIREMENT AND IRRIGATION CAPACITY STUDIES

Research studies were conducted at Colby and Garden City, Kansas from 1989-1991 to determine the water requirement of subsurface drip-irrigated corn. Careful management of SDI systems reduced net irrigation needs by nearly 25%, while still maintaining top yields of 200 bu/a (Lamm et. al., 1995). The 25% reduction in irrigation needs potentially translates into 35-55% savings when compared to sprinkler and furrow irrigation systems which typically are operating at 85 and 65% application efficiency. Corn yields at Colby were linearly related to calculated crop water use (Figure 2), producing 19.6 bu/a of grain for each inch of water used above a threshold of 12.9 inches (Lamm et al., 1995). The relationship between corn yields and irrigation is curvilinear (Figure 2.) primarily because of greater drainage for the heavier irrigation amounts (Figure 3).

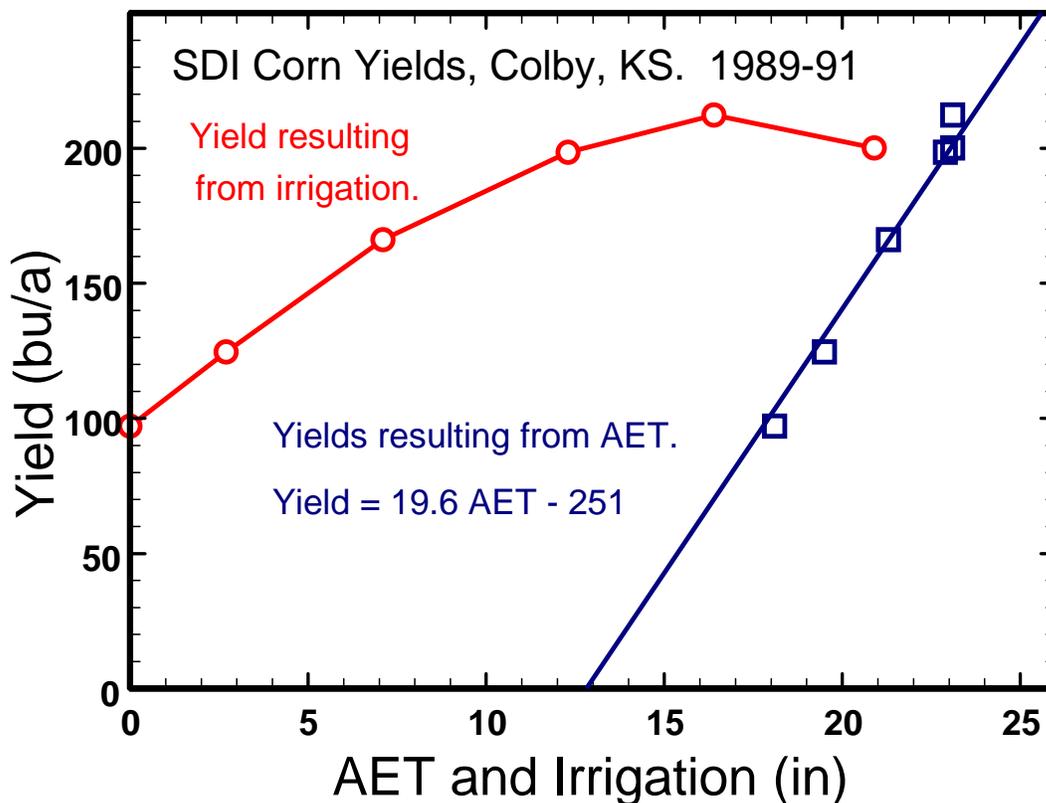


Figure 2. Corn yield as related to irrigation and calculated evapotranspiration (AET) in a SDI water requirement study, Colby, Kansas, 1989-1991.

SDI technology can make significant improvements in water use efficiency through better management of the water balance components. The 25% reduction in net irrigation needs is primarily associated with the reduction in in-season drainage, elimination of irrigation runoff and reduction in soil evaporation, all non-beneficial components of the water balance. Additionally, drier surface soils allow for increased infiltration of occasional precipitation events.

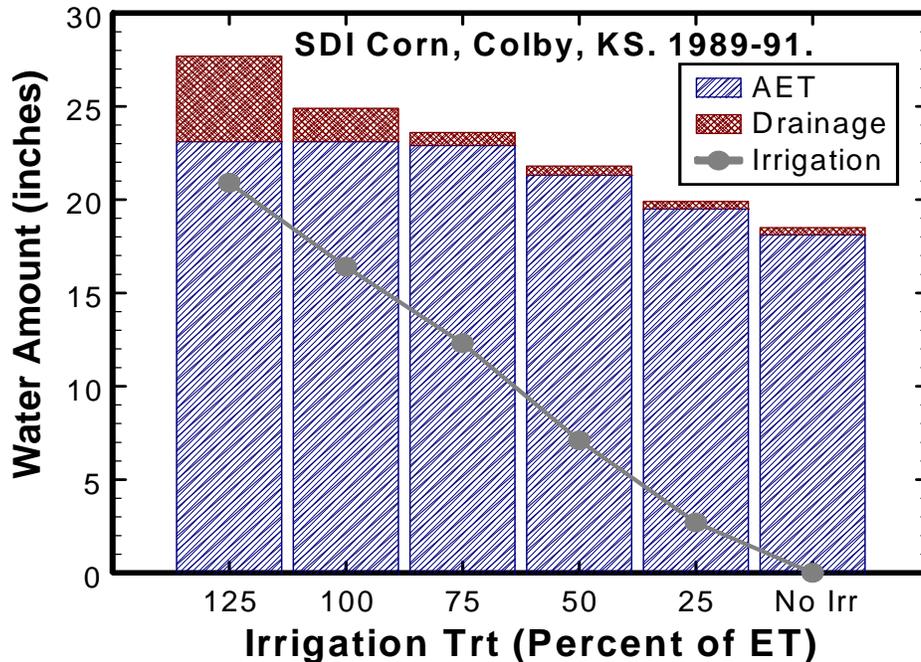


Figure 3. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI water requirement study, Colby, Kansas, 1989-1991.

In a later study (1996-2001), corn was grown under 6 different SDI capacities (0, 0.10, 0.13, 0.17, 0.20 and 0.25 inches/day) and 4 different plant densities (33100, 29900, 26800, and 23700 plants/acre). Daily SDI application of even small amounts of water (0.10 inches) doubled corn grain yields from 93 to 202 in extremely dry 2000 and 2001. Results suggested an irrigation capacity of 0.17 inches/day might be adequate SDI capacity when planning new systems in this region on deep silt loam soils (Lamm and Trooien, 2001). It was concluded that small daily amounts of water can be beneficial on these deep silt loam soils in establishing the number of sinks (kernels) for the accumulation of grain. The final kernel weight is established by grain filling conditions between the reproductive period and physiological maturity (last 50-60 days of crop season). Thus, the extent of soil water depletion during this period will have a large effect on final kernel weight and ultimately, corn grain yield. Increasing plant density from 22,500 to 34,500 plants/acre generally increased corn grain yields, particularly in good corn production years. There was very little yield penalty for increased plant density even when irrigation was severely limited or eliminated.

The results from four SDI studies on corn water use were summarized by Lamm, 2005. Relative corn yield reached a plateau region at about 80% of full irrigation and continued to remain at that level to about 130% of full irrigation (Figure 4). Yield variation as calculated from the regression equation for this plateau region is less than 5% and would not be considered significantly different. The similarity of results for all four studies is encouraging because the later studies included the effect of the four extreme drought years of 2000 through 2003.

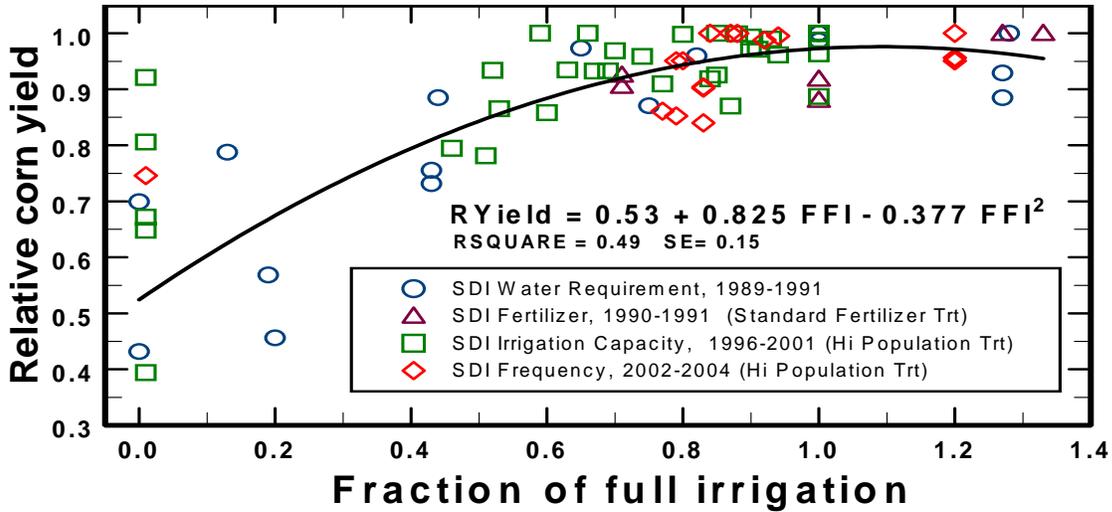


Figure 4. Relative corn grain yield for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas.

An examination of water use efficiency for the same four studies indicates that water use efficiency plateaus for levels of full irrigation ranging from 61% to 109% with less than 5% variation in WUE (Figure 5). The highest WUE occurs at an irrigation level of approximately 82% of full irrigation. This value agrees with results summarized by Howell, (2001) for multiple types of irrigation systems. The highest WUE (82% of full irrigation) also occurred in the plateau region of highest corn yield (80 to 130% of full irrigation). This suggests that both water- and economically-efficient production can be obtained with SDI levels of approximately 80% of full irrigation across a wide range of weather conditions on these soils in this region.

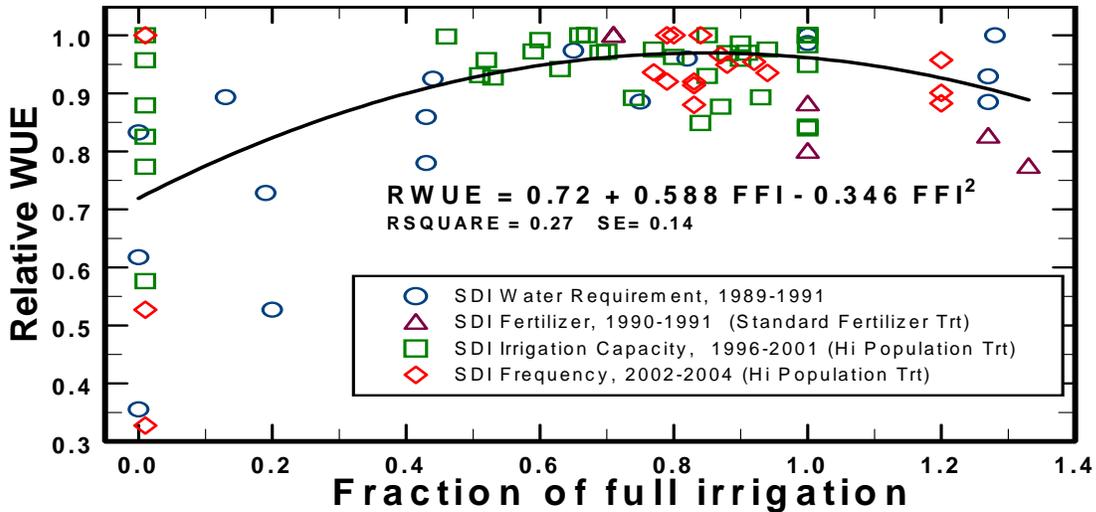


Figure 5. Relative water use efficiency of corn for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas.

SDI FREQUENCY

Typically, a smaller volume of soil is wetted with SDI as compared to other types of irrigation systems and as a result, crop rooting may be limited. Crops may benefit from frequent irrigation under this condition. However, in a study conducted at the KSU Southwest Research-Extension Center in Garden City, Kansas, corn yields were excellent (190 to 200 bu/a) regardless of whether a frequency of 1, 3, 5, or 7 days was used for the SDI events (Caldwell et al., 1994). Higher irrigation water use efficiencies were obtained with the longer 7-day frequency because of improved storage of in-season precipitation and because of reduced drainage below the rootzone. The results indicate there is little need to perform frequent SDI events for fully-irrigated corn on the deep silt loam soils of western Kansas.

These results agree with a literature review of SDI (Camp, 1998) that indicated that SDI frequency is often only critical for shallow rooted crops on shallow or sandy soils. An additional study conducted in the U.S. Southern Great Plains indicated that SDI frequencies had little or no effect on corn yields provided soil water was managed within acceptable stress ranges (Howell et al., 1997).

In a 2002-2004 study at Colby, Kansas, four irrigation frequencies at a limited irrigation capacity were compared against fully irrigated and non-irrigated treatments (Lamm and Aiken, 2005). The hypothesis was that under limited irrigation, higher frequency with SDI might be beneficial during grain filling and the latter portion of the season as soil water reserves become depleted. The four irrigation frequencies were 0.15 inches/day, 0.45 inches/3 days, 0.75 inches/5 days and 1.05 inches/7 days which are equivalent but limited capacities. As a point of reference, a 0.25 inch/day irrigation capacity will match full irrigation needs for sprinkler irrigated corn in this region in most years. The fully irrigated treatment was limited to 0.30 inches/day. The non-irrigated treatment only received 0.10 inches in a single irrigation to facilitate nitrogen fertigation for those plots. However, all 6 treatments were irrigated each year in the dormant season to replenish the soil water in the profile. Corn yields were high in all three years for all irrigated treatments (Figure 6.) Only in 2002 did irrigation frequency significantly affect yields and the effect was the opposite of the hypothesis. In the extreme drought year of 2002, the less frequent irrigation events with their larger irrigation amounts (0.75 inches/5 days and 1.05 inches/7 days) resulted in yields approximately 10 to 20 bushels/acre higher. The yield component most greatly affected in 2002 was the kernels/ear and was 30-40 kernels/ear higher for the less frequent events. It is suspected that the larger irrigation amounts for these less frequent events sent an early-season signal to the corn plant to set more potential kernels. Much of the potential kernel set occurs before the ninth leaf stage (corn approximately 24-36 inches high), but there can be some kernel abortion as late as two weeks after pollination. The results suggest that irrigation frequencies from daily to weekly should not have much effect on corn yields in most years.

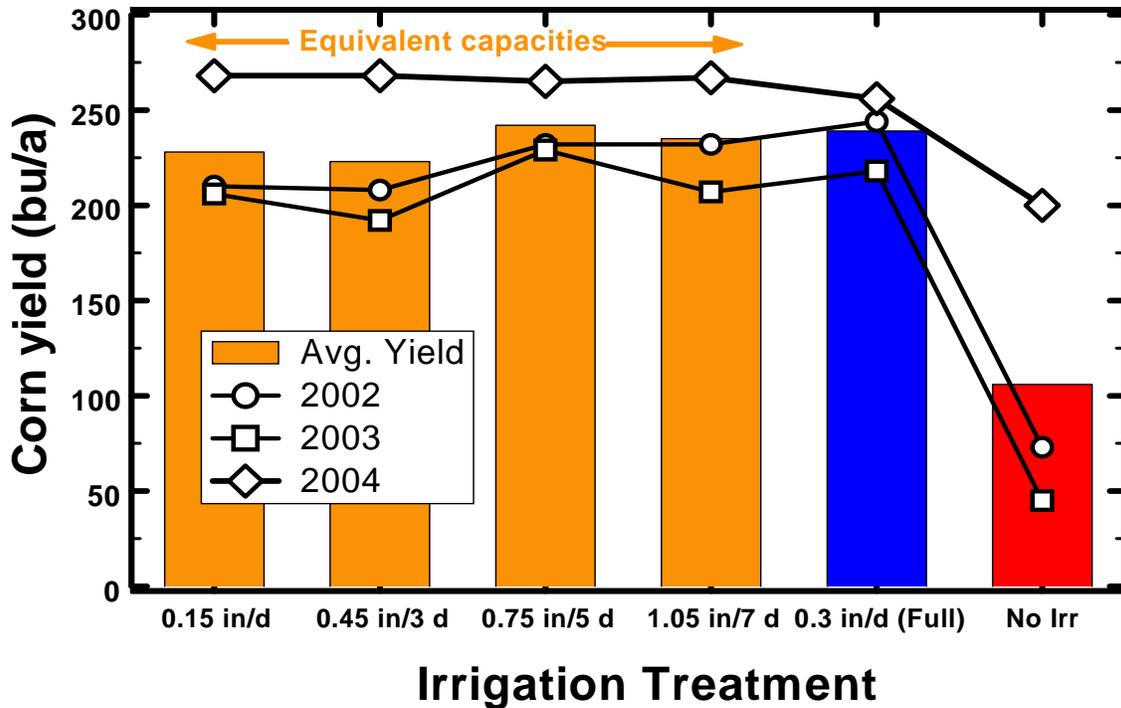


Figure 6. Corn grain yields as affected by irrigation treatment in a study examining SDI frequency under limited irrigation, Colby, Kansas, 2002 to 2004.

OPTIMAL DRIPLINE SPACING

Increasing the spacing of dripline laterals would be one of the most important factors in reducing the high investment costs of SDI. Soil type, dripline installation depth, crop type and the reliability and amount of in-season precipitation are major factors that determine the maximum dripline spacing.

Two studies have been conducted in semi-arid western Kansas to determine the optimum dripline spacing (installed at a depth of 16-18 inches) for corn production on deep, silt-loam soils (Spurgeon, et al., 1991; Manges et al., 1995; Darusman et al., 1997; Lamm et al., 1997a). The first study at the KSU Southwest Research-Extension Center at Garden City, Kansas evaluated 4 dripline spacings (2.5, 5, 7.5, and 10 ft) with corn planted in 30 inches rows perpendicular to the dripline lateral. The other study at the KSU Northwest Research-Extension Center at Colby, Kansas evaluated 3 spacings (5, 7.5, and 10 ft) with corn planted in 30 inch rows parallel to the driplines. Average yields for corresponding treatments were similar between sites even though row orientation was different (Table 1).

The highest average yield was obtained by the 2.5-ft dripline spacing at Garden City, Kansas. However, the requirement of twice as much dripline (dripline ratio, 2.00) would be uneconomical for corn production as compared to the standard 5-ft. dripline spacing. The results, when incorporated into an economic model,

showed an advantage for the wider dripline spacings (7.5 and 10 ft.) in some higher rainfall years. However, the standard 5-ft dripline spacing was best when averaged over all years for both sites. When subsurface driplines are centered between alternate pairs of 30-inch spaced corn rows, each corn row is within 15 inches of the nearest dripline (Figure 1.)

Table 1. Corn yields obtained with various dripline spacing treatments under full and reduced irrigation at Garden City and Colby, Kansas, 1989-91.

Spacing treatment	Irrigation treatment	Dripline ratio in relation to 5-ft. trt.	Corn yield (bu/a)	
			Garden City 1989-91	Colby 1990-91
2.5 ft.	Full irrigation	2.00	230	----
5.0 ft	Full irrigation	1.00	218	216
7.5 ft	Full Irrigation	0.67	208	204
7.5 ft	Reduced irrigation (67%)	0.37	----	173
10.0 ft	Full irrigation	0.50	194	194
10.0 ft	Reduced irrigation (50%)	0.50	----	149

Wider dripline spacings will not consistently (year-to-year) or uniformly (row-to-row) supply crop water needs. In 1990 at Colby, yields for the 5 and 7.5 ft dripline spacings were equal when full irrigation was applied, partially because soil water reserves were high at planting. In 1991, following a dry winter, yields for the wider 7.5 ft dripline spacing were reduced by 25 bu/a (Lamm et al., 1997a). Similar results were reported by Spurgeon et al. (1991) at Garden City. The studies at Colby also sought to resolve whether equivalent amounts of water should be applied to the wider dripline spacings or whether irrigation should be reduced in relation to the dripline ratio. Yields were always lower for the corn rows furthest from the dripline in the wider dripline spacings regardless of which irrigation scheme was used (Figure 7). However in 1991, there was complete crop failure in the corn rows furthest from the dripline when irrigation was reduced in relation to the dripline ratio. Full irrigation on the wider dripline spacings at Colby resulted in excessive deep percolation (Darusman et al., 1997) and reduced overall water use efficiency (Lamm et al., 1997a). Soils having a restrictive clay layer below the dripline installation depth might allow a wider spacing without affecting crop yield. Wider spacings may also be allowable in areas of increased precipitation as the dependency of the crop on irrigation is decreased (Powell and Wright, 1993).

One of the inherent advantages of a SDI system is the ability to irrigate only a fraction of the crop root zone. Careful attention to proper dripline spacing is, therefore, a key factor in conserving water and protecting water quality. These

research studies at Colby and Garden City, Kansas determined that driplines spaced 60 inches apart are most economical for corn grown in rows spaced 30 inches apart at least on the deep silt loam soils of the region. However, different soil types, such as sands, or different crops with less extensive root systems might require closer dripline spacing.

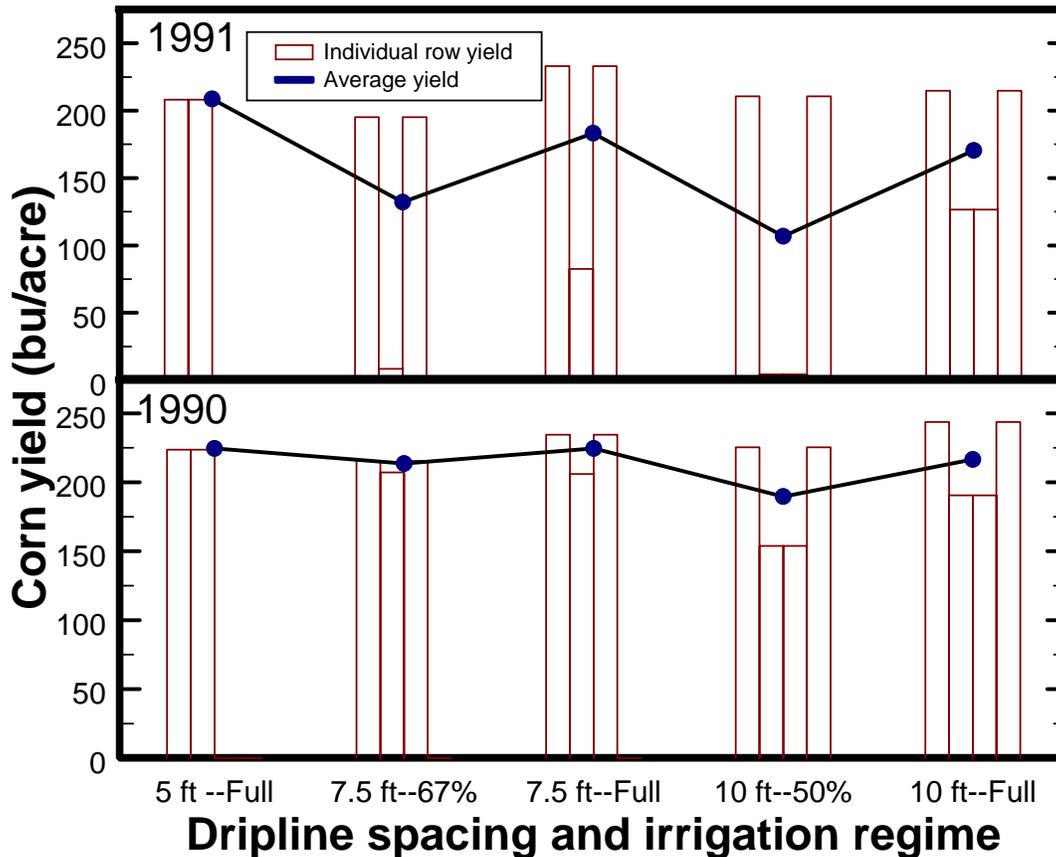


Figure 7. Corn yield distribution as affected by dripline spacing and irrigation regime, Colby, Kansas, 1990-1991. Note: Individual row yields are mirrored about a centerline half way between two adjacent driplines for display purposes.

DRIPLINE DEPTH STUDY

In some areas, SDI has not been readily accepted because of problems with root intrusion, emitter clogging and lack of visual indicators of the wetting pattern. In high value crops, these indeed can be valid reasons to avoid SDI. However, in the Central Great Plains, with typically relatively low value commodity crops such as corn, only long term SDI systems where installation and investment costs can be amortized over many years, have any realistic chance of being economically justified. Kansas irrigators are beginning to try SDI on their own and there has been a lack of research-based information on appropriate depth for driplines.

Camp (1998) reviewed a number of SDI studies concerning depth of installation and concluded the results are often region specific and optimized for a particular crop. Five dripline depths (8, 12, 16, 20 or 24 inches) were evaluated at Colby, Kansas for corn production and SDI system integrity and longevity (Lamm and Trooien, 2005). System longevity was evaluated by monitoring individual flowrates and pressures at the end of each cropping season to estimate system degradation (clogging) with time. There was no appreciable or consistent effect on corn grain yields during the period 1999-2002 (Figure 8.). The study area has not been used to examine the effects of dripline depth on germination in the spring, but damp surface soils were sometimes observed for the 8 and 12 inch dripline depths during the irrigation season, but not for the deeper depths. There was a tendency to have slightly more late season grasses for the shallower 8 and 12 inch depths, but the level of grass competition with the corn is not intense. The dripline depth study was managed with the modified ridge-till system (5-ft. bed) as shown in Figure 1. Cultivation for weeds in early summer has been routinely practiced and there was no instances of tillage tool damage to the shallow 8-inch depth driplines.

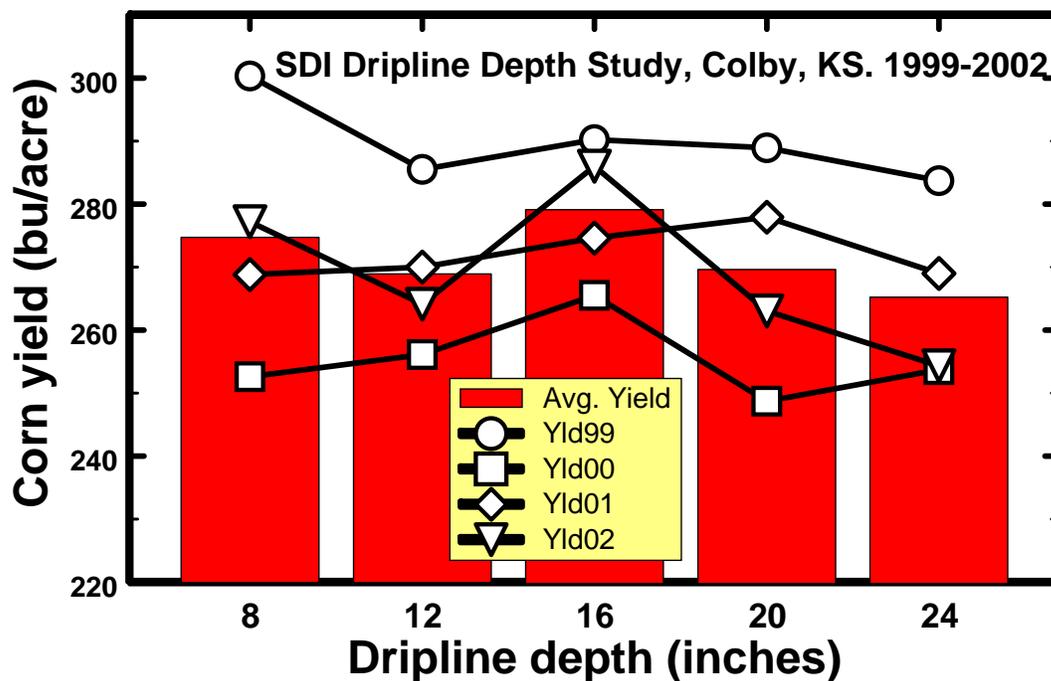


Figure 8. Corn grain yields as affected by dripline depth, 1999-2002, Colby, Kansas.

Similar dripline depth studies were conducted for soybean (2005 and 2007), grain sorghum (2006 and 2008) and sunflower (2004 and 2007). There were no significant differences in yields for any of the crops in any year as affected by dripline depth (Table 2.)

Table 2. Crop yield of soybean, grain sorghum and sunflower as affected by dripline depth, KSU Northwest Research-Extension Center, Colby Kansas, 2003-2008.

Dripline depth inches	Soybean yield bu/acre			Grain Sorghum bu/acre			Sunflower lbs/acre		
	2005	2007	Mean	2006	2008	Mean	2004	2007	Mean
8	80	76	78	166	153	159	3128	3487	3307
12	82	71	76	159	155	157	2838	3309	3074
16	80	76	78	165	169	167	2941	3580	3261
20	80	74	77	159	157	158	2992	3489	3241
24	78	78	78	155	141	148	2942	3497	3220
Mean	80	75	77	161	155	158	2968	3473	3220
LSD 0.05	NS	NS	-	NS	NS	-	NS	NS	-

NITROGEN FERTILIZATION WITH SDI

Because properly designed SDI systems have a high degree of uniformity and can apply small frequent irrigation amounts, excellent opportunities exist to better manage nitrogen fertilization with these systems. Injecting small amounts of nitrogen solution into the irrigation water can spoonfeed the crop, while minimizing the pool of nitrogen in the soil that could be available for percolation into the groundwater.

In a study conducted at the KSU Northwest Research-Extension Center at Colby, Kansas from 1990-91, there was no difference in corn grain yields between preplant surface-applied nitrogen and nitrogen injected into the driplines throughout the season. Corn yields averaged 225 to 250 bu/a for the fully irrigated and fertilized treatments. Water use was increased ($P=0.05$) in 1991 and for the two year average by injection of N fertilizer with the SDI system. The additional in-season fertigation allowed for healthier and more vigorous plants that were better able to utilize soil water. The results suggest that a large portion of the applied N could be delayed until weekly injections begin with the first irrigation provided there is sufficient residual soil N available for early growth. In both years, nearly all of the residual nitrate nitrogen measured after corn harvest was located in the upper 12 inches of the soil profile for the preplant surface-applied nitrogen treatments, regardless of irrigation level. In contrast, nitrate concentrations increased with increasing levels of nitrogen injected with SDI and migrated deeper in the soil profile with increased irrigation (Lamm et. al., 2001). Nitrogen applied with SDI at a depth of 16-18 inches redistributed differently in the soil profile than surface-applied preplant nitrogen banded in the furrow (Figure 9). Since residual soil-nitrogen levels were higher where nitrogen was injected using SDI, it may be possible to obtain similar high corn yields using lower amounts of injected nitrogen.

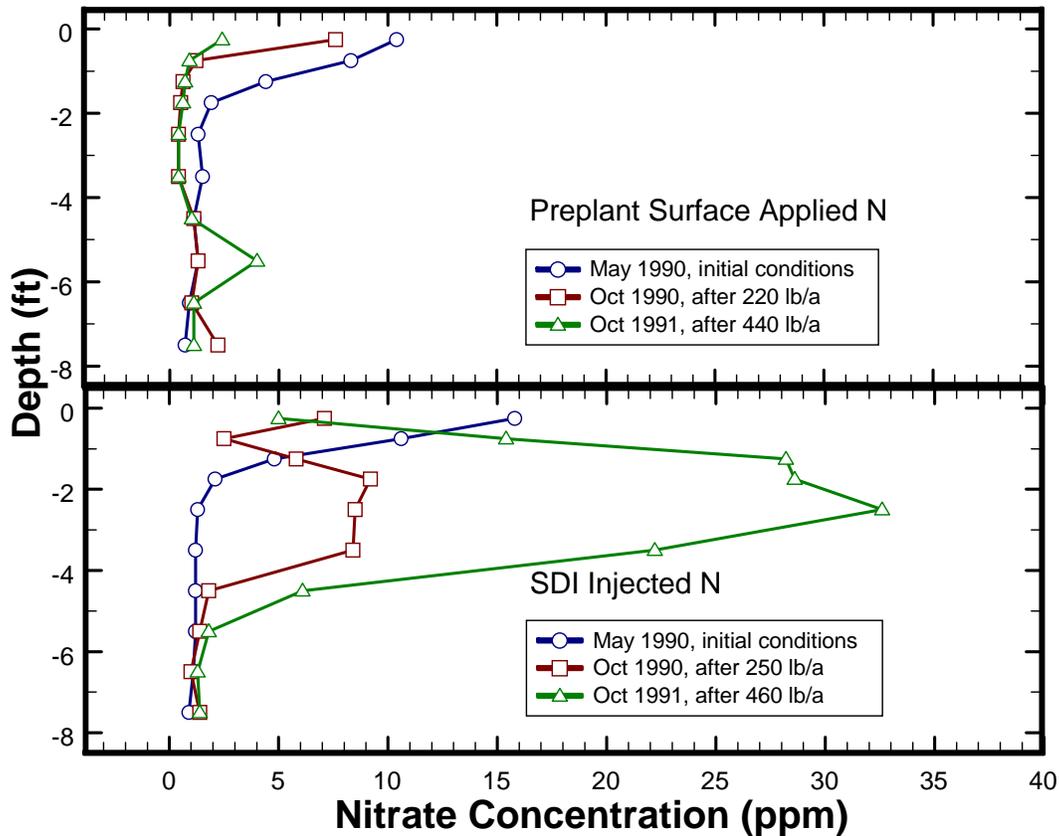


Figure 9. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of AET).

A follow-up four year study was conducted at the KSU Northwest Research-Extension Center at Colby, Kansas on a deep Keith silt loam soil to develop a Best Management Practice (BMP) for nitrogen fertigation for corn using SDI. Residual ammonium- and nitrate-nitrogen levels in the soil profile, corn yields, apparent nitrogen uptake (ANU) and water use efficiency (WUE) were utilized as criteria for evaluating six different nitrogen fertigation rates, 0, 80, 120, 160, 200, and 240 lbs/acre. The final BMP was a nitrogen fertigation level of 160 lbs/acre with other non-fertigation applications bringing the total applied nitrogen to approximately 190 lbs/acre (Lamm et. al., 2004). The BMP also states that irrigation is to be scheduled and limited to replace approximately 75% of ET. Corn yield, ANU, and WUE all plateaued at the same level of total applied nitrogen which corresponded to the 160 lbs/acre nitrogen fertigation rate (Figure 10). Average yields for the 160 lbs/acre nitrogen fertigation rate was 213 bu/acre. Corn yield to ANU ratio for the 160 lbs/acre nitrogen fertigation rate was a high 53:1. The results emphasize that high-yielding corn production also can be efficient in nutrient and water use.

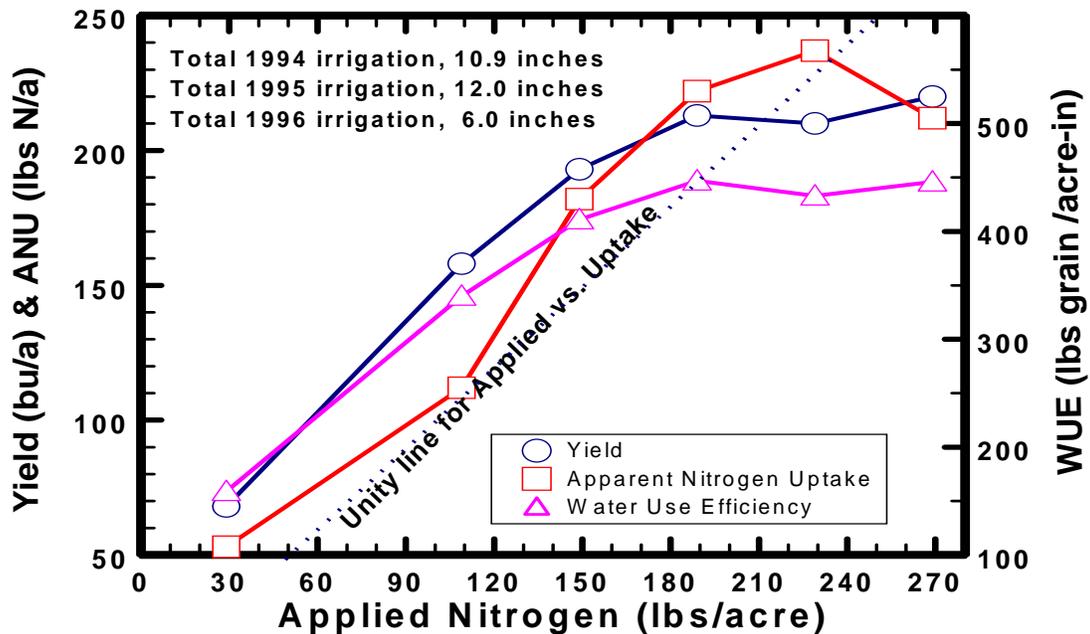


Figure 10. Average (1994-96) corn yield, apparent nitrogen uptake in the above-ground biomass, and water use efficiency as related to the total applied nitrogen (preseason amount, starter fertilizer, fertigation, and the naturally occurring N in the irrigation water). Total applied nitrogen exceeded fertigation applied nitrogen by 30 lb/acre.

COMPARISON OF SDI AND SIMULATED LEPA SPRINKLER IRRIGATION

A seven-year field study (1998-2004) compared simulated low energy precision application (LEPA) sprinkler irrigation to subsurface drip irrigation (SDI) for field corn production on deep silt loam soils at Colby, Kansas (Lamm, 2004). There was very little difference in average corn grain yields between system type (235 and 233 bushels/acre for LEPA and SDI, respectively) across all comparable irrigation capacities (Figure 11). However, LEPA had higher grain yields for 4 extreme drought years (approximately 15 bushels/acre) and SDI had higher yields in 3 normal to wetter years (approximately 15 bushels/acre).

The difference in system types between years was unanticipated and remains unexplained. In the course of conducting this experiment it became apparent that system type was affecting grain yields particularly in the extreme drought years. Higher LEPA yields were associated with higher kernels/ear as compared to SDI (534 vs. 493 kernels/ear in dry years). Higher SDI yields were associated with higher kernel weight at harvest as compared to LEPA (34.7 vs. 33.2 grams/100 kernels in normal to wetter years). Although the potential number of kernels/ear is determined by hybrid genetics and early growth before anthesis, the actual number of kernels is usually set in a 2-3 week period centering around

anthesis. Water and nitrogen availability and hormonal signals are key factors in determining the actual number of kernels/ear. The adjustment of splitting the fertilizer applications to both preplant and inseason in 2002 did not remove the differences in kernels/ear between irrigation system types. Hormonal signals sent by the roots may have been different for the SDI treatments in the drought years because SDI may have had a more limited root system. Seasonal water use was approximately 4% higher with LEPA than SDI and was associated with the period from anthesis to physiological maturity. Further research is being conducted to gain an understanding of the reasons between the shifting of the yield components (kernels/ear and kernel weight) between irrigation systems as climatic conditions vary.

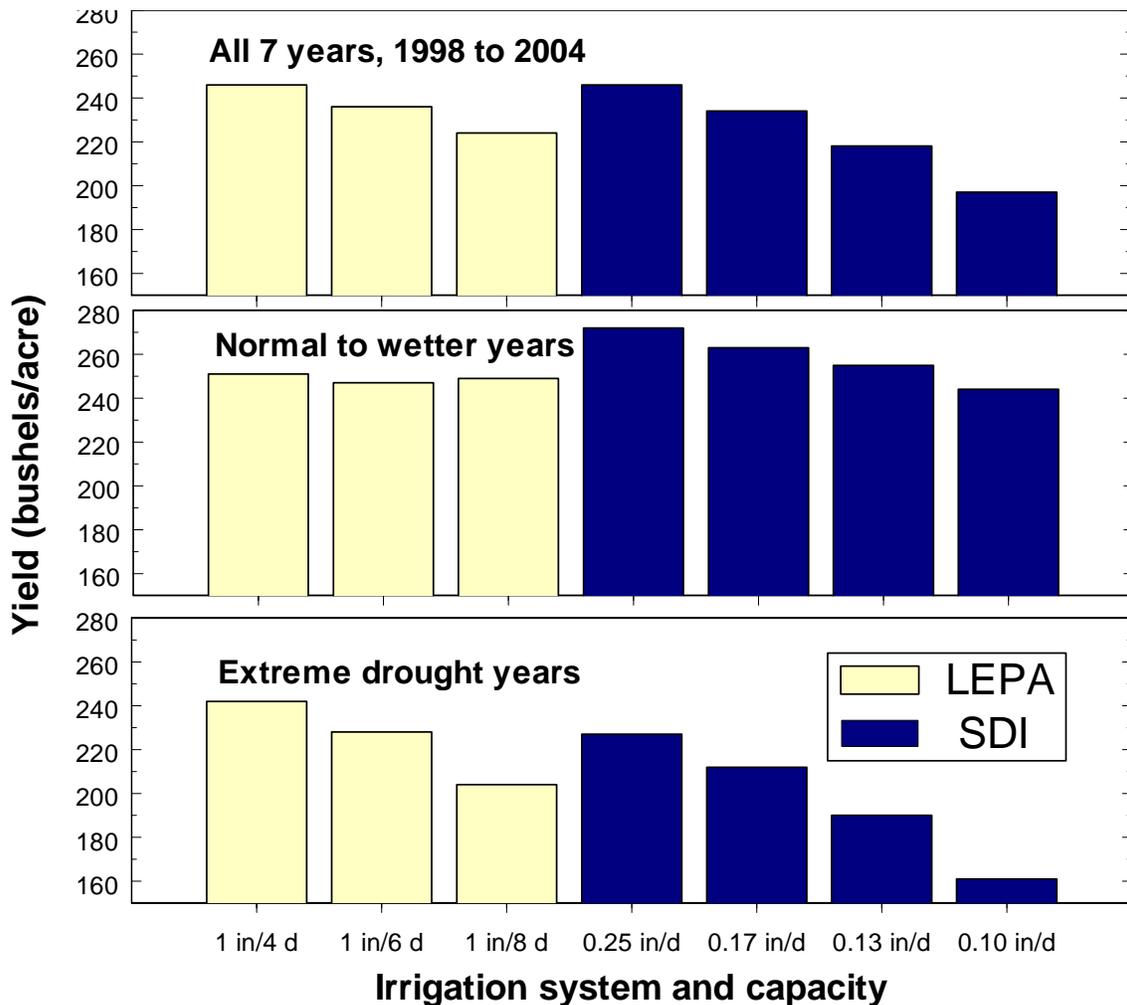


Figure 11. Variation in corn yields across years and weather conditions as affected by irrigation system type and capacity, Colby Kansas.

Additional studies were conducted to compare LEPA sprinkler irrigation to SDI for production of soybeans (2005), grain sorghum (2006 and 2008) and sunflower (2004 and 2007). In these studies, weather-based water-budget irrigation schedules were used to replace ET at replacement levels of 100, 80 and 60% for both types of irrigation system.

There were no significant differences in soybean yield but there was a trend towards SDI having greater yield at deficit irrigation levels and LEPA having greater yield at the full irrigation level (Table 3). Similar statistically non-significant results were obtained for sunflower with attend towards SDI resulting in greater yields under deficit irrigation (0.6 and 0.8 ET) than LEPA, but LEPA having greater yields at full irrigation in both years. Grain sorghum tended to have greater yields with LEPA than with SDI at all levels of irrigation and was statistically significant in 2008. Further analysis and research is needed to determine the reasons for these results.

Irrigation method	Irrigation Treatment	Soybean yield bu/a	Grain Sorghum bu/a			Sunflower yield bu/a		
		2005	2006	2008	Mean	2004	2007	Mean
SDI	100% ET	73	169	154 b*	161	3098	2824	2961
	80% ET	70	175	144 b	159	3442	3292	3367
	60% ET	70	155	131 c	143	3346	3273	3309
	<i>Mean SDI</i>	71	166	143	155	3295	3130	3212
LEPA	100% ET	75	179	170 a	174	3694	3354	3524
	80% ET	71	180	169 a	175	3285	2929	3107
	60% ET	63	175	160 a	167	3125	2729	2927
	<i>Mean LEPA</i>	69	178	167	172	3368	3004	3186
<i>LSD 0.05</i>		NS	NS	13	-	NS	NS	-
<i>* Values followed by the same lower case letter are not significantly different at the P=0.05 level.</i>								

ALFALFA PRODUCTION WITH SDI

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 (Hengeller, 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.

A study was conducted from 2004 through 2007 to evaluate alfalfa production using an SDI system with a 5-ft dripline spacing and a 20 inch dripline depth on a deep silt loam soil at the KSU Northwest Research-Extension Center at Colby, Kansas. Alfalfa production and quality was 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, 15, and 30 inches).

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% ET treatment and resulted in reduced overall annual yields (Figure 12). However, crude protein (a measure of alfalfa quality) and digestibility was greater at the greater distances and reduced ET (Figure 13 and 14). This helped compensate for the yield reduction.

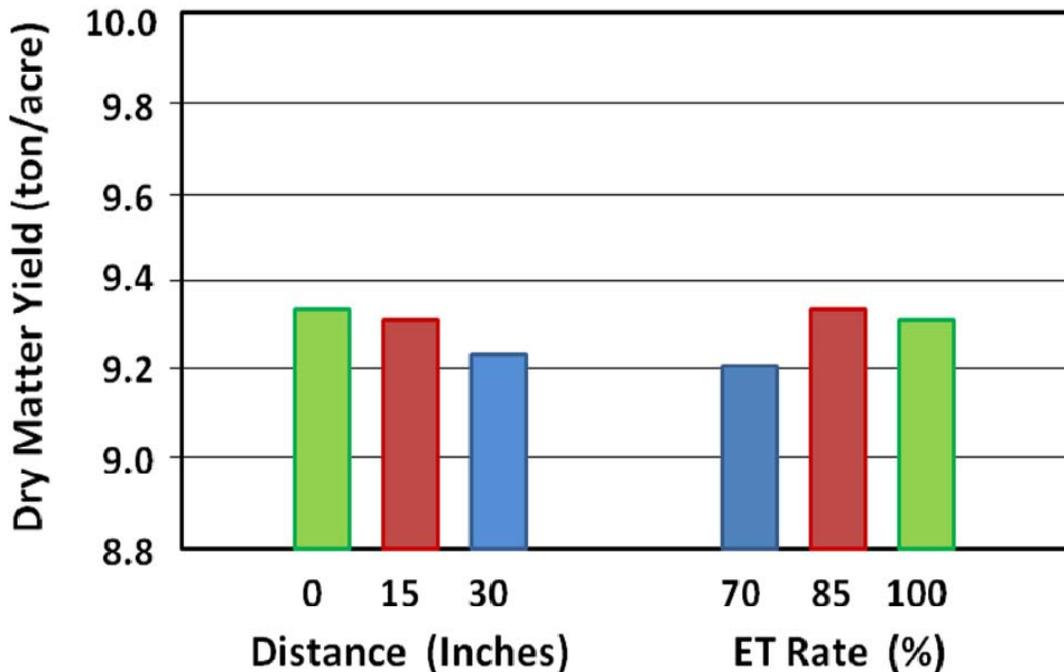


Figure 12. Dry matter yield of alfalfa as affected by perpendicular horizontal distance from dripline and irrigation level, KSU Northwest Research-Extension Center, Colby Kansas. Data is averaged over the years, 2005 through 2007.

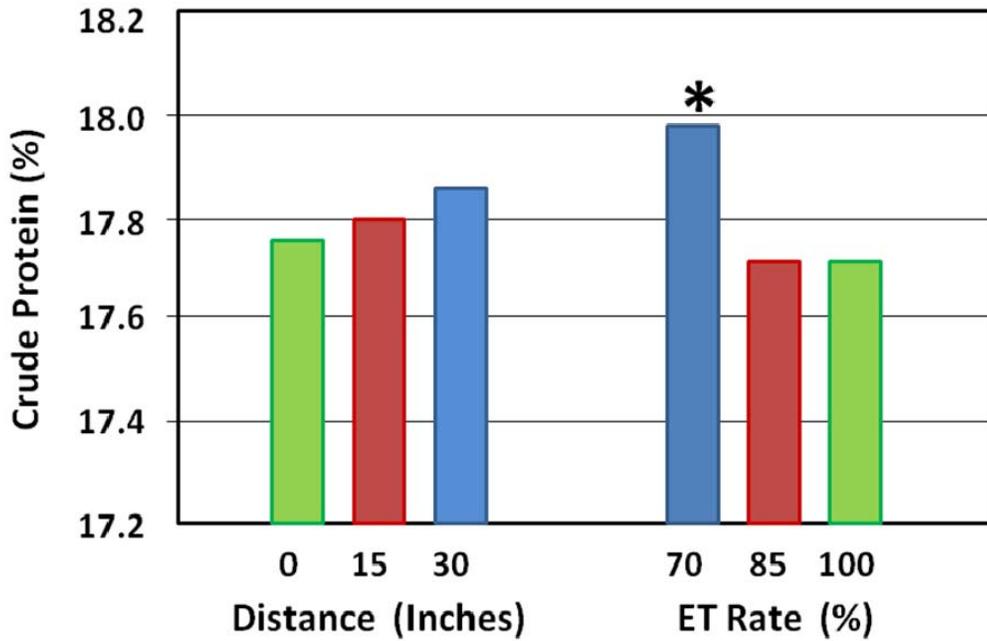


Figure 13. Crude protein percentage of alfalfa as affected by perpendicular horizontal distance from dripline and irrigation level, KSU Northwest Research-Extension Center, Colby Kansas. Data is averaged over the years, 2005 through 2007.

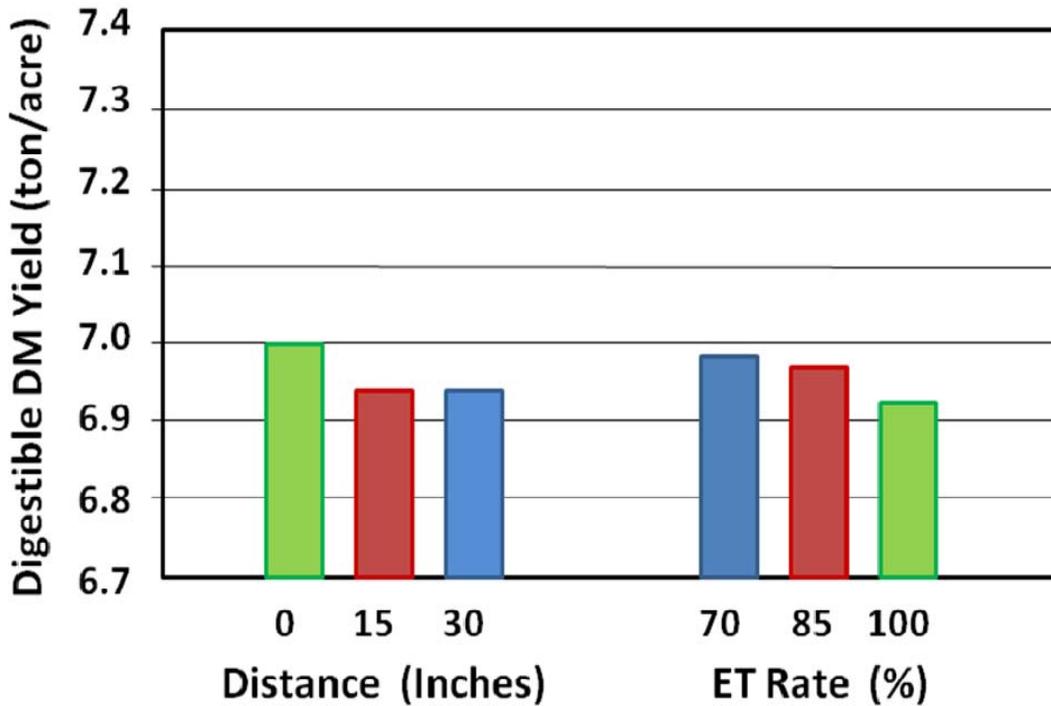


Figure 14. Digestible dry matter yield of alfalfa as affected by perpendicular horizontal distance from dripline and irrigation level, KSU Northwest

Research-Extension Center, Colby Kansas. Data is averaged over the years, 2005 through 2006.

APPLICATION OF LIVESTOCK EFFLUENT WITH SDI

Subsurface drip irrigation (SDI) can be successfully used for application of livestock effluent to agricultural fields with careful consideration of design and operational issues. Primary advantages are that exposure of the effluent to volatilization, leaching, runoff into streams, and humans can be reduced while the primary disadvantages are related to system cost and longevity, and the fixed location of the SDI system.

An engineering feasibility study (1998 to 2002, commercial beef feedlot in Gray County, Kansas) conducted by Kansas State University with beef feedlot effluent has indicated that driplines with discharge of 0.4 to 1 gal/hr-emitters can be used successfully with little clogging. However, the smaller emitter sizes normally used with high quality groundwater in the Central Great Plains may be risky for use with beef feedlot effluent. The discharge of the two smallest emitter sizes, 0.15 and 0.24 gal/hr-emitter decreased approximately 40% and 30%, respectively, during the four seasons, indicating considerable emitter clogging (Figure 15). The three driplines with the highest flow rate emitters (0.40, 0.60, and 0.92 gal/hr-emitters) have had approximately 7, 8, and 13% reductions in flow rate, respectively. Following an aggressive freshwater flushing, acid and chlorine injections in April of 2002, the flowrates of the lowest two emitter sizes (0.15 and 0.24 gal/hr-emitter) were restored to nearly 80 and 97% of their initial flowrates, respectively.

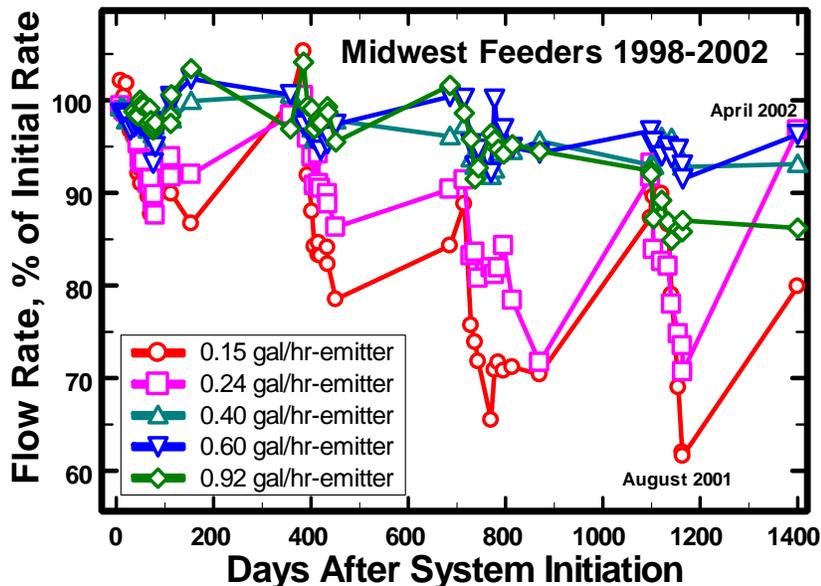


Figure 15. Decrease in emitter discharge during four seasons of operation of an SDI system with biological effluent at Midwest Feeders, Ingalls, Kansas, 1998 to 2002.

A second livestock effluent study using SDI was conducted in 2000 through 2001 at the KSU Northwest Research-Extension Center, Colby, Kansas (Lamm et al., 2006; Lamm et al., 2007). The overall objective of this project was to compare the environmental, cropping, and irrigation system impacts of swine effluent applied with SDI or simulated LEPA sprinkler irrigation. SDI tended to have greater corn yields (Table 4) and better nutrient utilization (Data not shown) than low-energy precision application (LEPA) center pivot sprinklers.

Table 4. Yield component and water use data for corn in a swine effluent study, KSU Northwest Research-Extension Center, Colby Kansas, 2000 to 2001.

Irrigation System & Effluent Amount	Irrigation inches	Applied N ¹ lb/a	Grain yield bu/a	Water use ² inches	WUE ³ lb/acre-in
Year 2000					
SDI, Control	19.5	245	253	30.1	472
SDI, 1.0 inch effluent	19.5	229	252	30.4	464
SDI, 2.0 inches effluent	19.5	388	260	29.5	492
LEPA, 0.6 inches effluent	20.0	155	237	33.2	399
LEPA, 1.0 inches effluent	20.0	229	250	32.8	427
LEPA, 2.0 inches effluent	20.0	388	246	33.2	415
<i>LSD P=0.05</i>			NS	1.5	51
Year 2001					
SDI, Control	18.0	244	262	28.5	517
SDI, 1.0 inch effluent	18.0	209	270	27.4	553
SDI, 2.0 inches effluent	18.0	356	267	28.1	531
LEPA, 0.6 inches effluent	18.0	143	214	28.2	427
LEPA, 1.0 inches effluent	18.0	209	251	28.7	493
LEPA, 2.0 inches effluent	18.0	356	237	30.3	439
<i>LSD P=0.05</i>			22	NS	53
Mean of both years 2000 - 2001					
SDI, Control			258	29.3	495
SDI, 1.0 inch effluent			261	28.9	509
SDI, 2.0 inches effluent			263	28.8	512
LEPA, 0.6 inches effluent			225	30.7	413
LEPA, 1.0 inches effluent			251	30.8	460
LEPA, 2.0 inches effluent			241	31.7	427
<i>LSD P=0.05</i>			20	1.0	35

1 Total applied N-P-K from the three sources: starter treatment at planting (30 lbs N/acre + 45 lbs/a P205), wastewater application, and the amount naturally occurring in the irrigation water (0.75 lbs/acre-inch).

2 Total of seasonal change of soil water storage in the 8 ft profile plus irrigation and precipitation.

3 Water use efficiency (WUE) is defined as grain yield in lb/acre divided by total water use in inches.

ECONOMICS OF SDI

SDI has not been typically used for row crop production in the Central Great Plains. 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 acres (Figure 15). Small and irregular shape fields may be ideal candidates for SDI.

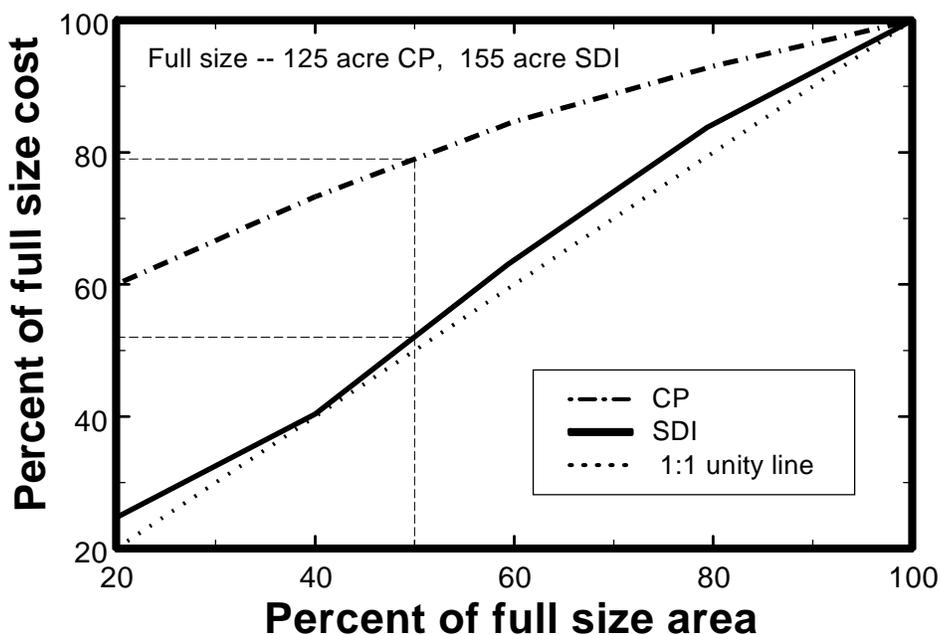


Figure 15. Center pivot sprinkler (CP) and SDI system costs as related to field size. (after O'Brien et al., 1997)

Economic comparisons of CP and SDI systems are sensitive to the underlying assumptions used in the analysis (Lamm et. al., 2003). The results show that these comparisons are very sensitive to size of CP irrigation system, shape of field (full vs. partial circle CP system), life of SDI system, SDI system cost with advantages favoring larger CP systems and cheaper, longer life SDI systems. 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.oznet.ksu.edu/sdi/Software/SDISoftware.htm>

SYSTEM LIFE OF SDI

SDI system life must be at least 10-15 years to reasonably approach economic competitiveness with full sized center pivot sprinkler systems that typically last 20-25 years. 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. The system performance of the K-State SDI research plots has been monitored annually since 1989 with few signs of significant degradation (Figure 16). The 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). It is possible that the depth of the SDI system (16-18 inches) has reduced the chemical clogging hazards due to less temperature fluctuations and negligible evaporation directly from the dripline.

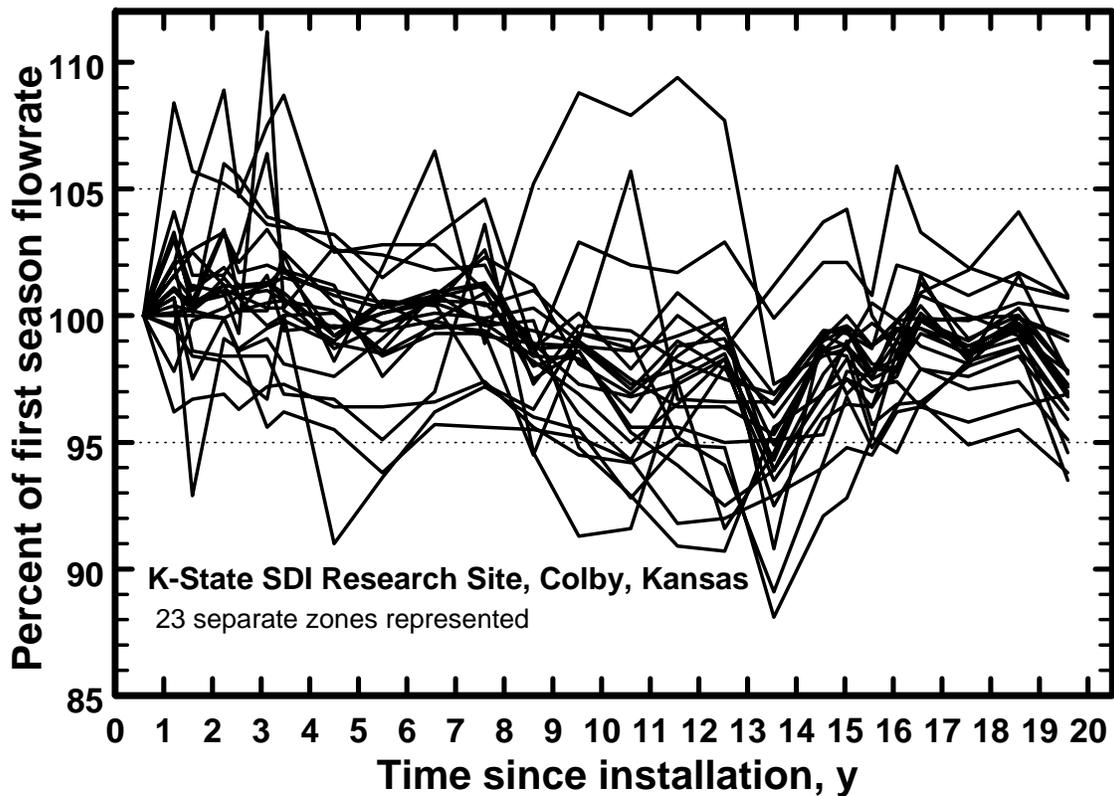


Figure 12. Stability in zone flowrates from the initial first season as related to time for an SDI system installed at Kansas State University, Colby, Kansas, 1989-2007.

CONCLUDING STATEMENTS

Research progress has been steady since 1989. Much of K-State's SDI research is summarized at K-State's SDI Website, SDI in the Great Plains at <http://www.oznet.ksu.edu/sdi/>. Irrigators are watching the results of K-State closely. Some irrigators have begun to experiment with the technology and most appear happy with the results they are obtaining. It is K-State's hope that by developing a knowledge base in advance of the irrigator adoption phase that the misapplication of SDI technology and overall system failures can be minimized. Economics of the typical Great Plains row crops will not allow frequent system replacement or major renovations. Irrigators must carefully monitor and maintain the SDI system to assure a long system life. Continued or new areas of research are concentrating on optimizing allocations of water, seed, and nutrients, utilizing livestock wastewater, developing information about SDI use with other crops besides corn, soil water redistribution, water and chemical application uniformity, and finally system design characteristics and economics with a view towards system longevity.

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REFERENCES

- Caldwell, D. S., W. E. Spurgeon and H. L. Manges. 1994. Frequency of irrigation for subsurface drip-irrigated corn. *Trans. ASAE* 37(4):1099-1103.
- Camp, C. R., F. R. Lamm, R. G. Evans and C. J. Phene. 2000. Subsurface drip irrigation – Past, present and future. In *Proc. Fourth Decennial Nat'l Irrigation Symp.*, Nov. 14-16, 2000, Phoenix, AZ. Sponsored by ASAE. pp. 363-372. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2000/K-StateRep/campis.htm>
- Camp, C.R. 1998. Subsurface drip irrigation: A review. *Trans. ASAE* 41(5):1353-1367. Also available at http://www.florence.ars.usda.gov/publist/sw_3247_.pdf
- Darusman, A. H. Khan, L. R. Stone, and F. R. Lamm. 1997. Water flux below the root zone vs. drip-line spacing in drip-irrigated corn. *Soil Sci Soc. Am. J.* 61:1755-1760. Also available at <http://www.oznet.ksu.edu/sdi/Reports/1997/WaterFluxSpacing.pdf>
- Hengeller, J. 1995. Use of drip irrigation on alfalfa. In: *Proc. Central Plains Irrigation Shortcourse*, Feb. 7-8, 1995, Garden City, Kansas. Kansas State Univ. Extension Biol. and Agric. Engr. Dept., Manhattan, KS. pp. 160-167.

- Howell, T. A. 2001. Enhancing water use efficiency in irrigated agriculture. *Agron J.* 93(2):281-289. Also available at <http://www.cprl.ars.usda.gov/wmru/pdfs/howell2001.pdf>
- Howell, T. A., A. D. Schneider, and S. R. Evett. 1997. Subsurface and surface microirrigation of corn—Southern High Plains. *Trans. ASAE* 40(3):635-641.
- Kincaid, D. E. and D. F. Heerman. 1974. Scheduling Irrigation Using a Programmable Calculator. USDA Pub. ARS-NC-12, February, 1974. 55 pp.
- Lamm, F. R. 2004. Comparison of SDI and Simulated LEPA Sprinkler Irrigation for Corn. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., November 14-16, 2004, Tampa, FL. Available from Irrigation Assn., Falls Church VA. IA Paper No. IA04-1098. pp 475-485. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2004/LS100104.pdf>
- Lamm, F. R. 2005. SDI for conserving water in corn production. In Proc. ASCE-EWRI Water Congress, May 15-19, 2005, Anchorage, AK. 12 pp. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2005/ASC000557.pdf>
- Lamm, F. R. and R. M. Aiken. 2005. Effect of irrigation frequency for limited subsurface drip irrigation of corn. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., November 6-8, 2005, Phoenix, AZ. Available from Irrigation Assn., Falls Church VA. IA Paper No. IA05-1264. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2005/SDIFreqIA.pdf>
- Lamm, F. R. and T. P. Trooien. 2001. Irrigation capacity and plant population effects on corn production using SDI. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., Nov. 4-6, 2001, San Antonio, TX. Pages 73-80. Available from Irrigation Assn., Falls Church VA. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2001/icpp.pdf>
- Lamm, F. R. and T. P. Trooien. 2005. Dripline depth effects on corn production when crop establishment is nonlimiting. *Appl. Engr in Agric.* 21(5):835-840. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2005/DepthSDI.pdf>
- Lamm, F. R., A. J. Schlegel, and G. A. Clark. 2004. Development of a Best Management Practice for Nitrogen Fertigation of Corn Using SDI. *Appl. Engr in Agric.* 20(2):211-220. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2004/SDIFert04.pdf>
- Lamm, F. R., T. P. Trooien, and A. J. Schlegel. 2006. Applying swine effluent with SDI and LEPA sprinkler irrigation. Proc. 27th Annual Int'l. Irrig. Assoc. Tech. Conf., San Antonio, Texas, Nov. 5-7, 2008. Available from Irrig. Assoc., Falls Church, VA. Paper No. IA06-1517. pp. 513-526. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2006/LammIA.pdf>
- Lamm, F. R. T. P. Trooien, and A. J. Schlegel. 2007. Application and utilization of livestock effluent through SDI systems. In: Int'l Symposium on Air Quality and Waste Management for Agriculture, Broomfield, CO. Sept. 15-19, 2007. ASABE. 8 pp. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2007/AppUtlSDIWW.pdf>
- Lamm, F. R., D. M. O'Brien, D. H. Rogers, and T. J. Dumler. 2003. Center pivot sprinkler and SDI economic comparisons. In Proc. of the Central Plains Irrigation Conf., February 4-5, 2003, Colby Kansas. Proceedings available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 199-211. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2003/CPSDI03.pdf>

- Lamm, F. R., L. R. Stone, H. L. Manges, and D. M. O'Brien. 1997a. Optimum lateral spacing for subsurface drip-irrigated corn. Trans. ASAE, 40(4):1021-1027. Also available at <http://www.oznet.ksu.edu/sdi/Reports/1997/OptSpacing.pdf>
- Lamm, F. R. T. P. Trooien, H. L. Manges, and H. D. Sunderman. 2001. Nitrogen fertilization for subsurface drip-irrigated corn. Trans ASAE 44(3):533-542. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2001/dfert.pdf>
- Lamm, F. R., H. L. Manges, D. H. Rogers, W. E. Spurgeon, and M. H. Farmer. 1990. Design and installation of a drip irrigation system for research purposes. Presented at the international winter meeting of the ASAE, Chicago, IL, Dec. 18-21, 1990. ASAE Paper No. 902530, ASAE, St. Joseph, MI. 21 pp. Also available at <http://www.oznet.ksu.edu/sdi/Reports/1990/Design&Instal.pdf>
- 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., T. P. Trooien, G. A. Clark, L. R. Stone, M. Alam, D. H. Rogers, and A. J. Schlegel. 2002. Using beef lagoon wastewater with SDI. In Proc. Irrig. Assoc. Int'l. Irrigation Technical Conf., October 24-26, 2002, New Orleans, LA. Available from Irrig. Assoc., Falls Church, VA. 8 pp. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2002/MWIAPaper.pdf>
- Manges, H. L., W. E. Spurgeon, Z. M. Huang, and D. J. Tomsicek. 1995. Subsurface dripline spacing and plant population for corn production. In Proceedings of the Fifth Int'l Microirrigation Congress, Orlando, Florida, April 2-6, 1995. pp 388-394. ASAE, St. Joseph, MI, USA. 978 pp.
- Nakayama, F. S. and D. A. Bucks. 1986. Trickle irrigation for crop production. Edited by F. S. Nakayama, and D. A. Bucks. Elsevier Publications, Netherlands. 383 pp.
- 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. Applied Engr in Ag., 14(4):391-398. Also available at <http://www.oznet.ksu.edu/sdi/Reports/1998/EconSDICP.pdf>
- Powell, N. L. and F. S. Wright. 1993. Grain yield of subsurface microirrigated corn as affected by irrigation line spacing. Agron. J. 85:1164-1170.
- Spurgeon, W. E., H. L. Manges, and T. P. Makens. 1991. Drip line spacing and plant population for corn. Presented at the int'l winter meeting of the ASAE. ASAE Paper No. 912592, ASAE, St. Joseph, MI. 12 pp.
- Trooien, T. P., F. R. Lamm, L. R. Stone, M. Alam, D. H. Rogers, G. A. Clark, and A. J. Schlegel. 2000. Subsurface drip irrigation using livestock wastewater: Dripline flow rates. Appl. Engr. in Agric. 16(5):505-508. Also available at <http://www.oznet.ksu.edu/sdi/Reports/2000/SDILWaste.pdf>