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# Twenty Years of Progress with SDI in Kansas.

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**Abstract.** *This paper will summarize research efforts with subsurface drip irrigation in Kansas that have occurred during the period 1989 through 2009. Special emphasis will be made on brief summaries of the different types of research that have been conducted including water and nutrient management for the principal crops of the region, SDI design parameters and system longevity and economics. Annual system performance evaluations have shown that dripline flowrates are within 5% of their original values. Economic analysis shows that systems with such longevity can be cost competitive even for the lower-valued commodity crops grown in the region.*

**Keywords.** microirrigation, irrigation design, irrigation management, drip irrigation, Great Plains.

## Introduction and 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 1.2 ha 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 1.2 ha 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 5.3 ha and 121 different research plots. This same funding provided for a 4.0 ha SDI research site at Holcomb, Kansas administered by the SWREC. By June of 1990, K-State Research and Extension had established 10 ha 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 2.2 ha 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. Three research block areas originally used in a 1989 dripline spacing study have been refurbished with new 1.5 m spaced driplines to examine alfalfa production and emitter flowrate effects on soil water redistribution. The NWREC SDI research site comprising 7.8 ha 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 productivity, 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 480 mm of plant available soil water in the 2.4 m 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 430 mm. 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 0.40 to 0.45 m with a 1.5-m spacing between dripline laterals. Emitter spacing was 0.3 m and the dripline flowrate was 3.1 L/Min-100 m. The corn was planted so each dripline lateral is centered between two corn rows (Fig. 1).

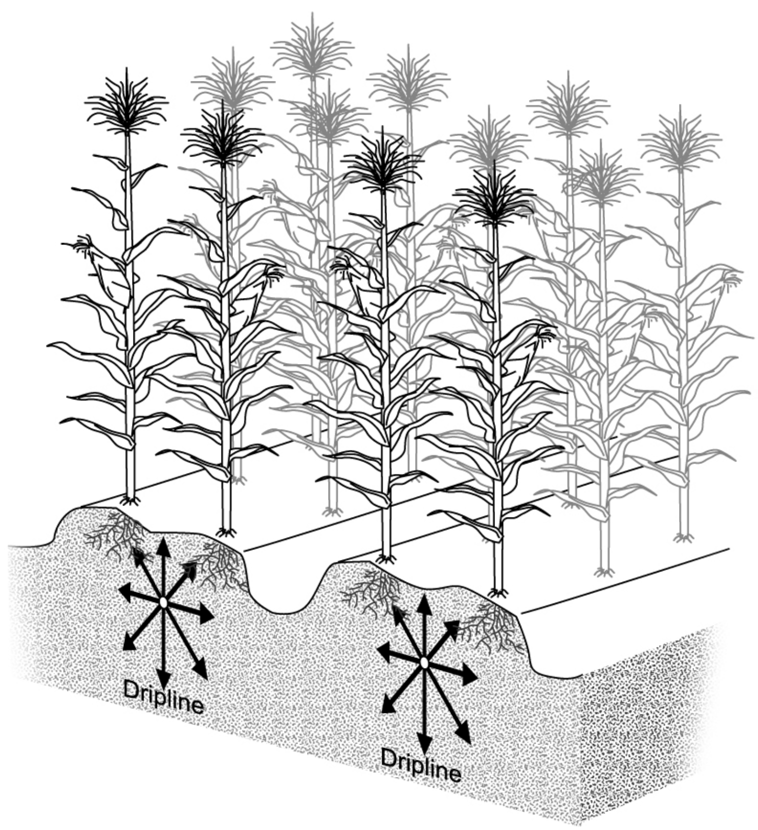


Figure 1. Physical arrangement of the subsurface dripline in relation to the corn rows.

A modified ridge-till system was used in corn production with two corn rows, 0.75 m apart, grown on a 1.5 m 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 Heermann (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 0.3 m increments to a depth of 2.4 m.

## Results and Discussion

### *Water Requirement and Irrigation Capacity Studies*

Research studies were conducted at Colby 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 0.048 Mg/ha of grain for each mm of water used above a threshold of 328 mm (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).

SDI technology can make significant improvements in water productivity 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.

In a later study (1996-2001), corn was grown under 6 different SDI capacities (0, 2.5, 3.3, 4.3, 5.1 and 6.4 mm/day) and 4 different plant densities (85,300, 75,900, 66,200, and 55,600 plants/ha). Daily SDI application of even small amounts of water (2.5 mm) doubled corn grain yields from 5.8 to 12.7 Mg/ha in extremely dry 2000 and 2001. Results suggested an irrigation capacity of 4.3 mm/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 mass 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 mass and ultimately, corn grain yield. Increasing plant density from 55,600 to 85,300 plants/ha 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.

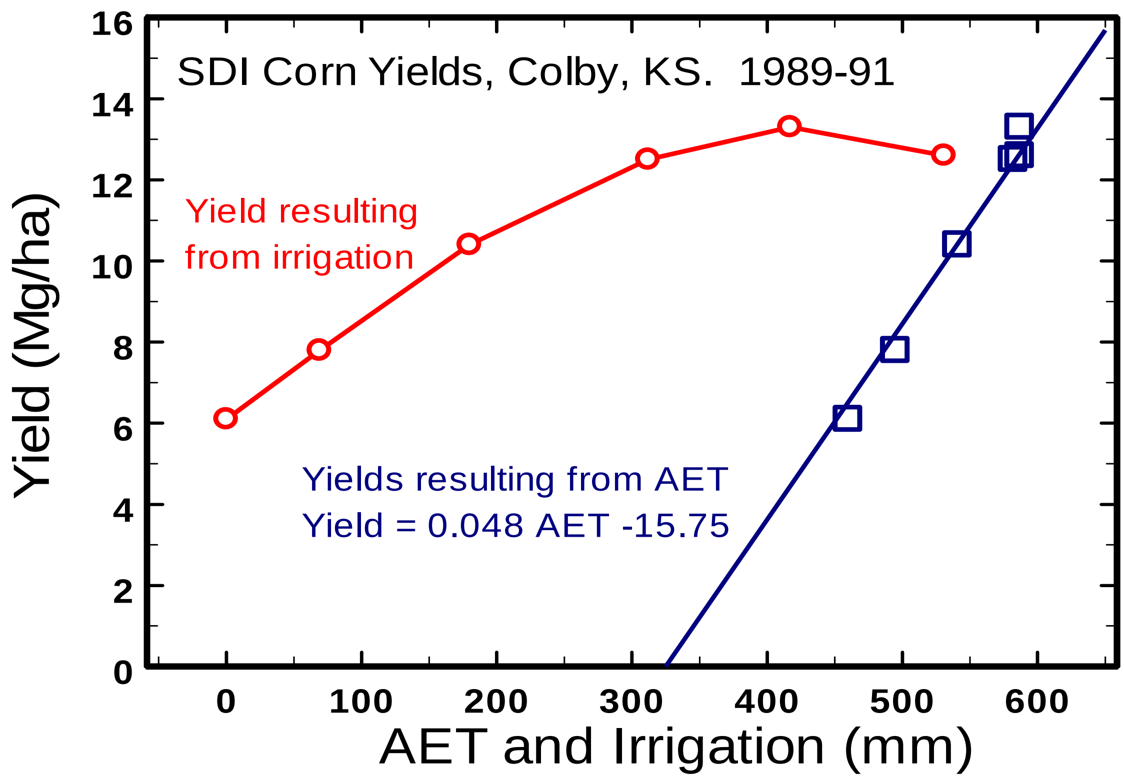


Figure 2. Corn yield as related to irrigation and calculated evapotranspiration (AET) in a SDI water requirement study, Colby, Kansas, 1989-1991.

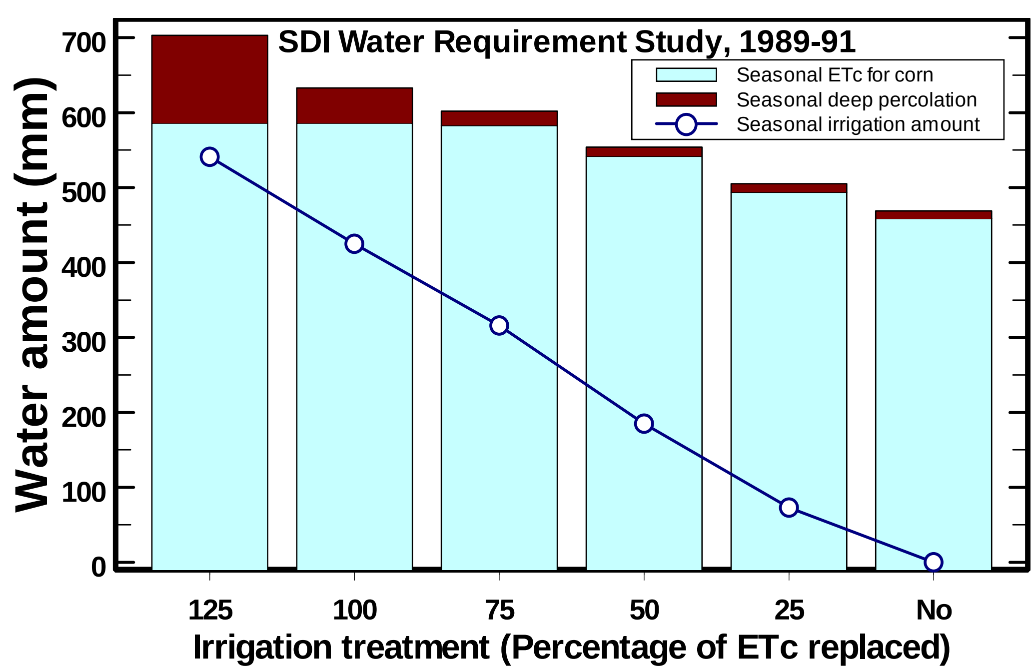


Figure 3. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI water requirement study, Colby, Kansas, 1989-1991.

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.

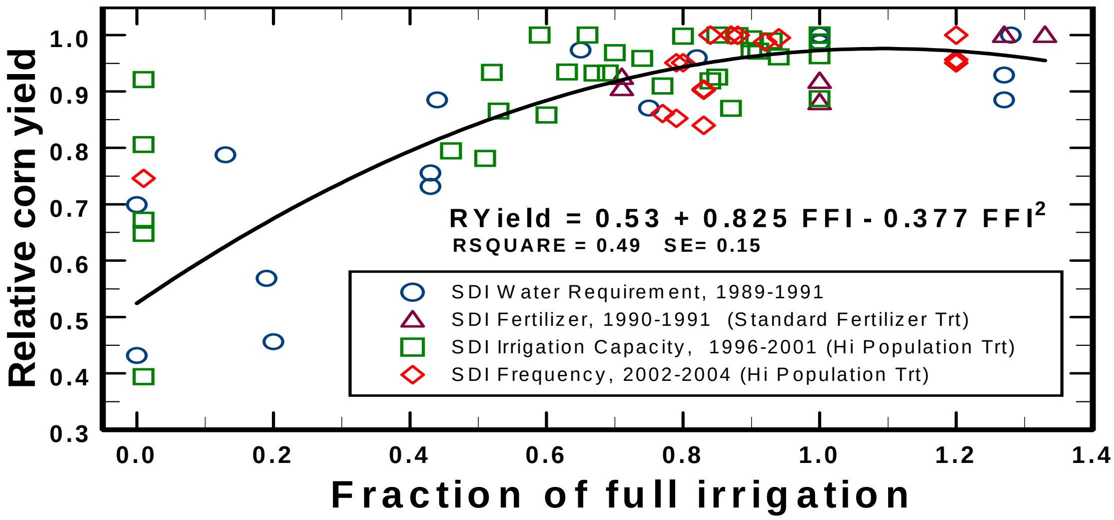


Figure 4. Relative corn grain yield for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas.

An examination of water productivity (WP) for the same four studies indicates that water productivity plateaus for levels of full irrigation ranging from 61% to 109% with less than 5% variation in WP (Figure 5). The highest WP 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 greatest WP (82% of full irrigation) also occurred in the plateau region of greatest 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.

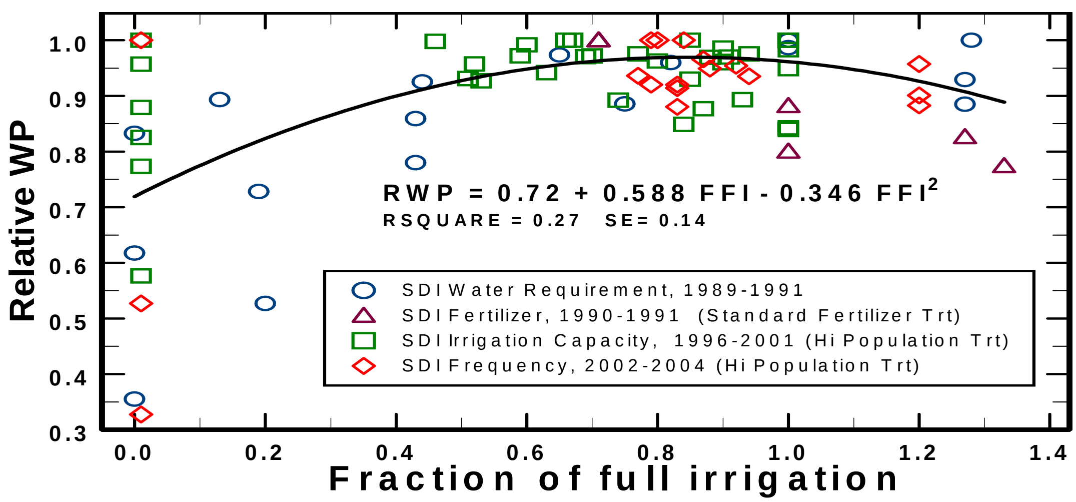


Figure 5. Relative water use productivity (WP) of corn for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas.

### *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 (11.9 to 12.5 Mg/ha) 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 <u>fully-irrigated corn on the deep silt loam soils</u> 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 3.8 mm/day, 11.4 mm/3 days, 19.1 mm/5 days and 26.7 mm/7days which are equivalent but limited capacities. As a point of reference, a 6.4 mm/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 7.6 mm/day. The non-irrigated treatment only received 2.5 mm 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.)

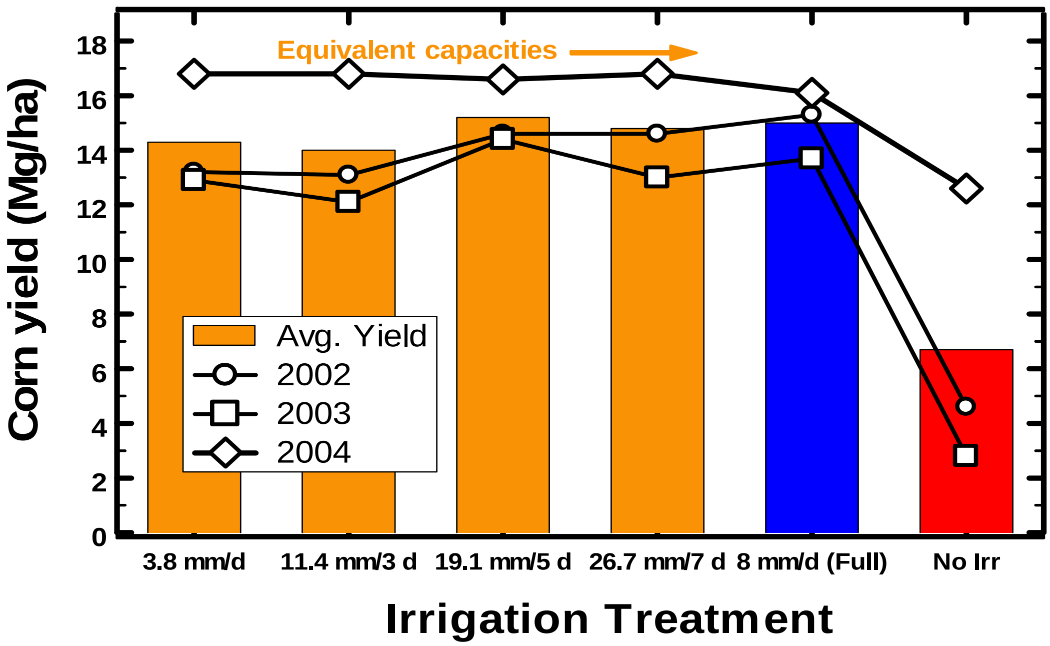


Figure 6. Corn grain yields as affected by irrigation treatment in a study examining SDI frequency under limited irrigation, Colby, Kansas, 2002 to 2004.

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 (19.1 mm/5 days and 26.7 mm/7 days) resulted in yields approximately 0.6 to 1.2 Mg/ha 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 0.6 to 0.9 m tall), 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.

### *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 0.40 to 0.45 m) 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 (0.75, 1.5, 2.3 and 3.0 m) with corn planted in 0.75-m spaced rows perpendicular to the dripline lateral. The other study at the KSU Northwest Research-Extension Center at Colby, Kansas evaluated 3 spacings (1.5, 2.3, and 3.0 m) with corn planted in 0.75-m spaced rows parallel to the driplines. Average yields for corresponding treatments were similar between sites even though row orientation was different (Table 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 1.5-m trt. | Corn yield (Mg/ha) Garden City 1989-91 | Corn yield (Mg/ha) Colby 1990-91 |
|---|---|---|---|---|
| 0.75 m | Full irrigation | 2.00 | 14.4 | ---- |
| 1.5 m | Full irrigation | 1.00 | 13.7 | 13.6 |
| 2.3 m | Full Irrigation | 0.67 | 13.1 | 12.8 |
| 2.3 m | Reduced irrigation (67%) | 0.37 | ---- | 10.9 |
| 3.0 m | Full irrigation | 0.50 | 12.2 | 12.2 |
| 3.0 m | Reduced irrigation (50%) | 0.50 | ---- | 9.4 |

The highest average yield was obtained by the 0.75-m 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 1.5-m dripline spacing. The results, when incorporated into an economic model, showed an advantage for the wider dripline spacings (2.3 and 3.0 m) in some higher rainfall years. However, the standard 1.5-m dripline spacing was best when averaged over all years for both sites. When subsurface driplines are centered between alternate pairs of 0.75-m spaced corn rows, each corn row is within 0.38 m of the nearest dripline (Figure 1.)

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 1.5 m and 2.3 m 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 2.3 m dripline spacing were reduced by 1.6 Mg/ha (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 productivity (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).

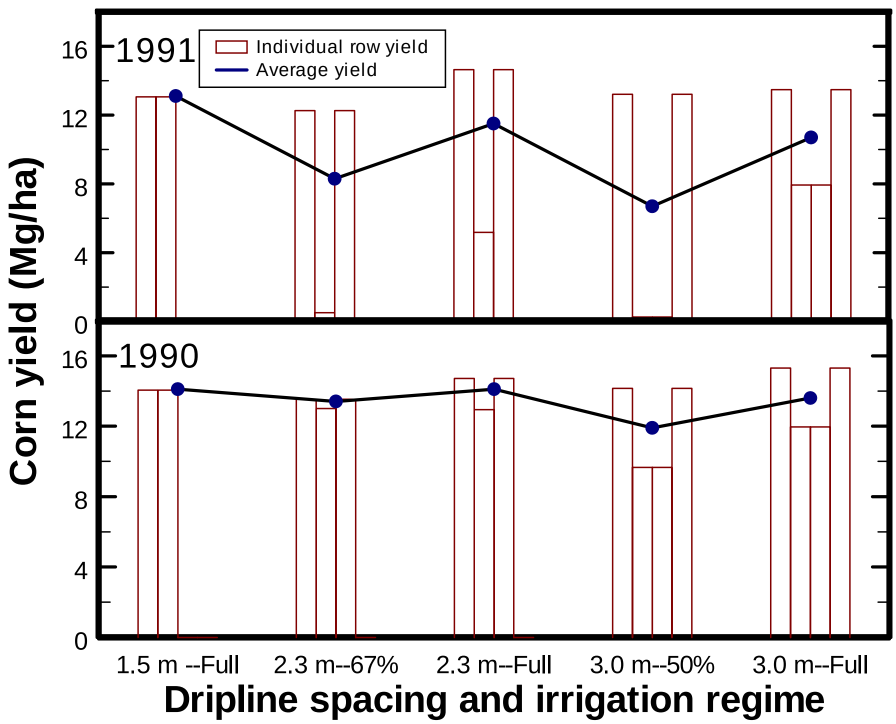


Figure 7. Corn yield distribution as affected by dripline spacing and irrigation regime, Colby, Kansas, 1990-1991. Note: Individual row yields are mirrored about a centerline half way between two adjacent driplines for display purposes.

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 1.5 m apart are most economical for corn grown in rows spaced 0.75 m 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.

### *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 (0.2, 0.3, 0.4, 0.5 and 0.6 m) 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.).

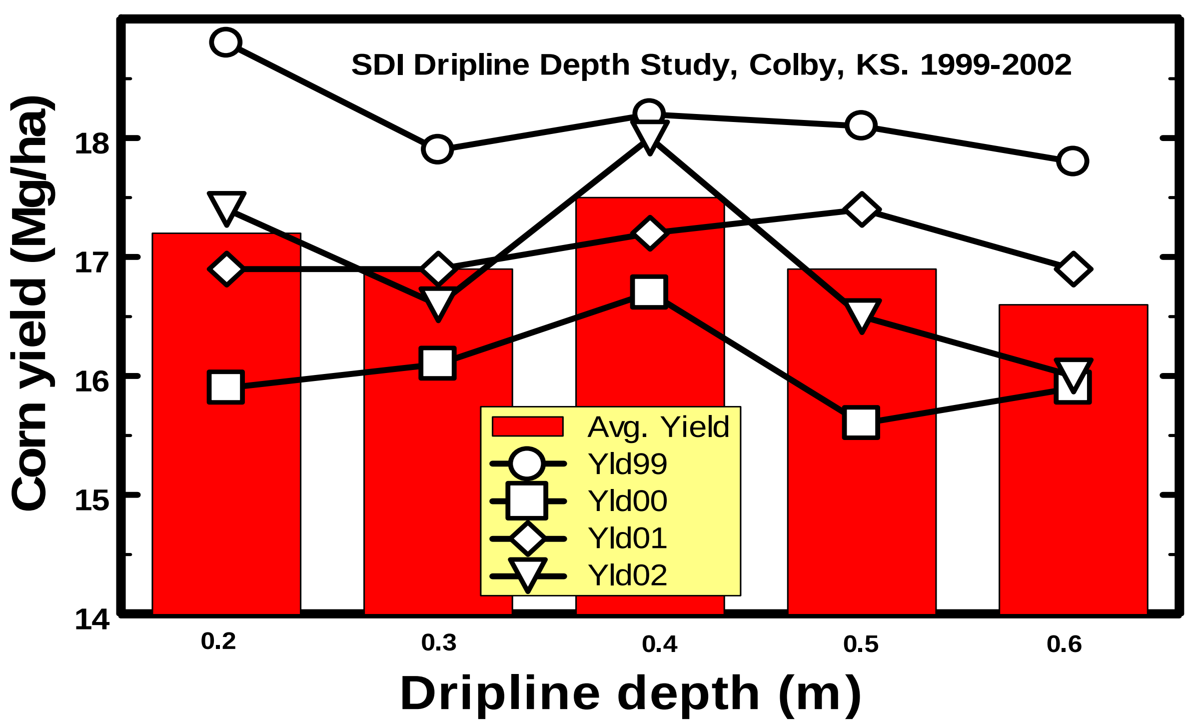


Figure 8. Corn grain yields as affected by dripline depth, 1999-2002, Colby, Kansas.

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 0.2 and 0.3 m 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 0.2 and 0.3 m 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 (1.5-m bed) as shown in Figure 1.  Cultivation for weeds in early summer has been routinely practiced and there were no instances of tillage tool damage to the shallow 0.2-m depth driplines.

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 m | Soybean yield Mg/ha | | | Grain Sorghum Mg/ha | | | Sunflower Mg/ha | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2007 | Mean | 2006 | 2008 | Mean | 2004 | 2007 | Mean |
| 0.2 | 5.4 | 5.1 | 5.2 | 10.4 | 9.6 | 10.0 | 3.5 | 3.9 | 3.7 |
| 0.3 | 5.5 | 4.8 | 5.1 | 10.0 | 9.7 | 9.9 | 3.2 | 3.7 | 3.4 |
| 0.4 | 5.4 | 5.1 | 5.2 | 10.4 | 10.6 | 10.5 | 3.3 | 4.0 | 3.7 |
| 0.5 | 5.4 | 5.0 | 5.2 | 10.0 | 9.9 | 9.9 | 3.4 | 3.9 | 3.6 |
| 0.6 | 5.2 | 5.2 | 5.2 | 9.7 | 8.9 | 9.3 | 3.3 | 3.9 | 3.6 |
| Mean | 5.4 | 5.0 | 5.2 | 10.1 | 9.7 | 9.9 | 3.3 | 3.9 | 3.6 |
| *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 14.1 to 15.7 Mg/ha 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 0.3 m 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 0.40 to 0.45 m 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.*

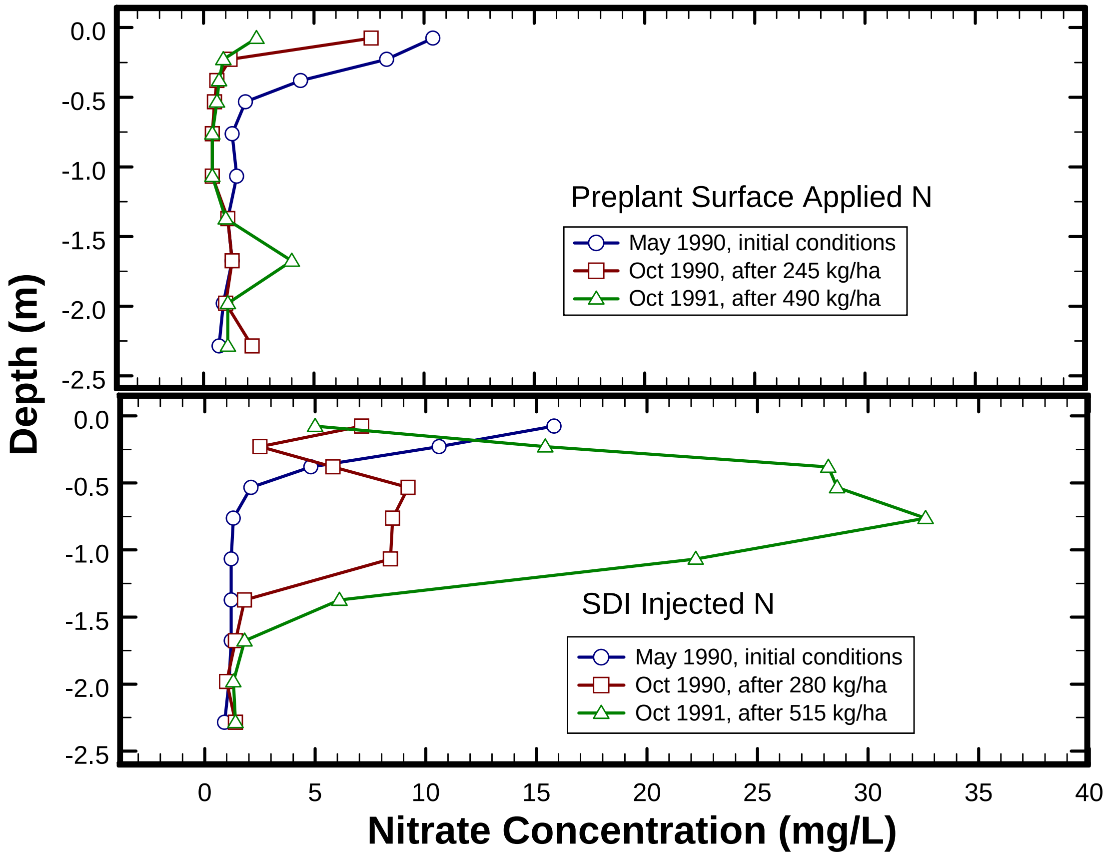


Figure 9. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of AET).

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 productivity (WP) were utilized as criteria for evaluating six different nitrogen fertigation rates, 0, 90, 135, 180, 225, and 270 kg/ha. The final BMP was a nitrogen fertigation level of 180 kg/ha with other non-fertigation applications bringing the total applied nitrogen to approximately 215 kg/ha (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 WP all plateaued at the same level of total applied nitrogen which corresponded to the 180 kg/ha nitrogen fertigation rate (Figure 10). Average yields for the 180 kg/ha nitrogen fertigation rate was 13.4 Mg/ha. Corn yield to ANU ratio for the 180 kg/ha 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.

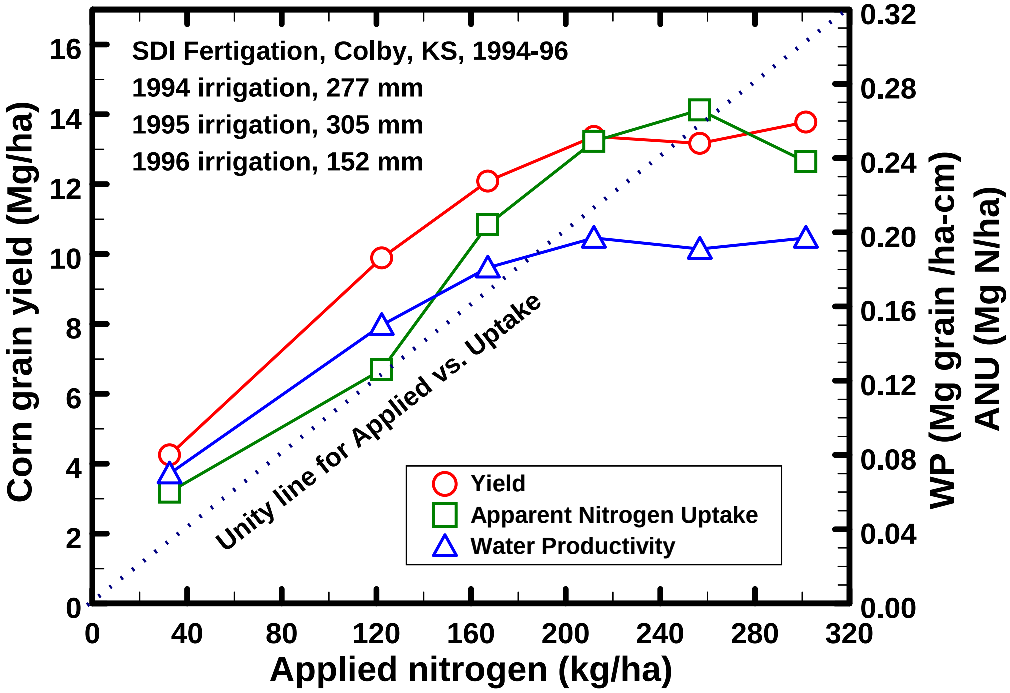


Figure 10. Average (1994-96) corn yield, apparent nitrogen uptake in the above-ground biomass, and water productivity as related to the total applied nitrogen (preseason amount, starter fertilizer, fertigation, and the naturally occurring N in the irrigation water). Total applied nitrogen exceeded fertigation applied nitrogen by 35 kg/ha.

### *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 (14.8 and 14.6 Mg/ha for LEPA and SDI, respectively) across all comparable irrigation capacities (Figure 11). However, LEPA had higher grain yields for 4 extreme drought years (approximately 0.9 Mg/ha) and SDI had higher yields in 3 normal to wetter years (approximately 0.9 mg/ha).

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 mass at harvest as compared to LEPA (347 vs. 332 mg/kernel 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 mass) between irrigation systems as climatic conditions vary.

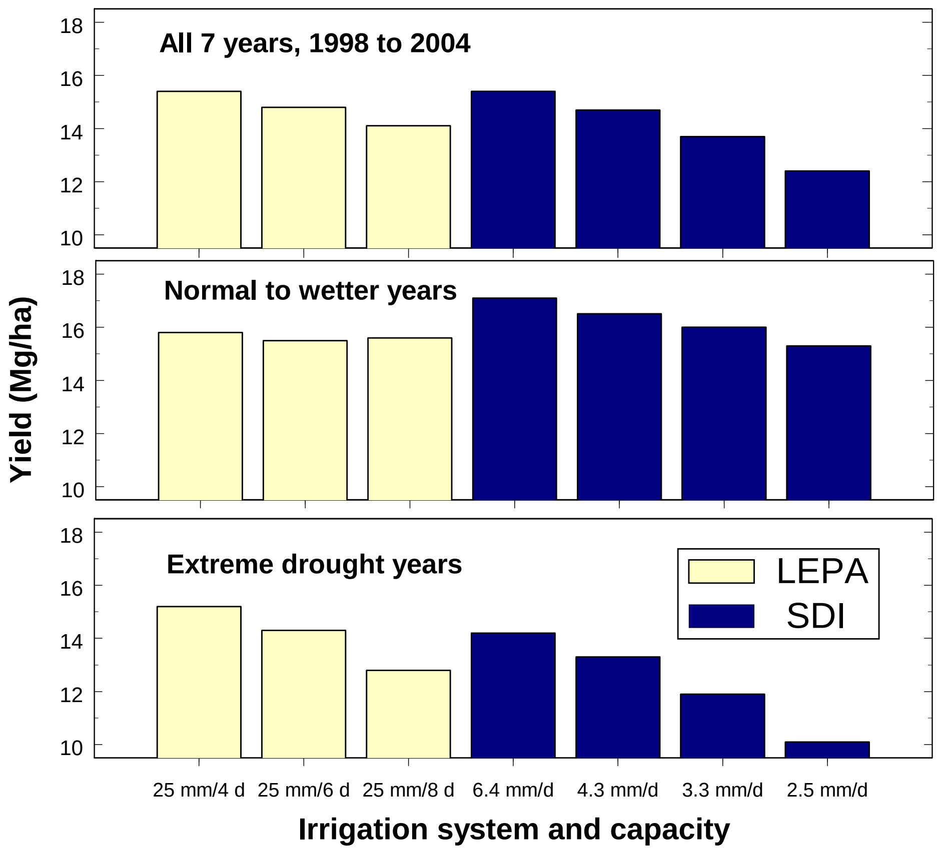


Figure 11. Variation in corn yields across years and weather conditions as affected by irrigation system type and capacity, Colby Kansas.

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 a trend 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.

Table 3. Crop yield of soybean, grain sorghum and sunflower as affected by irrigation method and irrigation treatment, KSU Northwest Research-Extension Center, Colby Kansas, 2004-2008.

| Irrigation method | Irrigation Treatment | Soybean yield Mg/ha | Grain Sorghum Mg/ha | | | Sunflower yield Mg/ha | | |
|---|---|---|---|---|---|---|---|---|
| | | 2005 | 2006 | 2008 | Mean | 2004 | 2007 | Mean |
| SDI | 100% ET | 4.9 | 10.6 | 9.7 b* | 10.8 | 3.5 | 3.2 | 3.3 |
| | 80% ET | 4.7 | 11.0 | 9.0 b | 10.0 | 3.9 | 3.7 | 3.8 |
| | 60% ET | 4.7 | 9.7 | 8.2 c | 9.0 | 3.8 | 3.7 | 3.7 |
| | *Mean SDI* | 4.8 | 10.4 | 9.0 | 9.7 | 3.7 | 3.5 | 3.6 |
| LEPA | 100% ET | 5.0 | 11.2 | 10.7 a | 11.7 | 4.1 | 3.8 | 3.9 |
| | 80% ET | 4.8 | 11.3 | 10.6 a | 11.8 | 3.7 | 3.3 | 3.5 |
| | 60% ET | 4.2 | 11.0 | 10.0 a | 11.2 | 3.5 | 3.1 | 3.3 |
| | *Mean LEPA* | 4.6 | 11.2 | 10.5 | 11.6 | 3.8 | 3.4 | 3.6 |
| | *LSD 0.05* | NS | NS | 0.8 | - | NS | NS | - |

** Values followed by the same lower case letter are not significantly different at the P=0.05 level.*

### *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 an 1.5-m dripline spacing and a 0.5-m 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 (trts. 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% 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. This helped compensate for the yield reduction.

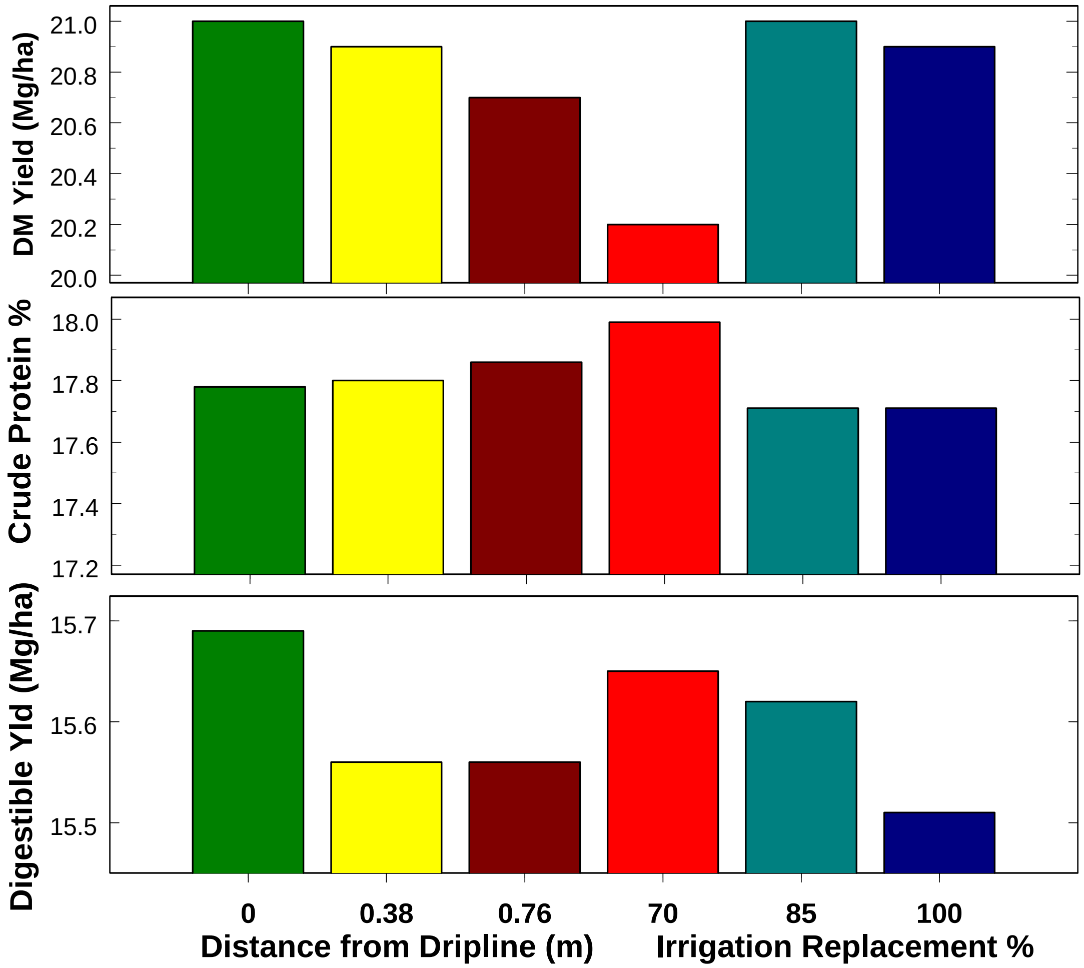


Figure 12. Dry matter yield, percentage crude protein and digestible dry matter yield as affected by perpendicular horizontal distance from dripline and irrigation level, KSU Northwest Research-Extension Center, Colby Kansas. Data is averaged over the years, 2005 through 2007.

Additional data collected from a field demonstration study conducted by K-State indicates that a 1-m spacing of dripline for alfalfa may recover the additional investment cost. This is more so for the traditional alfalfa growing areas in Kansas which tend to have comparatively light textured soils (Alam et al., 2009).

### *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 1.5 to 3.5 L/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, 0.6 and 0.9 L/hr-emitter decreased approximately 40% and 30%, respectively, during the four seasons, indicating considerable emitter clogging (Figure 13). The three driplines with the highest flow rate emitters (1.5, 2.3, and 3.5 L/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 (0.6 and 0.9 L/hr-emitter) were restored to nearly 80 and 97% of their initial flowrates, respectively.

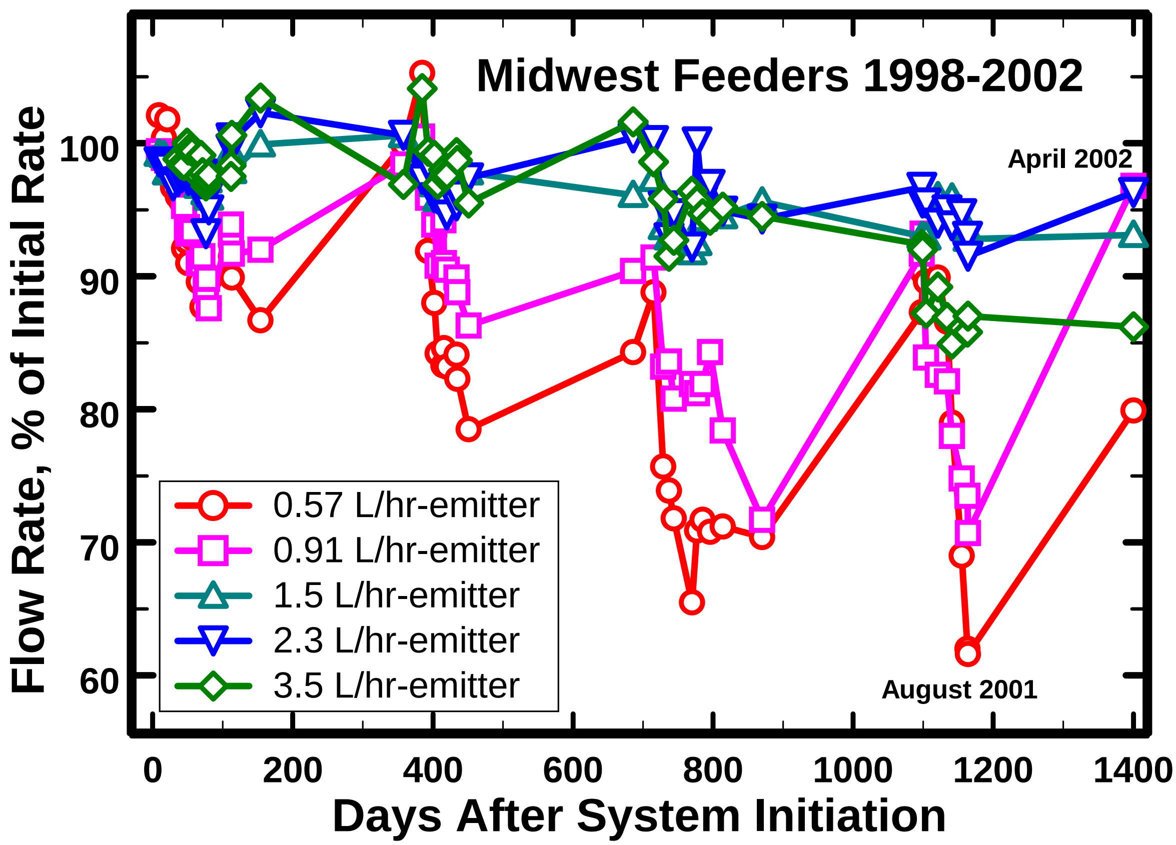


Figure 13. Decrease in emitter discharge during four seasons of operation of an SDI system with biological effluent at Midwest Feeders, Ingalls, Kansas, 1998 to 2002.

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 mm | Applied N[1] kg/ha | Grain yield Mg/ha | Water use[2] mm | WP[3] Mg/ha-mm |
|---|---|---|---|---|---|
| *Year 2000* | | | | | |
| SDI, Control | 495 | 275 | 15.9 | 765 | 0.0208 |
| SDI, 25 mm effluent | 495 | 257 | 15.8 | 772 | 0.0205 |
| SDI, 50 mm effluent | 495 | 435 | 16.3 | 749 | 0.0218 |
| LEPA, 15 mm effluent | 508 | 174 | 14.9 | 843 | 0.0176 |
| LEPA, 25 mm effluent | 508 | 257 | 15.7 | 833 | 0.0188 |
| LEPA, 50 mm effluent | 508 | 435 | 15.4 | 843 | 0.0183 |
| *LSD P=0.05* | | | NS | 38 | 0.0023 |
| *Year 2001* | | | | | |
| SDI, Control | 457 | 273 | 16.4 | 724 | 0.0227 |
| SDI, 25 mm effluent | 457 | 234 | 16.9 | 696 | 0.0244 |
| SDI, 50 mm effluent | 457 | 399 | 16.8 | 714 | 0.0235 |
| LEPA, 15 mm effluent | 457 | 160 | 13.4 | 716 | 0.0188 |
| LEPA, 25 mm effluent | 457 | 234 | 15.8 | 729 | 0.0216 |
| LEPA, 50 mm effluent | 457 | 399 | 14.9 | 770 | 0.0193 |
| *LSD P=0.05* | | | 1.4 | NS | 0.0002 |
| *Mean of both years 2000 - 2001* | | | | | |
| SDI, Control | | | 16.2 | 744 | 0.0218 |
| SDI, 25 mm effluent | | | 16.4 | 734 | 0.0223 |
| SDI, 50 mm effluent | | | 16.5 | 732 | 0.0226 |
| LEPA, 15 mm effluent | | | 14.1 | 780 | 0.0181 |
| LEPA, 25 mm effluent | | | 15.8 | 782 | 0.0201 |
| LEPA, 50 mm effluent | | | 15.1 | 805 | 0.0188 |
| *LSD P=0.05* | | | 1.3 | 25 | 0.0015 |

1 Total applied N-P-K from the 3 sources: starter treatment at planting (34 kg/ha N + 50 kg/ha P205), wastewater application, and the naturally occurring amount in the irrigation water (0.033 kg/ha-mm).

2 Total of seasonal change of soil water storage in the 2.4 m profile plus irrigation and precipitation.

3 Water productivity (WP) is defined as grain yield in Mg/ha divided by total water use in mm.

## *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 area (Figure 14). Small and irregular shape fields may be ideal candidates for SDI.

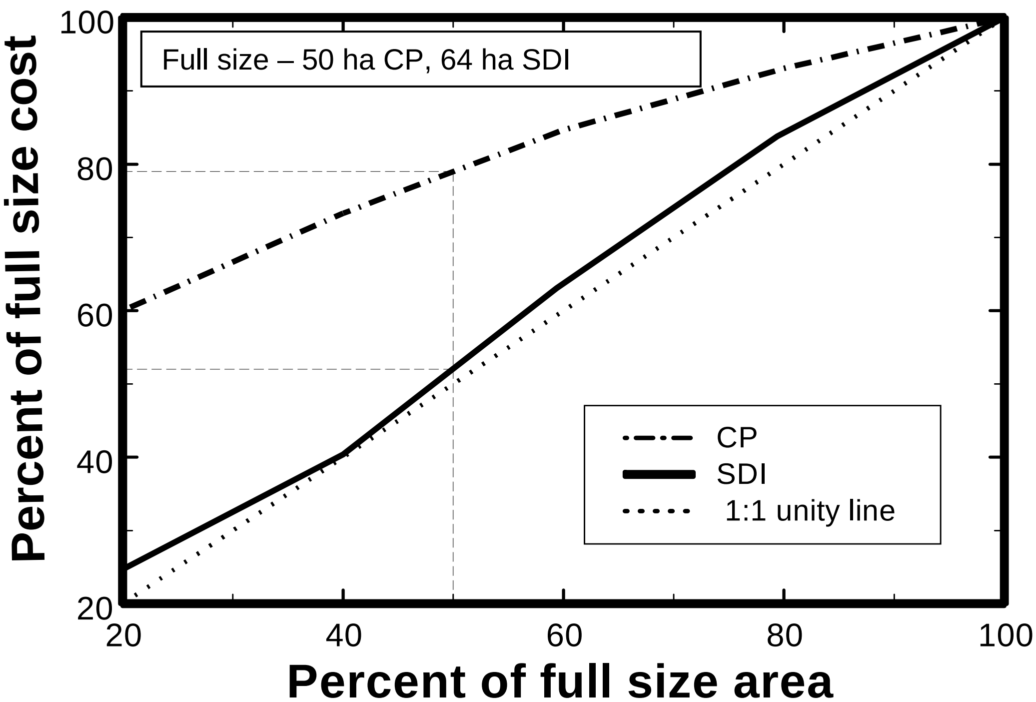


Figure 14. Center pivot sprinkler (CP) and SDI system costs as related to field size. (after O'Brien et al., 1997)

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.ksre.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 15). 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 (0.40 to 0.45 m) has reduced the chemical clogging hazards due to less temperature fluctuations and negligible evaporation directly from the dripline.

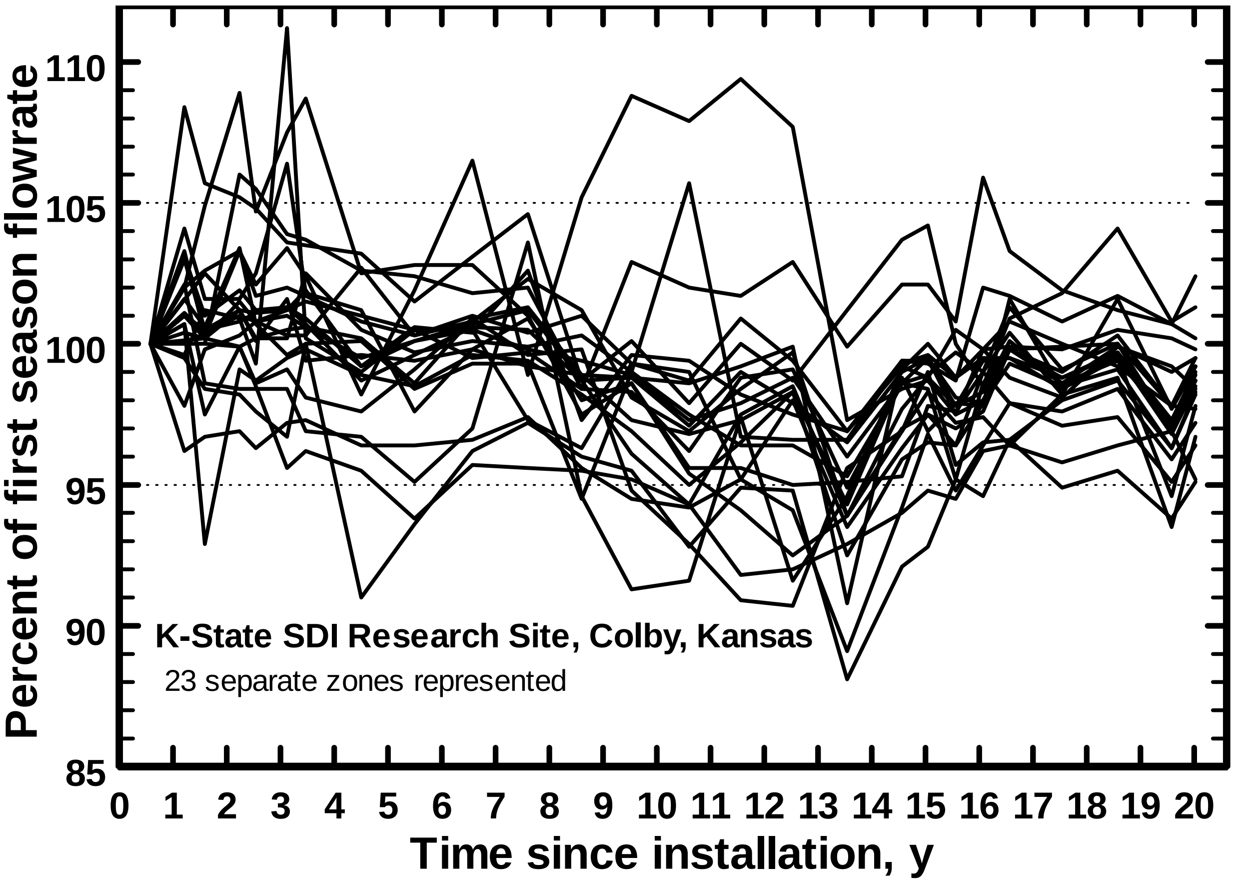


Figure 15. Stability in zone flowrates from the initial first season as related to time for an SDI system installed at Kansas State University, Colby, Kansas, 1989-2009.

## 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.ksre.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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[1] Mention of tradenames is for informational purposes only and does not constitute endorsement by the authors or by the institutions they serve.

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