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SDI FOR CORN PRODUCTION - A BRIEF REVIEW OF 25 YEARS OF KSU RESEARCH

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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 25 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. Currently, the NWREC SDI research site is comprised of 19 acres and 201 different research plots and is one of the largest facilities devoted expressly to small-plot row crop research in the world. Additional history is provided by Lamm et al., 2011.

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. This paper will limit discussion to the first two objectives and will be limited to SDI efforts with field corn (maize). 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 (grain yield/water use), 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.

CONSERVING WATER AND/OR INCREASING CROP WATER PRODUCTIVITY WITH SDI SYSTEMS

WATER CONSERVATION CONCEPTS WITH SDI

When properly managed, there is no need for any type of irrigation system to waste water. Using a similar train of thought, no irrigation system can save water. Only a human action or decision can actually save water. Howell and Evett (2005) correctly point out that difficulties can arise if incompatible temporal and spatial scales are used in statements about effective water use. For example, water savings from a reduction in deep percolation may be inconsequential if the temporal scale is large enough to allow return to the aquifer. Similarly, reduction of runoff is not a water savings on a large spatial scale when the runoff can be reused at a downstream location in the basin. The debate over the proper use of water conservation terms has and will continue to be the topic of many publications and presentations. Rather than go into this debate any further, discussion here will be limited to improvements in water usage at the farm level that can be obtained on a real-time basis. This temporal and spatial scale is highly relevant to the farmer in an economic sense, but is also relevant to society through stabilization of farm income and through its multiplying effect in the overall economy. Whether the water is actually conserved or extended to another beneficial use will not be the topic of this discussion.

Subsurface drip irrigation (SDI) applies water below the soil surface to the crop root zone through small emission points (emitters) that are in a series of plastic lines typically spaced between alternate pairs of crop rows (Figure 1). This method of irrigation can be used for small, frequent, just-in-time irrigation applications directly to crop root system.

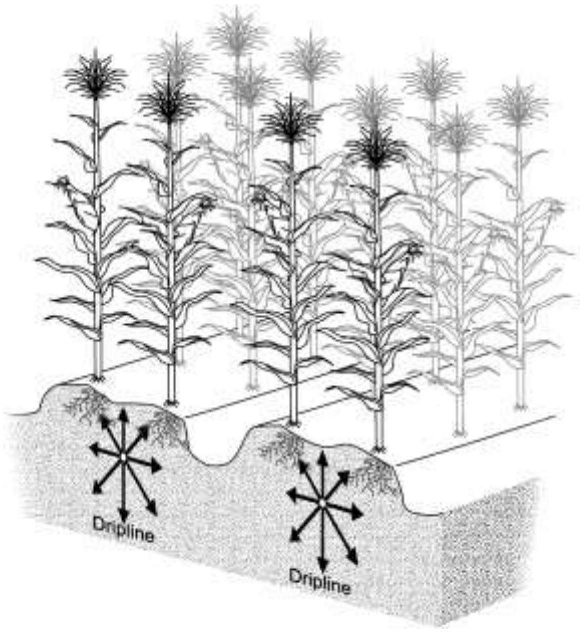

Figure 1. Alternate row/bed 5 ft SDI dripline spacing for corn rows spaced at 2.5 ft. Each plant row is approximately 1.25 ft from the nearest dripline and has equal opportunity to the applied water.

The primary ways that SDI can potentially increase crop water productivity and/or save water are:

- Reduction and/or elimination of deep drainage, irrigation runoff, and water evaporation
- Improved infiltration, storage, and use of precipitation
- Improved in-field uniformity and targeting of water within plant root zone
- Improved crop health, growth, yield, and quality.

GENERAL EFFECT OF IRRIGATION LEVEL ON CORN YIELDS AND WATER PRODUCTIVITY

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 2). 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. An examination of water productivity (WP) for the same four studies indicates that water productivity plateaus for levels of irrigation ranging from 61% to 109% of full irrigation with less than 5% variation in WP (Figure 3). The greatest 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.

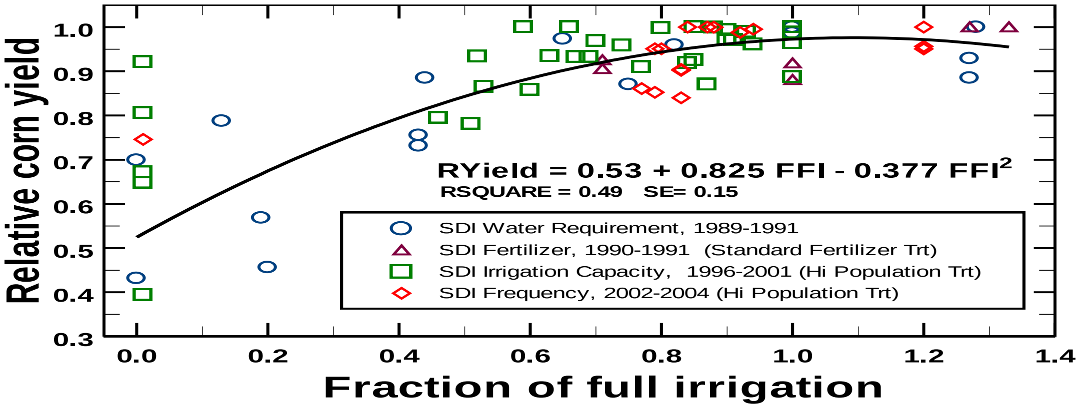

Figure 2. Relative corn grain yield for a given SDI research study and year as related to the fraction of full irrigation, KSU Northwest Research-Extension Center, Colby, Kansas.

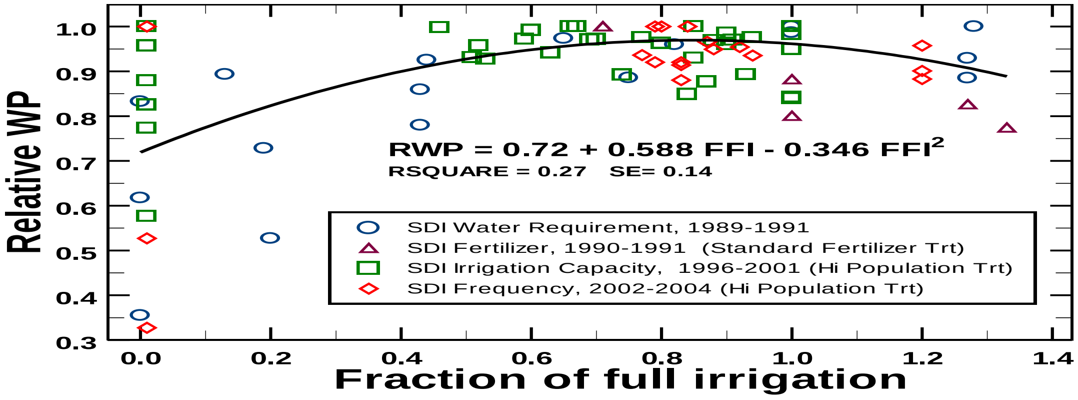

Figure 3. Relative water use productivity (WP) of corn for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas.

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 the soils in this region. Some of the stability in corn yield and water productivity across this range of irrigation levels may be explained by how deep percolation is managed and by how soil water is "mined" with SDI on this soil type and in this climatic region. These aspects are discussed in the next two sections.

MINIMIZATION OF DEEP PERCOLATION WITH SDI

Deep percolation can occur with SDI if design and management considerations such as soil characteristics, dripline spacing, dripline depth, and irrigation levels are not taken into account in operational strategies (Darusman et al., 1997 a and b; and Lamm and Trooien, 2003). However, with proper management deep percolation can be minimized with SDI. Appreciable reductions in deep percolation (7% of full irrigation amount) were obtained by Lamm et al., (1995) when the corn irrigation level was reduced to approximately 74% of full irrigation with SDI without affecting actual corn water use (Figure 4). That is, corn water needs were more closely matched with smaller and timelier irrigation events.

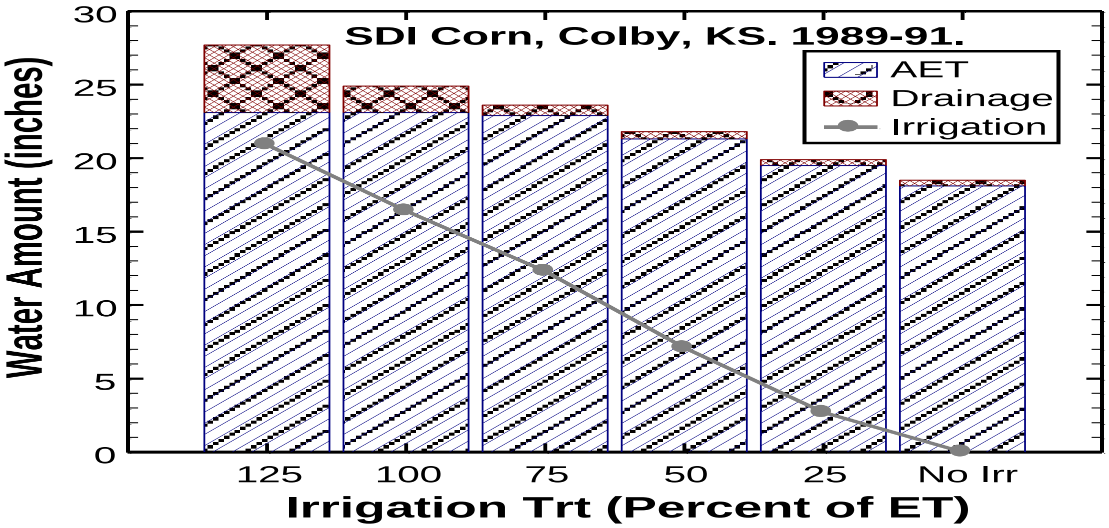

Figure 4. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI water requirement study, Colby, Kansas, 1989-1991.

"MINING" OF SOIL WATER WITH SDI

In a study from 1997 through 2000, corn was grown with SDI under 6 different irrigation capacities (0, 0.10, 0.13, 0.17, 0.20 or 0.25 inches/day) and 4 different plant populations (33100 29,900, 26800, or 23700 plants/acre). The study (Lamm and Trooien, 2001) indicated even small amounts of daily SDI can benefit corn production. Daily in-season application amounts of 0.10 inches/day resulted in corn yields of 253, 263, 236, and 201 bu/acre for the largest plant population in 1997, 1998, 1999, and 2000, respectively. Even in the extreme drought year of 2000, the 0.10 inches/day capacity resulted in corn yields twice that of the non-irrigated treatment and 78% of the maximum yield (Figure 5).

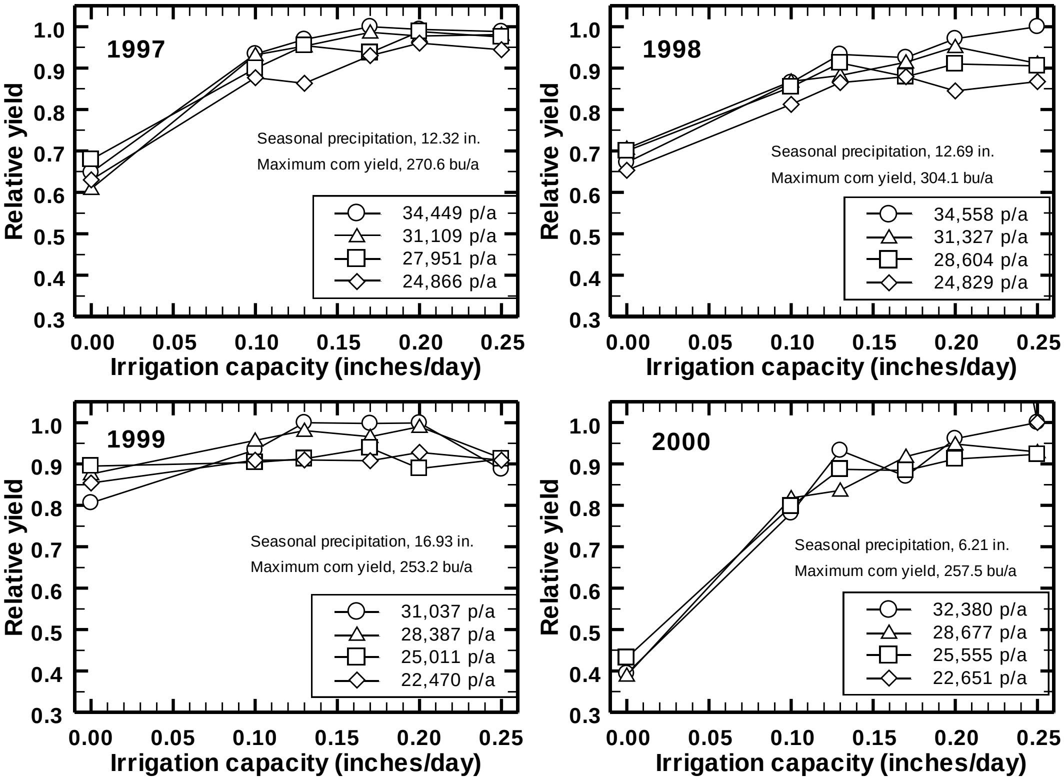

Figure 5. Relative corn grain yield as affected by daily SDI capacity and plant population. Note: Each annual panel indicates seasonal precipitation and maximum corn grain yield.

Examination of soil water profiles under these SDI capacities shows some distinctive grouping of adequately and inadequately irrigated treatments (Figure6). A possible rationale to explain the grouping is that the upper three treatments may group together because the range of 0.17 to 0.25 inches/day is sufficient to provide a large enough portion of the daily soil water needs. Even in the drier years, there are a few opportunities to shut off irrigation for the 0.20 - 0.25 inches/day treatments. This would allow these treatments to be closer to the effective value of 0.17 inches/day, which is a capacity sufficient to reach the yield plateaus shown in Figure 5. The 0.25 inches/day irrigation capacity is approximately the long term full irrigation requirement for northwest Kansas for corn using other irrigation methods. The higher efficiency, daily irrigation may allow the SDI to be more effective than other irrigation methods.

The lower three treatment may group together for almost the opposite reason. Available soil water reserves become depleted to a large extent and the corn crop begins to shut-down plant processes that use water. This shut-down tends to reduce grain yields depending on the severity and length of the water stress period. The fact that the 0.10 and 0.13 inches/day treatments obtain respectable corn yield increases over the nonirrigated control may be a good indication of how well this balancing of water use/water conservation is being handled by the daily infusion of at least some irrigation water. The grouping of the upper three treatments suggests that an irrigation capacity of 0.17 inches/day might be an adequate irrigation capacity if the producer has the desire to allocate water to an optimum land area. It should be noted that this limited irrigation capacity would not be sufficient on coarser-textured sandy soils which have limited water holding capacity.

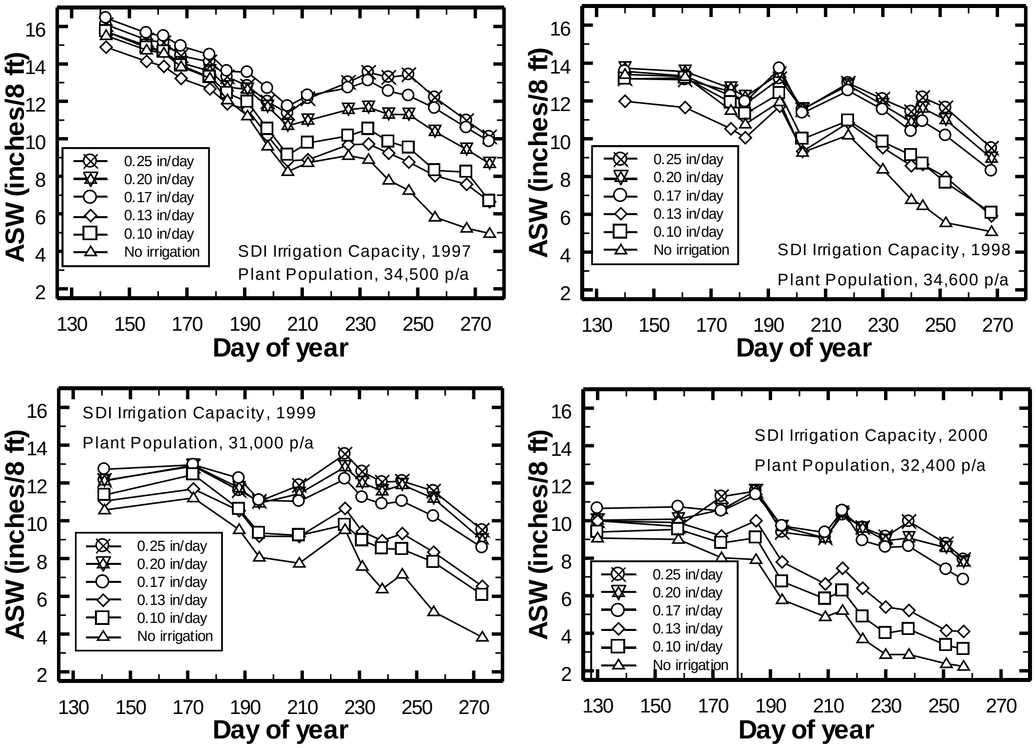

Figure 6. Progression of the available soil water in an 8 ft. profile as affected by daily SDI capacity for the highest plant population treatment.

Does SDI really increase crop per drop?

There is growing evidence from our K-State studies (Figure 7) and others in the Great Plains that SDI can stabilize yields at a greater level than alternative irrigation systems when deficit irrigated (Lamm et al., 2012).

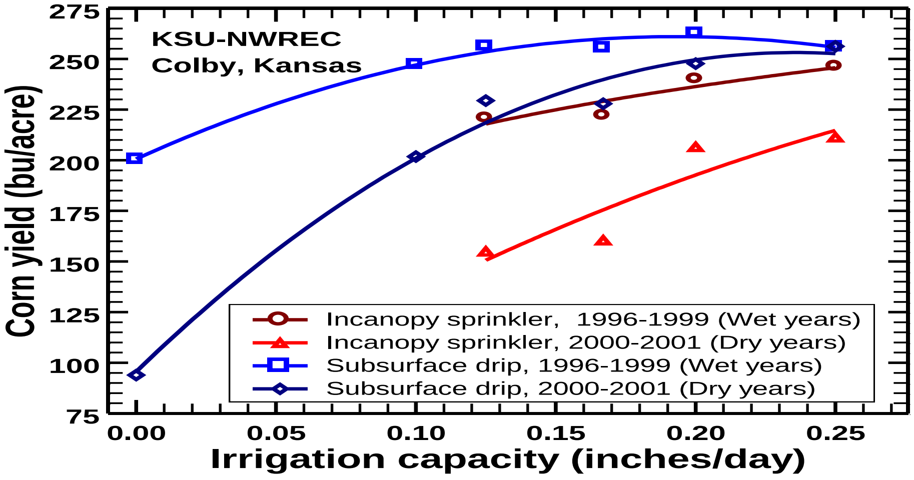

Figure 7. Corn yields for SDI and incanopy sprinkler irrigation in wet years and dry years at Colby, Kansas. Note: Results are from different but similar studies, so these are not statistical differences.

Although we believe this is true for most crop years, we have found that SDI sometimes experiences some reduction in kernel set in extremely dry years (Lamm, 2004). Research is continuing to examine this issue in search of a solution.

PROTECTING WATER QUALITY WITH SDI SYSTEMS

Properly designed SDI systems have a high degree of uniformity and can apply small frequent irrigation applications, and provide an excellent opportunity to better manage nitrogen fertilization with these systems. Injecting small amounts of nitrogen solution into the irrigation water can spoon-feed the crop just-in-time (i.e., nearer the point of actual crop need), while minimizing the pool of nitrogen in the soil that could be available for percolation into the groundwater.

COMPARISON OF PRE-PLANT BROADCAST APPLIED NITROGEN AND SDI FERTIGATION

In an early study at Colby, 1990-1991, results indicated that nitrogen applied with SDI redistributed differently in the soil profile than surface-applied preplant N (Lamm et al., 2001). Although corn yields were similar between the two fertilization methods, there was greater residual soil-N for the SDI fertigation (Figure 8).

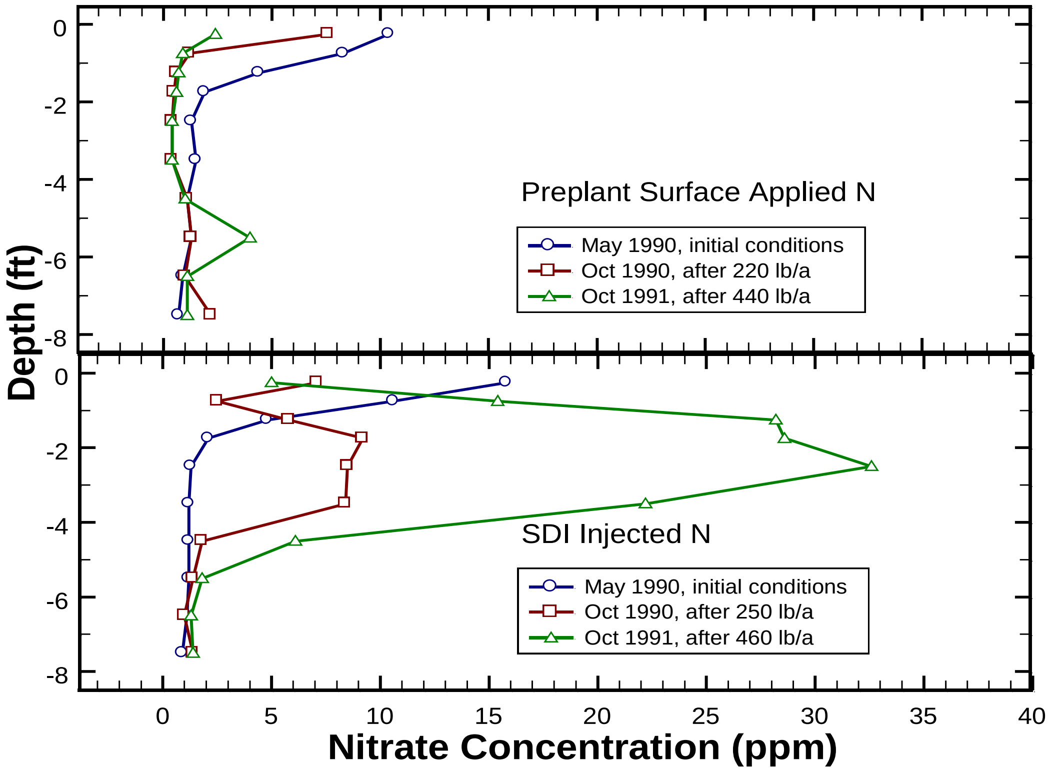

Figure 8. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, KSU Northwest Research-Extension Center, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of AET).

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 (Figure 8). This lead to a study to determine if SDI fertigation N needs could be lowered and still retain excellent yields.

DEVELOPMENT OF BEST MANAGEMENT PRACTICE FOR SDI N FERTIGATION OF CORN

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 (Lamm et al., 2004). 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, 80, 120, 160, 200, and 240 lbs N/a. The final BMP was a nitrogen fertigation level of 160 lbs N/a with other non-fertigation applications bringing the total applied nitrogen to approximately 190 lbs N/a (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 160 lbs N/a nitrogen fertigation rate (Figure 9). Average yields for the 160 lbs N/a nitrogen fertigation rate was 213 bu/a. Corn yield to ANU ratio for the 160 lbs N/a nitrogen fertigation rate was high at 53:1 (lbs corn grain/lbs N whole plant uptake). The results emphasize that high-yielding corn production also can be environmentally sound and efficient in nutrient and water use.

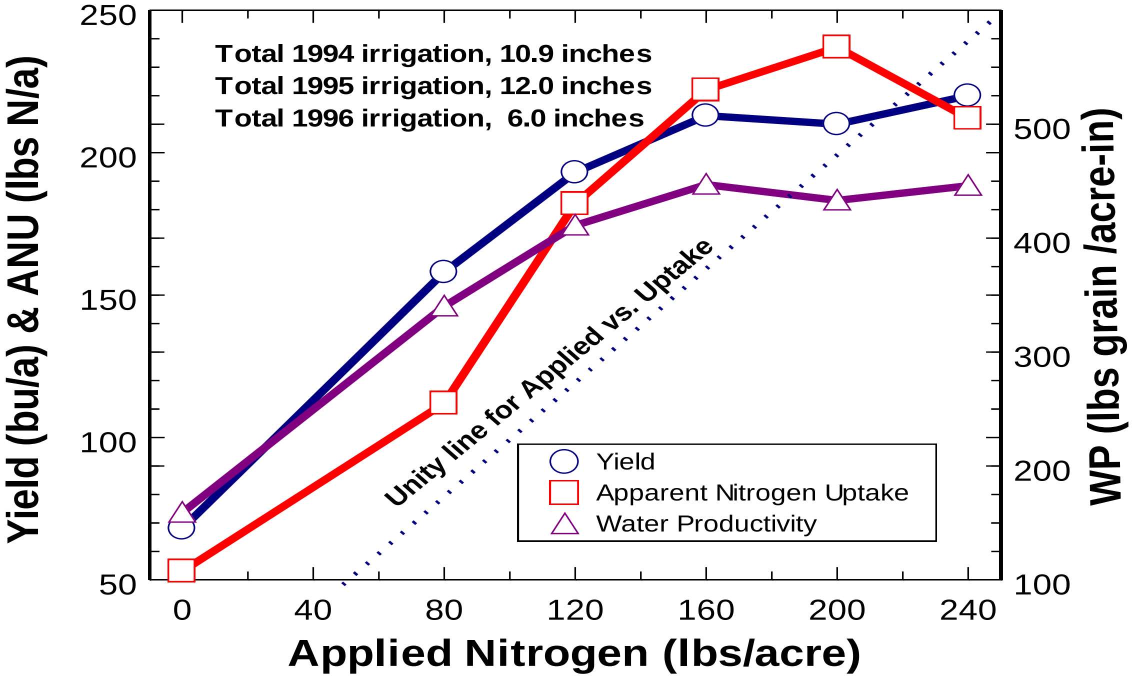

Figure 9. Average (1994-96) corn yield, apparent nitrogen uptake in the above-ground biomass, and water productivity as related to the total applied nitrogen (preseason amount, starter fertilizer, fertigation, and the naturally occurring N in the irrigation water). Total applied nitrogen exceeded fertigation applied nitrogen by 30 lb/acre.

After 4 years of continuous application of the fertigation treatments (Figure 10), nitrate-N levels in the soil were increasing and moving downward when the fertigation rate exceeded 160 lb N/a (i.e., equivalent to 190 lbs N/a total applications from all sources).

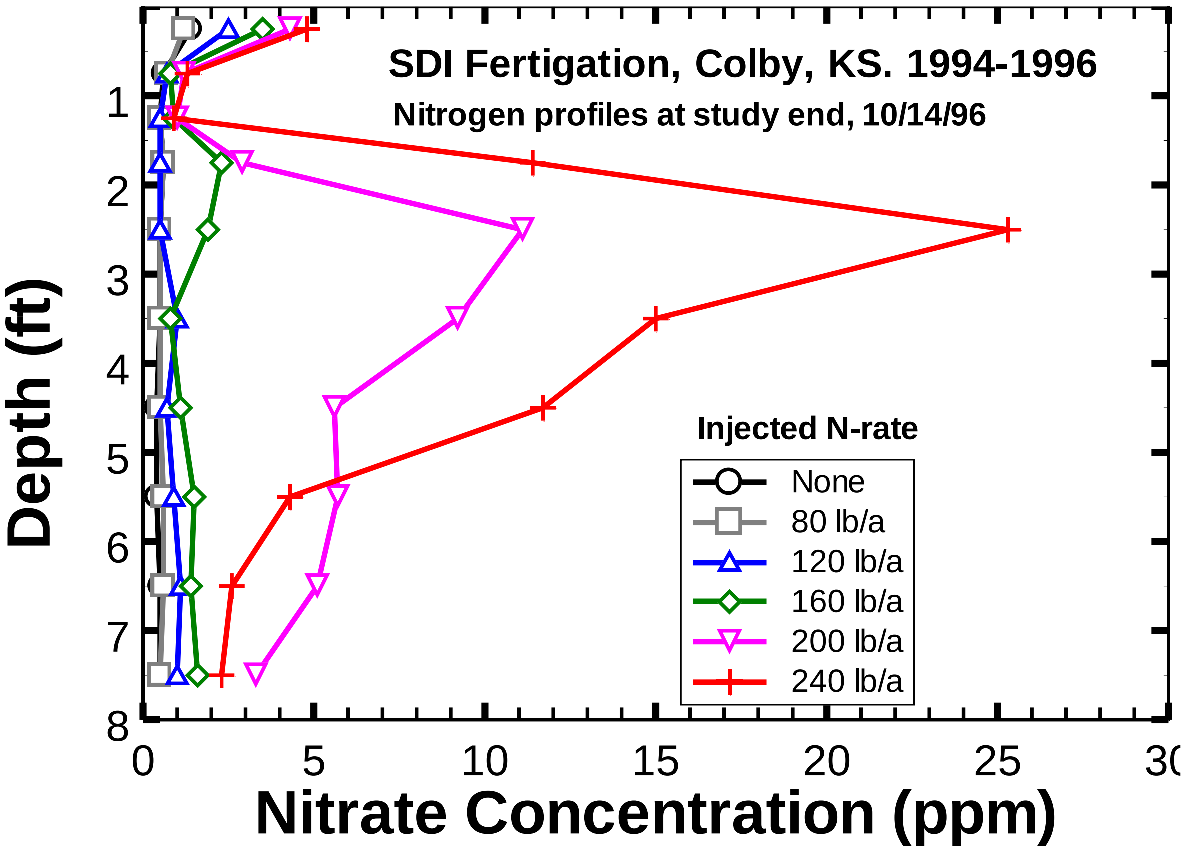

Figure 10. Nitrate concentrations within the 8 ft soil profile as affected by SDI fertigation N rate after four years of continuous application, KSU Northwest Research-Extension Center, Colby Kansas.

TIMING OF NITROGEN FERTIGATION AS AFFECTED BY IRRIGATION CAPACITY

A study was conducted at the KSU Northwest Research-Extension Center at Colby, Kansas in 2010 and 2012 to examine subsurface drip irrigation (SDI) capacity and nitrogen fertigation timing on corn production (Lamm and Schlegel, 2013). Targeted SDI N fertigation events at 3 specific early season growth stages (V5, V9 or VT) were compared under 2 levels of irrigation (0.25 inches/day or 0.25 inches/2 days). Treatment effects were evaluated in terms of corn yield components, crop water use, and crop water productivity. Overall, corn grain yields, kernels/area, kernel mass, and water productivity generally were numerically greater when nitrogen fertigation timing was earlier in the crop growth and development (Table 1). The greatest corn grain yield and greatest water productivity was obtained in 2010 by the fully irrigated treatment receiving supplement nitrogen fertigation at the V6 growth stage. The lack of supplemental nitrogen fertigation greatly reduced grain yields and water productivity in both years. Conjunctive management of both irrigation and inseason N fertigation are important for corn production with SDI.

Table 1. Corn yield component, biomass and water use results from a subsurface drip irrigated corn study as affected by irrigation capacity and nitrogen fertigation timing, KSU Northwest Research-Extension Center, Colby Kansas, 2010 and 2012.

Irrigation capacity	N-Fertigation timing	Yield, bu/a	Kernels/area, Million Kernel/acre	Kernel mass, mg	Biomass, lb/a	Water use, in	WP, lb/a-in
Crop year, 2010							
0.25 in/d	None	155.0	14.11	279	14219	23.08	376
	V6	277.0	18.71	376	22003	23.62	657
	V9	237.0	17.82	336	19143	23.33	569
	VT	239.2	17.60	345	19365	23.66	566
Mean 0.25 in/d	V6 thru V9	251.1	18.04	353	20170	23.54	597
0.25 in/2 d	V6	241.4	19.00	323	16493	21.97	615
	V9	238.2	18.68	324	18869	21.72	614
	VT	239.5	17.55	347	17070	21.52	624
Mean 0.25 in/2 d	V6 thru V9	239.7	18.41	331	17477	21.73	617
Crop year, 2012							
0.25 in/d	None	185.0	14.78	318	12150	29.13	358
	V6	246.5	17.69	354	20152	28.33	499
	V9	235.6	17.14	349	17826	27.86	477
	VT	248.1	17.92	352	20551	26.09	536
Mean 0.25 in/d	V6 thru V9	243.4	17.58	351	19510	27.43	504
0.25 in/2 d	V6	218.8	15.74	353	18431	19.29	644
	V9	220.9	16.05	349	17635	22.27	554
	VT	224.2	16.08	354	15058	20.99	609
Mean 0.25 in/2 d	V6 thru V9	221.3	15.96	352	17041	20.85	602
Mean, both years							
0.25 in/d	None	170.0	14.44	299	13184	26.11	367
	V6	261.7	18.20	365	21077	25.98	578
	V9	236.3	17.48	343	18485	25.59	523
	VT	243.7	17.76	348	19958	24.87	551
Mean 0.25 in/d	V6 thru V9	247.2	17.81	352	19840	25.48	551
0.25 in/2 d	V6	230.1	17.37	338	17462	20.63	629
	V9	229.5	17.37	337	18252	22.00	584
	VT	231.8	16.81	351	16064	21.25	616
Mean 0.25 in/2 d	V6 thru V9	230.5	17.18	342	17259	21.29	610

ACHIEVING THE GOALS OF CONJUNCTIVE MANAGEMENT OF WATER AND NUTRIENTS WITH SDI

When water and nutrients are highly managed for greatest effectiveness, there can be less margin of error. It is important that producers are diligent in observing the corn growth and development and in monitoring the SDI system. A couple of example cases will illustrate the need for this diligence.

Under drought conditions preplant surface-applied N can become positionally unavailable to the crop because of dry surface layers and no root exploration (Figure 11). One should immediately apply N through the SDI system to remedy this nitrogen deficiency when it is observed. The preplant nitrogen, although unavailable under these conditions, can be recovered and utilized later in the season or by future crops once the drought ends.

Water application with deeper SDI systems is largely unobserved. A problem as simple as a broken solenoid wire on a zone water valve can prevent irrigation (Figure 12). Producers should verify through flowrate and pressure that the applied irrigation is reaching the target. Soil water or plant water stress sensors can also be used to augment these observations.

Figure 11. SDI corn field experiencing N stress due to dry surface soil conditions despite having abundant nitrogen reserves in the soil surface layers.

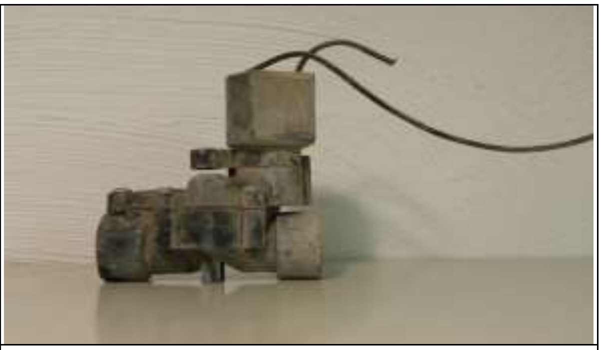

Figure 12. A broken solenoid wire on a zone valve might go unobserved if producers do not monitor there system flowrate and pressure.

CONCLUSIONS

Research progress has been steady since 1989. Much of K-State's SDI research is summarized at the 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. SDI can be a viable irrigation system option for corn production, enhancing the opportunities for wise use of limited water resources and also in protecting water quality.

ACKNOWLEDGEMENTS

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

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REFERENCES

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 at http://www.ksre.ksu.edu/sdi/Reports/2000/K-StateRep/campis.htm

Darusman, A. H. Khan, L. R. Stone, and F. R. Lamm. 1997a. Water flux below the root zone vs. drip-line spacing in drip irrigated corn. Soil Sci. Soc. Am. J. 61(6):1755-1760. Also available at http://www.ksre.ksu.edu/sdi/Reports/1997/WaterFluxSpacing.pdf

Darusman, A. H. Khan, L. R. Stone, W. E. Spurgeon, and F. R. Lamm. 1997b. Water flux below the root zone vs. irrigation amount in drip-irrigated corn. Agron. J. 89(3):375-379. Also available at http://www.ksre.ksu.edu/sdi/Reports/1997/WaterFluxIrrA.pdf

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/howell 2001.pdf

Howell, T. A. and S. R. Evett. 2005. Pathways to efficient applications. In: Proc. Central Plains Irrigation Conf., Sterling, CO., Feb. 16-17, 2005. Available from CPIA, 760 N. Thompson, Colby, KS. pp. 84-98. Also available at http://www.ksre.ksu.edu/irrigate/OOW/P05/Howell.pdf

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.ksre.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 at http://www.ksre.ksu.edu/sdi/Reports/2005/ASC000557.pdf

Lamm, F. R. and A. J. Schlegel. 2013. Effect of subsurface drip irrigation capacity and nitrogen fertigation timing on corn production. ASABE paper no. 131593348. Available from ASABE, St. Joseph, MI. 10 pp. Also available at http://www.ksre.ksu.edu/sdi/Reports/2013/LammNFT.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. pp. 73-80. Available from Irrigation Assn., Falls Church, VA. Also available at http://www.ksre.ksu.edu/sdi/Reports/2001/icpp.pdf

Lamm, F. R. and T. P. Trooien. 2003. Subsurface drip irrigation for corn production: A review of 10 years of research in Kansas. Irrig. Sci. 22(3-4):195-200. Also available at http://www.ksre.ksu.edu/sdi/Reports/2003/SDI10years.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.ksre.ksu.edu/sdi/Reports/2004/SDIFert04.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.ksre.ksu.edu/sdi/Reports/2001/dfert.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.ksre.ksu.edu/sdi/Reports/1995/WaterReq.pdf

Lamm, F. R., D. H. Rogers, M. Alam, D. M. O'Brien, and T. P. Trooien. 2011. Twenty-two years of SDI research in Kansas. In: Proc. 23rd annual Central Plains Irrigation Conf., Burlington, Colorado, Feb. 22-23, 2011. Available from CPIA, 760 N. Thompson, Colby, KS. pp. 68-92. Also available at http://www.ksre.ksu.edu/sdi/Reports/2011/Lamm11SDIa.pdf

Lamm, F.R., J. P. Bordovsky, L. J. Schwankl, G. L. Grabow, J. Enciso-Medina, R. T. Peters, P. D. Colaizzi, T. P. Trooien, and D. O, Porter. 2012. Subsurface drip irrigation: Status of the technology in 2010. Trans. ASABE 55(2): 483-491. Also athttp://www.ksre.ksu.edu/sdi/Reports/2012/SDI2010Status.pdf