

KSU RESEARCH FOR CORN PRODUCTION USING SDI: 14 YEARS OF PROGRESS

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BRIEF HISTORY

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, 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 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 the 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 14 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. The NWREC SDI research site comprising 18.5 acres and 167 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.

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. The following general 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 18 inches. Daily climatic data used in the studies were obtained from weather stations operated at each of the Centers.

The studies 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 (Figure 1).

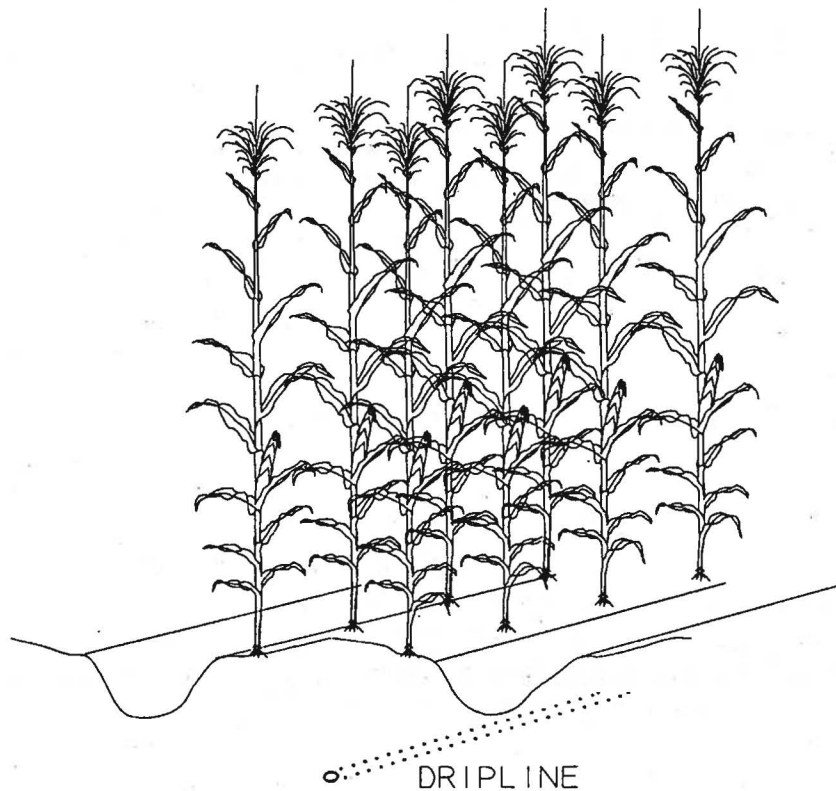


Figure 1. Physical arrangement of the subsurface dripline in relation to the corn rows.

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 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 mm of water used above a threshold of 12.9 inches (Lamm et al., 1995). The relationship between corn yields and irrigation is nonlinear (Figure 2.) primarily because of greater drainage for the heavier irrigation amounts (Figure 3).

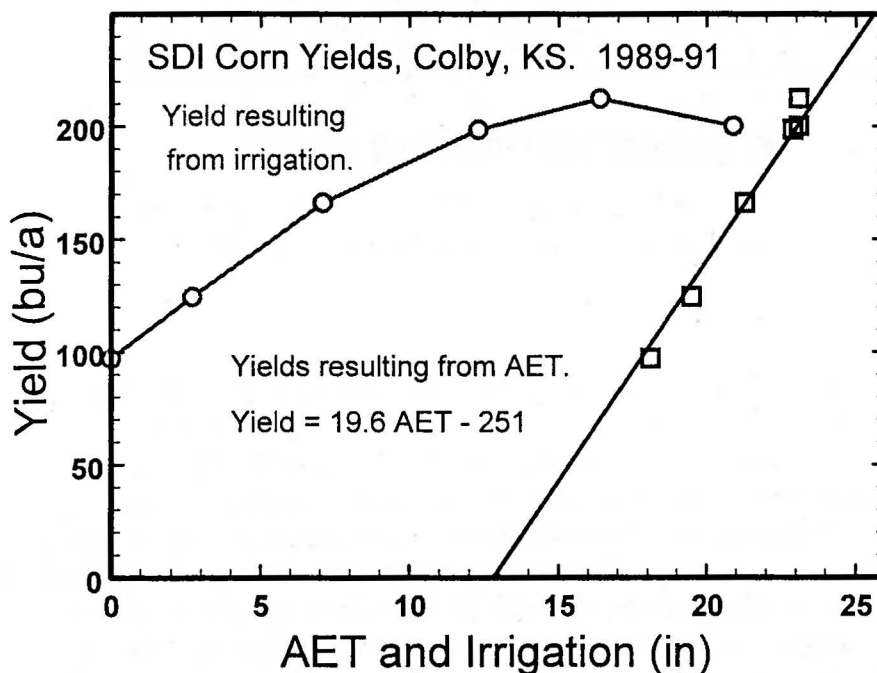


Figure 2. Corn yield as related to irrigation and calculated evapotranspiration (AET) in a SDI water requirement study, Colby, KS., 1989-1991.

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.

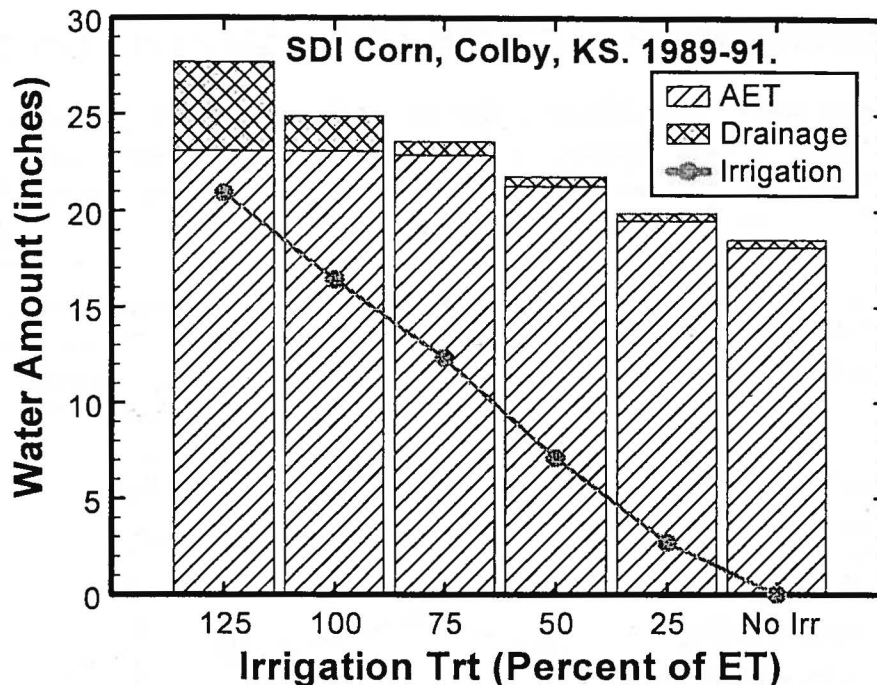


Figure 3. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI water requirement study, Colby, KS., 1989-1991.

In a later study (1996-2001), corn was grown with subsurface drip irrigation (SDI) under 6 different irrigation capacities (0, 0.10, 0.13, 0.17, 0.20 and 0.25 inches/day) and 4 different plant populations (33100, 29900, 26800, and 23700 plants/acre). All treatments were irrigated during the offseason to recharge the soil water profile. The purpose of the study was to determine appropriate inseason SDI capacities as related to different corn plant populations. 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 (Figure 4). 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). Analysis of the yield component data indicated that the number of kernels/acre is largely determined by providing just a small amount of SDI capacity over the nonirrigated control. 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 mining of the soil water reserves during this period will have a large effect on final kernel weight and ultimately, corn grain yield. Increasing plant population from approximately 22,500 to 34,500 plants/acre generally increased corn grain yields for SDI in this region, particularly in good corn production years. There was very little yield penalty for increased plant population even when irrigation was severely limited or eliminated.

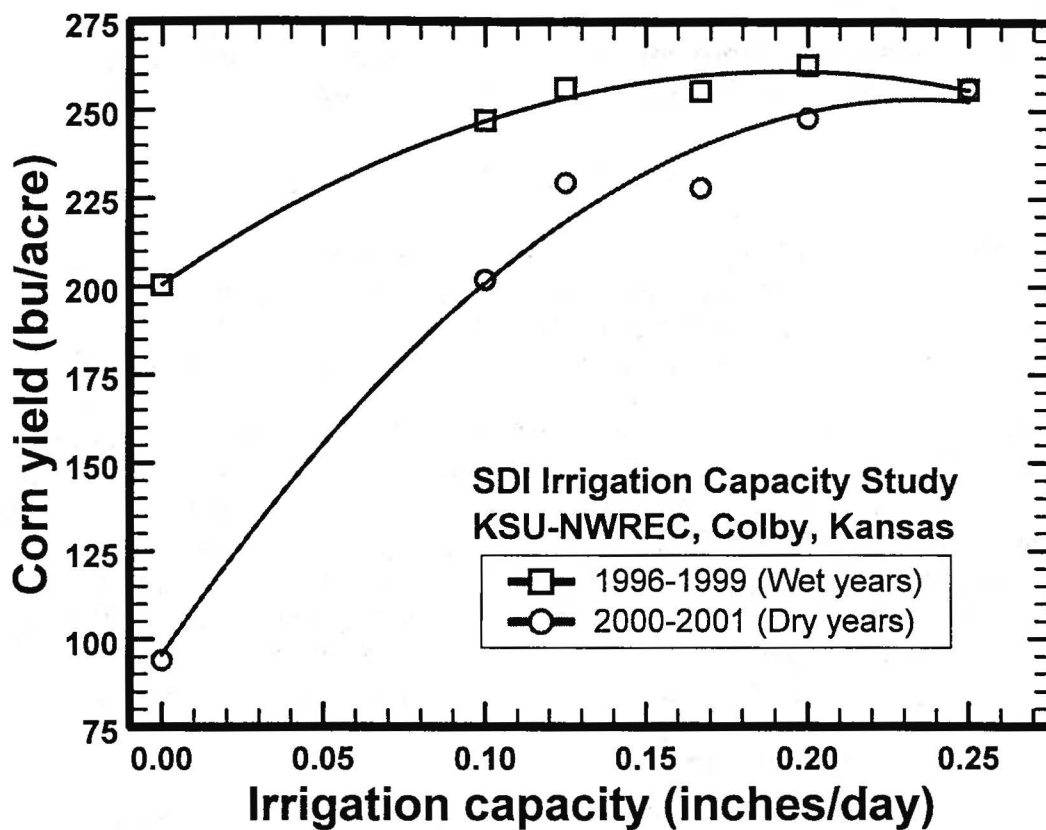


Figure 4. SDI corn grain yields as affected by irrigation capacity for wet (1996-1999) and dry years (2000-2001), KSU Northwest Research Extension Center, Colby, Kansas.

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 longer irrigation frequencies had no effect

on corn yields provided soil water was managed within acceptable stress ranges (Howell et al., 1997). There is some evidence that daily irrigation events may be beneficial under deficit irrigation conditions or in cases where fertigation is practiced. Several of the more advanced research studies currently underway at Kansas State University routinely utilize daily irrigation events.

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 (Lamm et al., 1997a, Manges et al., 1995). The first study at the KSU Southwest Research-Extension Center at Garden City, Kansas evaluated 4 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).

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

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.)

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 5). 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.

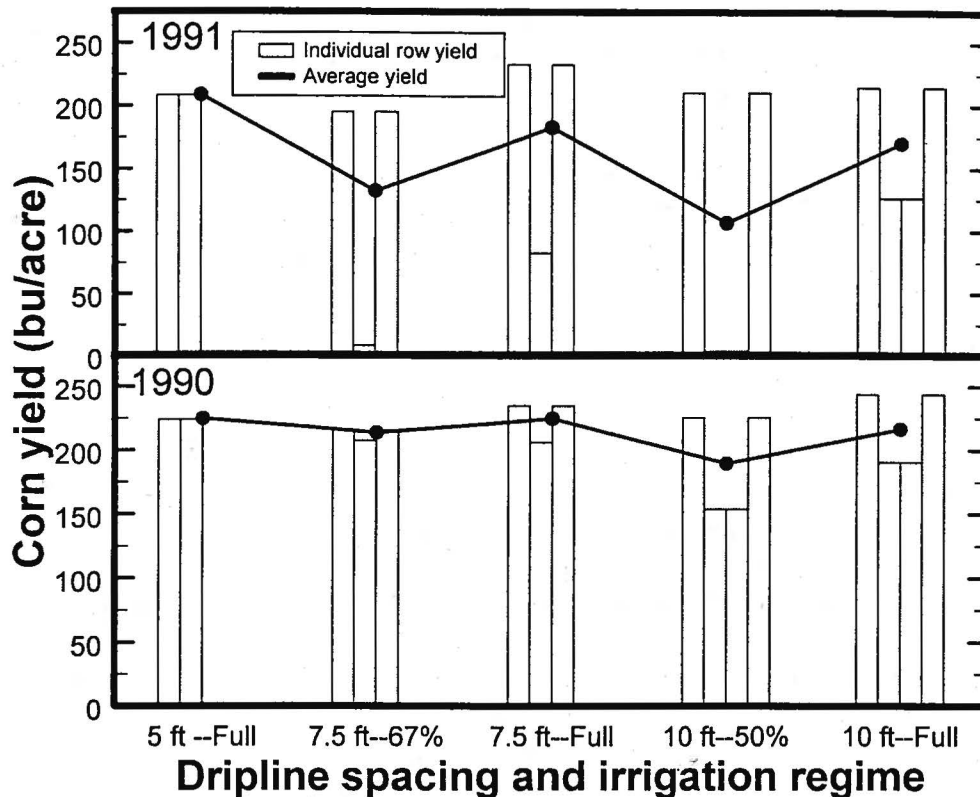


Figure 5. Corn yield distribution as affected by dripline spacing and irrigation regime, KSU Northwest Research-Extension Center, Colby, Kansas, 1990-1991. Note: Individual row yields are mirrored about a centerline half way between two adjacent driplines for display purposes.

DRIPLINE DEPTH STUDY

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 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.

A study was initiated at the KSU Northwest Research-Extension Center at Colby, Kansas in 1999 to evaluate the effect of dripline depth on corn production and SDI system integrity and longevity. The effects of five dripline depths (8, 12, 16, 20 and 24 inches) on SDI system longevity and corn production will be determined. System longevity will be 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 6.). However, it is still too early to answer questions about how depth affects longevity (chemical and biological clogging, pests, and tillage practices). The study area has not been used to examine the effects of dripline depth on germination in the spring, but studies in this regard may be conducted in the future. Damp surface soils are sometimes observed for the 8 and 12 inch dripline depths during the irrigation season, but not for the deeper depths. There is 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 great. The dripline depth study is 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 have been no instances thus far of tillage tool damage to the shallow 8-inch depth driplines.

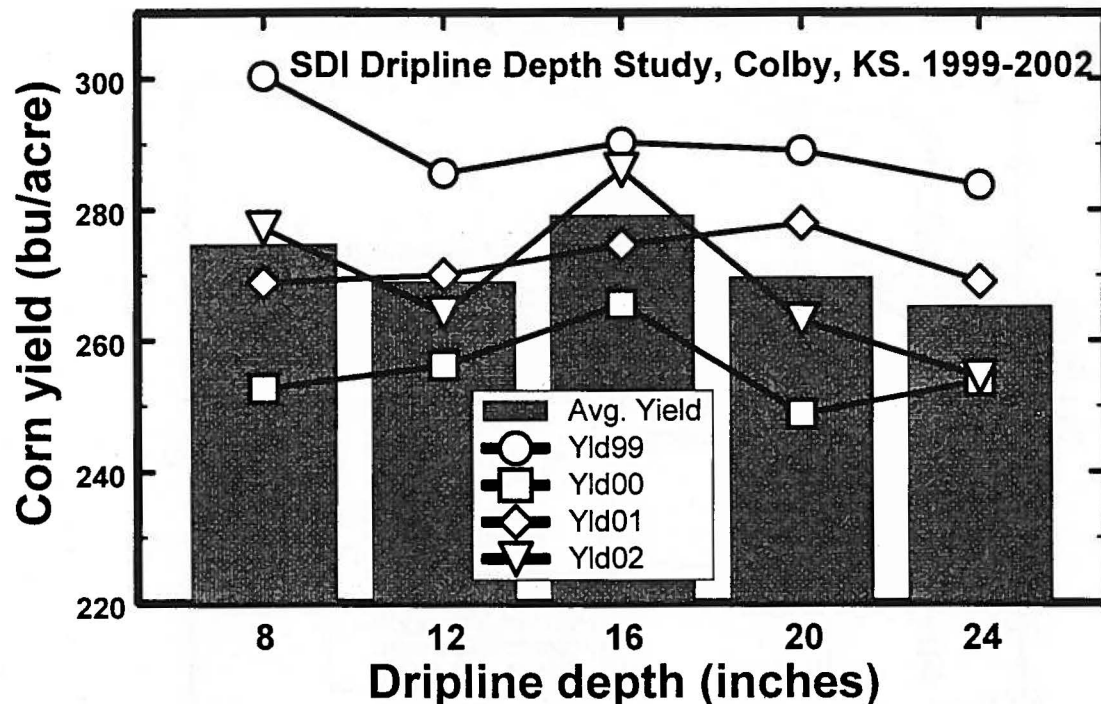


Figure 6. Corn grain yields as affected by dripline depth, 1999-2002, KSU Northwest Research-Extension Center, Colby, Kansas.

NITROGEN FERTILIZATION WITH SDI

Since 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 Colby, Kansas from 1990-91, there was no difference in corn 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. 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 7). 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.

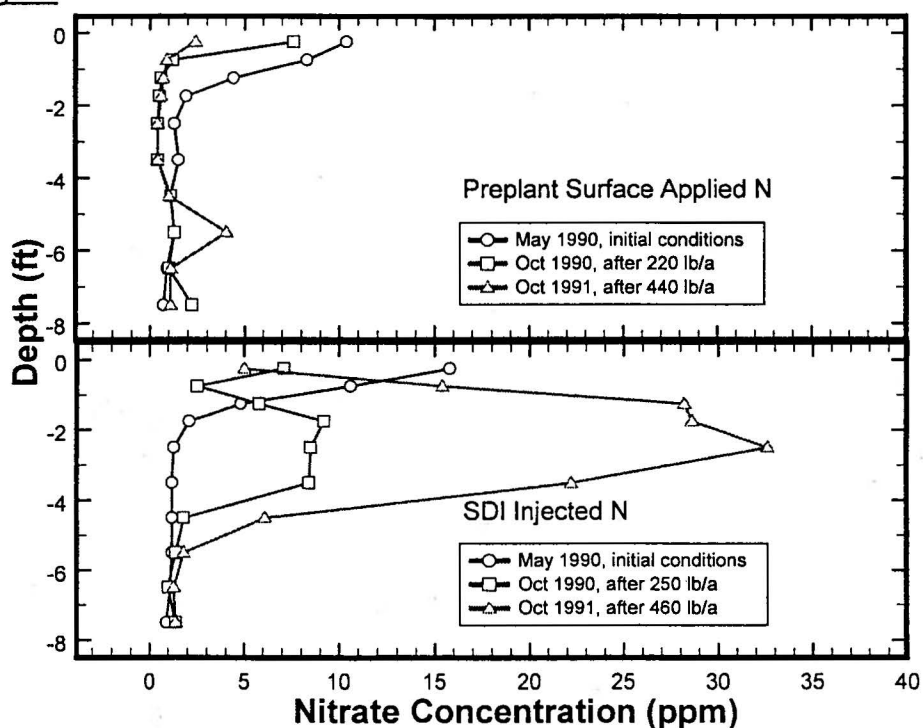


Figure 7. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of AET).

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., 1997b). 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 8). 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.

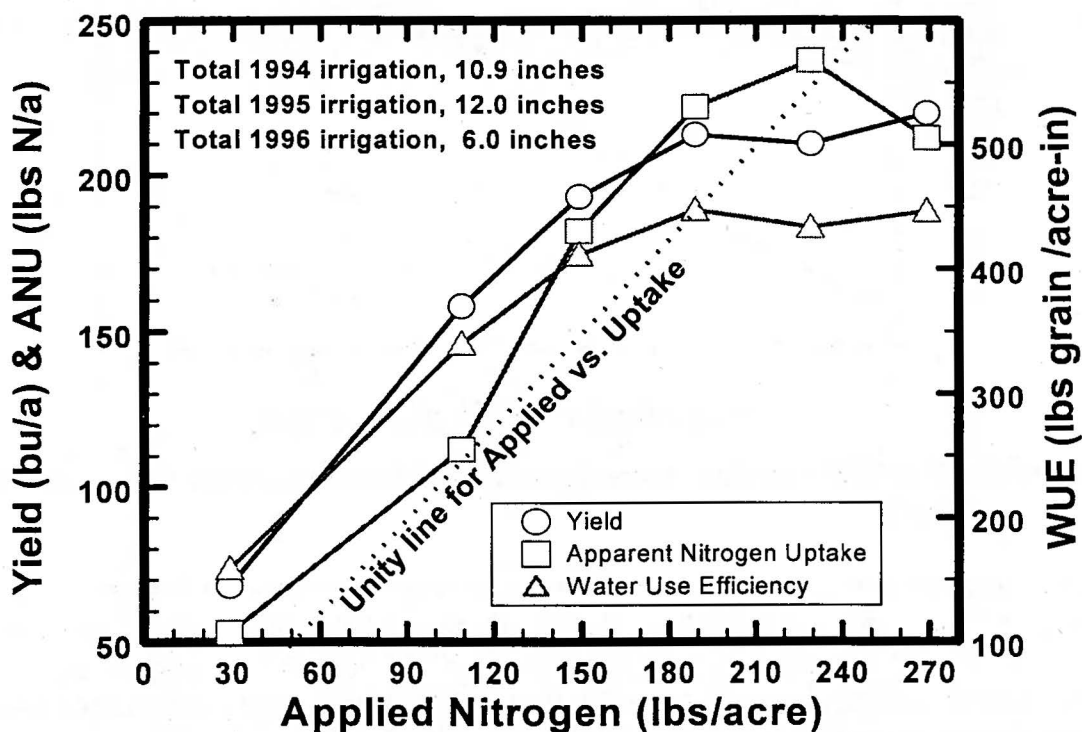


Figure 8. Average (1994-96) corn yield, apparent nitrogen uptake in the above-ground biomass, and water use efficiency as related to the total applied nitrogen (preseason amount, starter fertilizer, fertigation, and the naturally occurring N in the irrigation water). Total applied nitrogen exceeded fertigation applied nitrogen by 30 lb/acre.

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 9). Small and irregular shape fields may be ideal candidates for SDI.

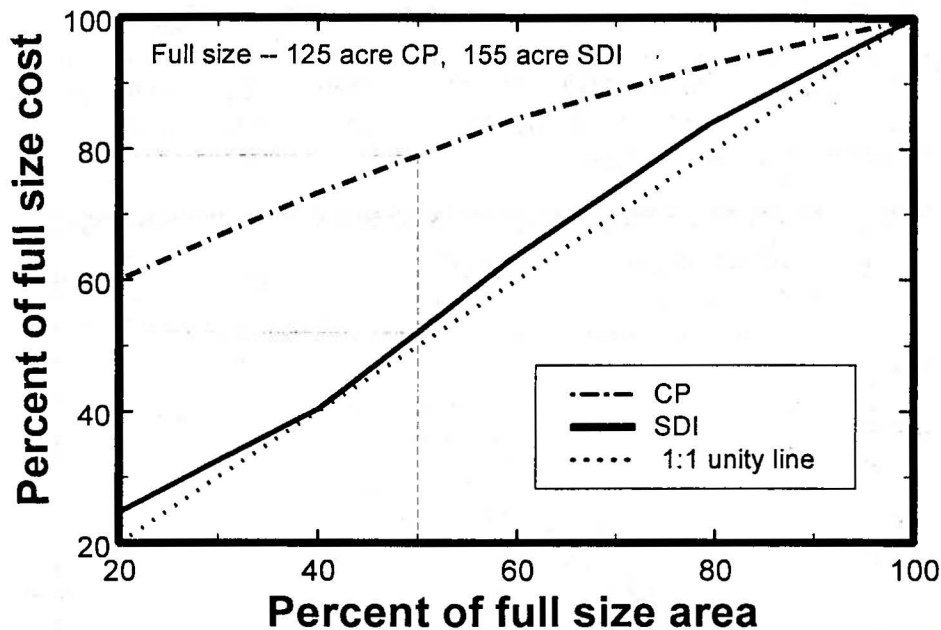


Figure 9. CP and SDI system costs as related to field size. (after O'Brien et al., 1997)

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 to make CP and SDI economic comparisons is available for downloading from the internet for free 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 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. 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 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.

CONCLUDING STATEMENTS

Research progress has been steady since 1989. Much of K-State's SDI research is summarized at K-State's SDI Website 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 preliminary information about SDI use with other crops besides corn, water and chemical application uniformity, and finally system design characteristics and economics with a view towards system longevity.

ACKNOWLEDGEMENTS

Several K-State faculty members in addition to the author have conducted and contributed to the progress of KSU SDI corn research over the years since 1989. These include, Bill Spurgeon, Todd Trooien, Harry Manges, Danny Rogers, Mahbub Alam, Loyd Stone, Alan Schlegel, Gary Clark, Dan O'Brien, Troy Dumler, Kevin Dhuyvetter, Mark Nelson and Norm Klocke.

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