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KSU RESULTS FROM TWENTY NINE YEARS OF IRRIGATION AND FERTIGATION STUDIES USING SDI

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QUICK FACTS

- *SDI can potentially save water and/or increase water productivity through reducing non-beneficial water losses, improving retention and utilization of natural precipitation, improving irrigation uniformity and improving crop yield and/or quality.*
- *SDI appears to optimize corn yields at irrigation levels in the range of 75 to 85% of full irrigation levels on the deep silt loam soils of western Kansas.*
- *Even small irrigation events (≈ 0.10 inches/day) can be effective with SDI and can greatly increase corn grain yields above rainfed conditions.*
- *Although individual study results vary about whether SDI can increase corn yields over alternative irrigation systems, there is increased evidence that SDI can stabilize yields at a greater level filtration unit is an important protection component of an SDI system under deficit irrigation.*
- *SDI is well suited to intensive management of inputs, such as nutrients and seeding rates, and the potential exists to further improve corn yields while maintaining high water productivity (crop per drop).*
- *SDI can better manage both nitrogen and phosphorus applications through in-season fertigation.*

INTRODUCTION

In March 1989, K-State Research and Extension initiated efforts to develop the techniques for successful application of subsurface drip irrigation (SDI) for crop production in the U. S. Great Plains region. Irrigation and nutrient management for field corn has been a major research topic during this 29 year period. The vast majority of the SDI crop research studies have been conducted with field corn (maize) 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. Field corn also uses considerable quantities of nutrients and their effectiveness can be affected timing of application and their retention or positioning within the crop root zone. Some of these nutrients are mobile subject to leaching (e.g., nitrogen) while others are rather immobile and this may limit their root uptake (e.g. phosphorus).

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

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. Daily irrigation amounts as small as 0.10 inches/day can be of great benefit to corn production when applied with SDI (Lamm and Trooien, 2001).

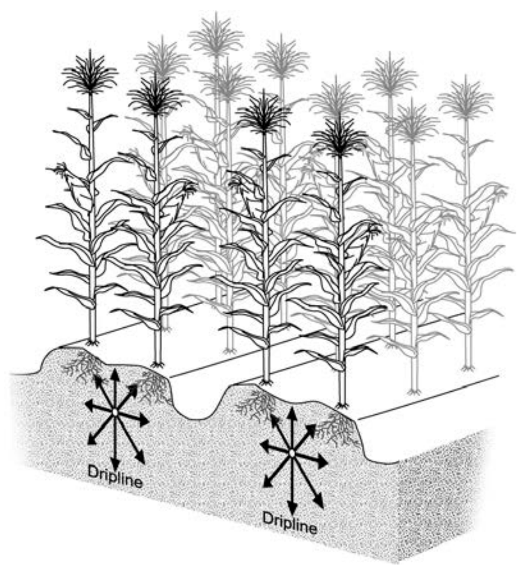

Figure 1. Alternate row/bed 5 ft SDI dripline spacing for corn rows spaced at 2.5 ft. Each plant row is approximately 1.25 ft from the nearest dripline and has equal opportunity to the applied water.

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 SDI 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.

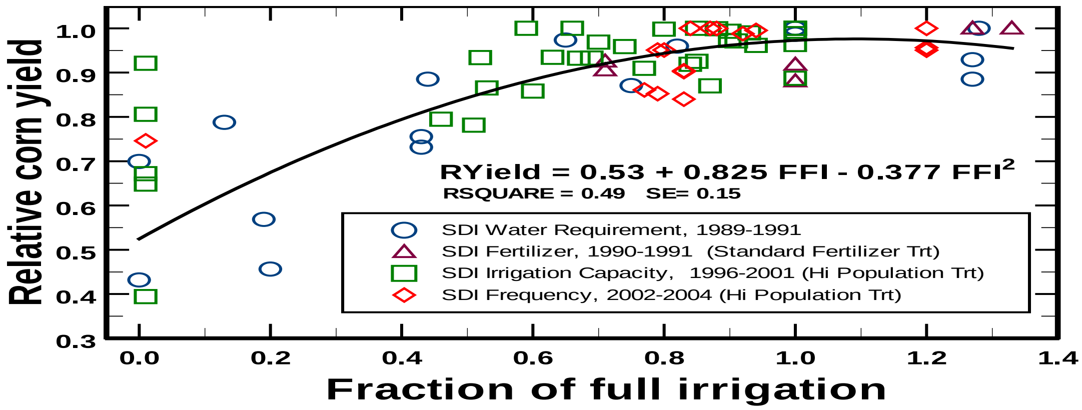

Figure 2. Relative corn grain yield for a given SDI research study and year as related to the fraction of full irrigation, KSU Northwest Research-Extension Center, Colby, Kansas.

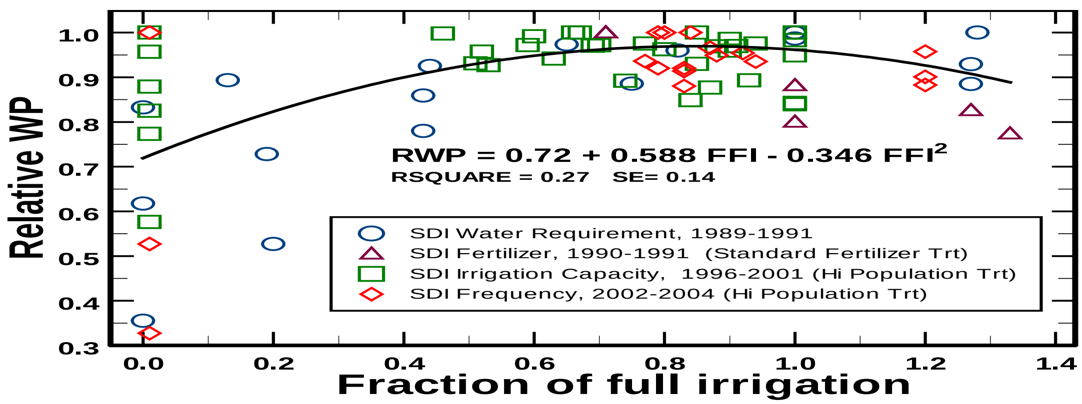

Figure 3. Relative water use productivity (WP) of corn for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas.

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 timely irrigation events.

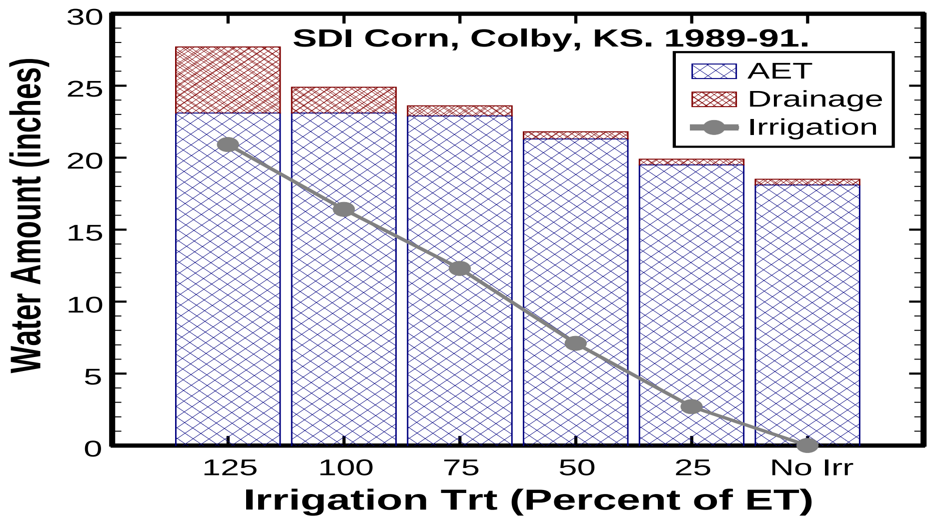

Figure 4. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI water requirement study, Colby, Kansas, 1989-1991.

"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).

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.

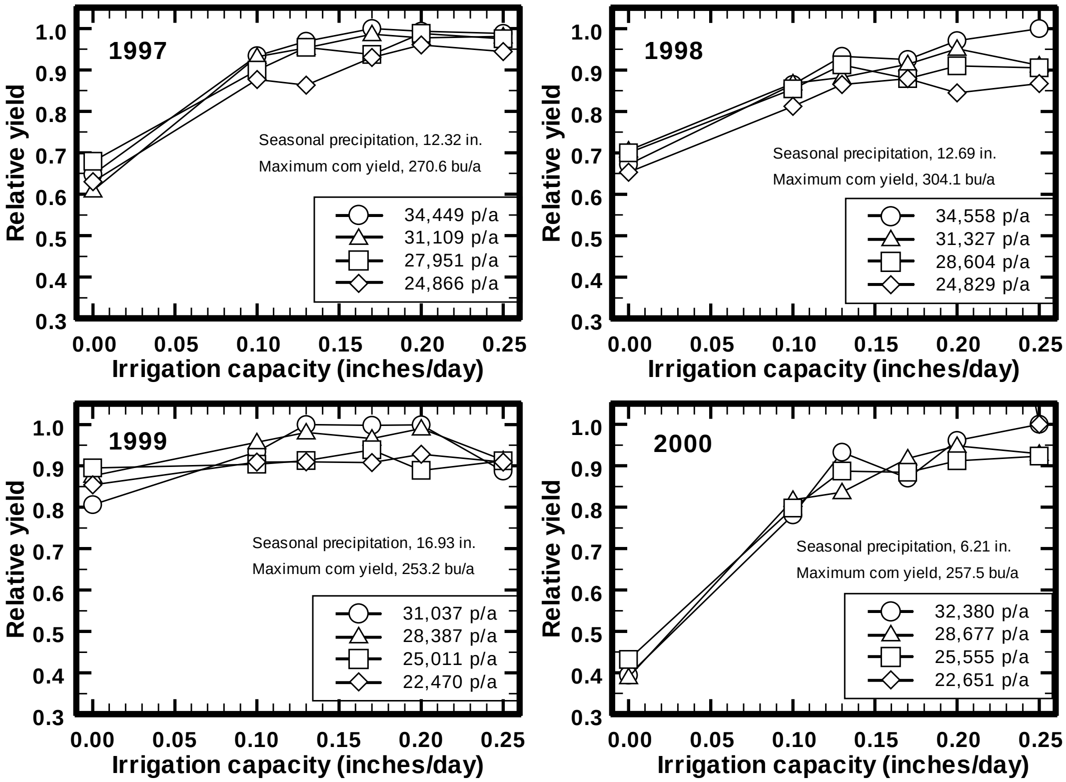

Figure 5. Relative corn grain yield as affected by daily SDI capacity and plant population. Note: Each annual panel indicates seasonal precipitation and maximum corn grain yield.

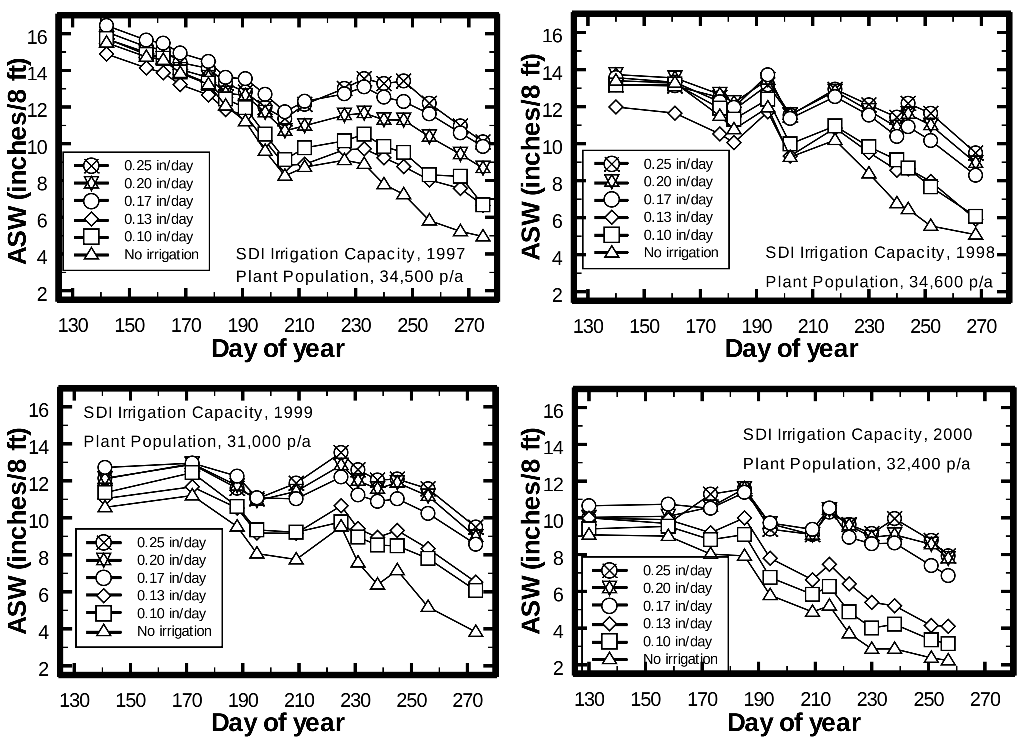

Figure 6. Progression of the available soil water in an 8 ft profile as affected by daily SDI capacity for the highest plant population treatment.

Does SDI Really Increase Crop per Drop?

There is growing evidence from our K-State studies (Figure 7, 8, and Table 1) 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).

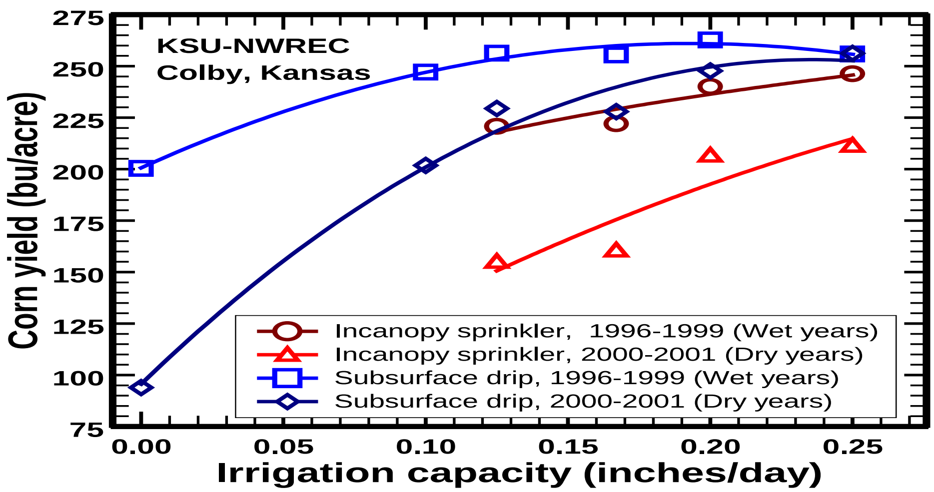

Figure 7. Corn yields for SDI and mid elevation spray application (MESA) sprinkler irrigation in wet years and dry years at Colby, Kansas. Note: Results are from different but similar studies, so these are not statistical differences.

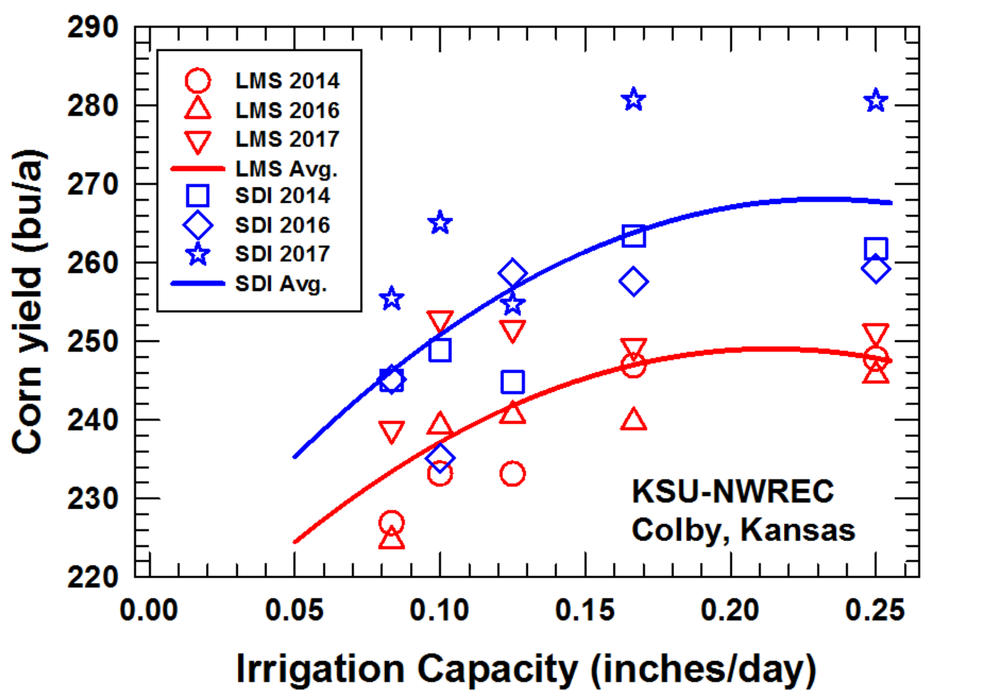

Figure 8. Corn yields for SDI and lateral move sprinkler (LMS) irrigation for 2014, 2016 and 2017 as affected by irrigation capacity at Colby, Kansas. Note: Results are from different but similar studies, so these are not statistical differences.

In two study periods, the first period from 1996 to 2001 and the second period 2014, 2016 and 2017, SDI generally had greater yields than mid-elevation spray application (MESA) with center pivot or lateral move sprinklers (Figure 7 and 8). There was also a greater plateau region of stable yields under SDI in dry years (Figure 7).

In other studies comparing SDI to either simulated LEPA (low energy precision application) or simulated MDI (mobile drip irrigation), the results were more mixed (Table 1). In nearly all years SDI outperformed LEPA in grain filling (i.e. greater kernel mass) as discussed in Lamm (2004). However, in some but not all extreme drought years LEPA had greater kernel set (i.e., kernels/ear) and as a result had greater yield than SDI in those years. Overall mean yield results for SDI and LEPA were similar with only a slight increase for SDI (Table 1). Similarly, in an ongoing study with SDI and MDI, yields have been similar and not statistically different (Table 1 and Figure 9). However, there was differences in crop water use with SDI using less water.

Table 1. Yield (bu/a) for corn grown with SDI and LEPA center pivot irrigation (1998 to 2014) and for SDI and MDI (2016 and 2017) under full and deficit irrigation at KSU-NWREC, Colby, Kansas. There was no crop harvested in 2011 and 2015.

Year	Full irrigation, limited to 0.25 inches/day		Deficit irrigation, limited to 0.17 inches/day	
	SDI	**LEPA**	**SDI**	**LEPA**
1998	278.2	246.2	260.7	250.1
1999	263.5	260.4	263.0	252.5
2000	241.5	238.7	219.4	229.9
2001	247.9	275.0	234.7	248.7
2002	221.6	234.2	198.2	218.8
2003	195.9	220.6	194.1	214.6
2004	274.1	245.9	264.5	238.8
2005	226.4	218.3	206.9	225.4
2006	252.1	261.0	258.7	255.6
2007	273.1	252.9	237.1	262.0
2008	264.6	250.2	275.4	232.2
2009	258.0	254.6	244.3	233.0
2010	232.5	233.4	236.8	205.2
2012	251.0	225.2	208.0	206.0
2013	191.2	186.2	179.4	180.2
2014	247.6	257.9	252.3	263.8
Mean	**244.9**	**241.3**	**233.3**	**232.3**
Year	**SDI**	**MDI**	**SDI**	**MDI**
2016	248.8	246.6	251.1	243.7
2017	272.9	271.6	278.5	271.9
Mean	**260.9**	**259.1**	**264.8**	**257.8**

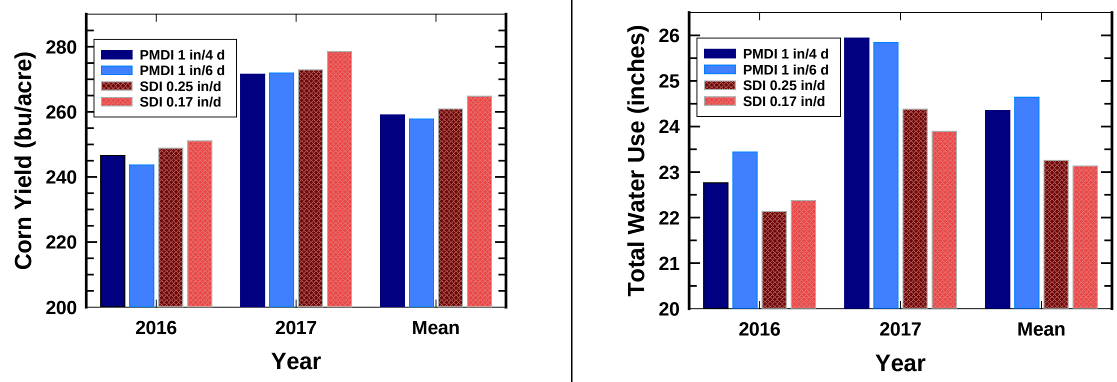

Figure 9. Corn yield and total water use for corn grown with subsurface drip irrigation (SDI) and precision mobile drip irrigation (PMDI) under two equivalent irrigation capacities at KSU-NWREC, Colby, Kansas in 2016 and 2017. Note: Total water used is the sum of the seasonal change in soil water, irrigation and precipitation.

Improving Crop Water Productivity through Intensive Management

A new SDI study was initiated in 2017 to evaluate the potential of increasing crop water productivity through intensive management of crop inputs. Fertility management was the same across all treatments but included in-season fertigation of all three macronutrients N, P and K along with some zinc applied at planting. Study variables were 3 irrigation levels (designed to meet 85, 100 or 115% of the ETc minus precipitation requirements), 2 high-yielding corn hybrids (Pioneer 1151 and Pioneer 1197) and 3 plant densities (34,000, 38,000 or 42,000 plants/acre). Yields were exceptionally high in this study in 2017 (Table 1).

Table 2. Corn yield and water use parameters in an SDI study with intensive management at the KSU-NWREC, Colby, Kansas in 2017.

Main Effect	Grain yield (bu/a)	Plant Density (p/acre)	Ears /Plant	Kernels /Ear	Kernel Mass (mg)	Crop Water Use (inches)	Water Productivity (lb/a-in)
Effect of Irrigation Level							
Irr 1, 115% ETc *(16.75 inches)*	293	37679	1.02	587	33.3	**29.19 A**	**563 C**
Irr 2, 100% ETc *(14.50 inches)*	292	37716	1.02	586	33.3	**27.10 B**	**605 B**
Irr 3, 85% ETc *(12.00 inches)*	289	37752	1.01	580	33.6	**25.50 C**	**638 A**
Effect of Hybrid							
Hybrid 1, Pioneer 1151	**280 B**	37873	1.01	**556 B**	33.7	**26.68 B**	**590 B**
Hybrid 2, Pioneer 1197	**304 A**	37558	1.02	**612 A**	33.1	**27.84 A**	**614 A**
Effect of Plant Density							
Plant Density 1, 42K p/a	**296 A**	**41600 A**	0.99	**552 C**	33.0	27.35	607
Plant Density 2, 38K p/a	**295 A**	**37788 B**	1.02	**587 B**	33.3	27.30	608
Plant Density 3, 34K p/a	**285 B**	**33759 C**	1.03	**614 A**	34.0	27.14	591

Data for a main effect within a column followed by different letters are significantly different at P=0.05 level.

Yields were not affected by irrigation level which agrees with earlier discussion that SDI levels matching approximately 75 to 80% of full irrigation will maximize yields. Crop water use was affected by irrigation but this is just reflecting the higher irrigation amounts which probably ended up as increased deep percolation. This is further emphasized by the greatest water productivity at the irrigation level designed to match 85% of ETc minus precipitation. There was a strong hybrid effect on yield (Pioneer 1197 exceeded Pioneer 1151 by 24 bu/acre) which emphasizes that hybrid selection remains an important factor in intensively managed corn. This yield increase for Pioneer 1197 was primarily caused by greater number of kernels/ear. Pioneer 1197 also had higher water productivity than Pioneer 1151, but crop water use was slightly greater with Pioneer 1197. Plant density of 38,000 or 42,000 plants/acre resulted in significantly greater yield than 34,000 plants/acre, but crop water use was not affected at approximately 27.26 inches. Although the lower plant density had greater number of kernels/ear, this value was not able to compensate for the lower plant density. This reflects a growing understanding that maximizing irrigated corn yields often requires maximizing the intermediate yield component of kernels/area (i.e. plant density x ears/plant x kernels /ear).

NUTRIENT MANAGEMENT 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 nutrients. Injecting small amounts of nitrogen solution into the irrigation water can spoonfeed 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 leaching into the groundwater. Likewise, utilization of immobile nutrients might be enhanced with SDI by application within the root zone periodically throughout the cropping season. Although traditional recommendations suggest that additional potassium is not typically required on the soils of the region for irrigated corn production, these recommendations may need another look when corn is intensively managed with SDI in high yielding systems.

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 10).

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

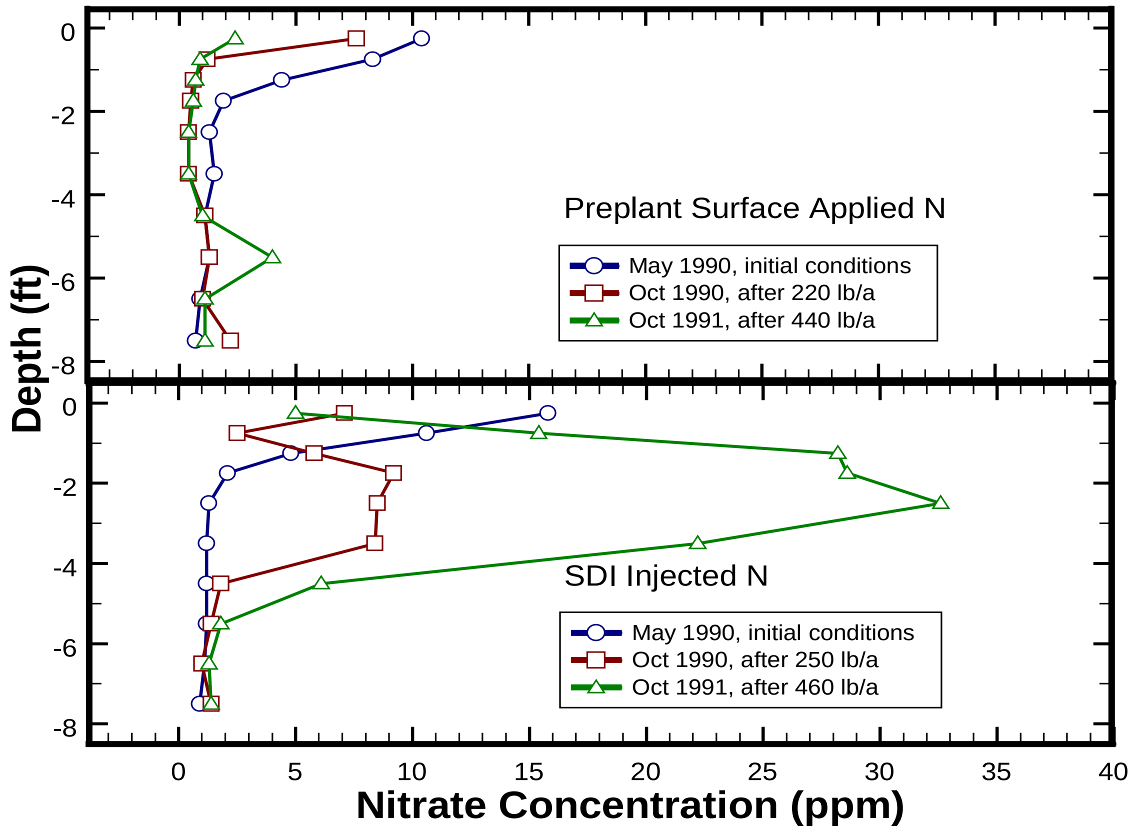

Figure 10. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, KSU Northwest Research-Extension Center, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of ETc-Rain).

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 (Figure11). 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.

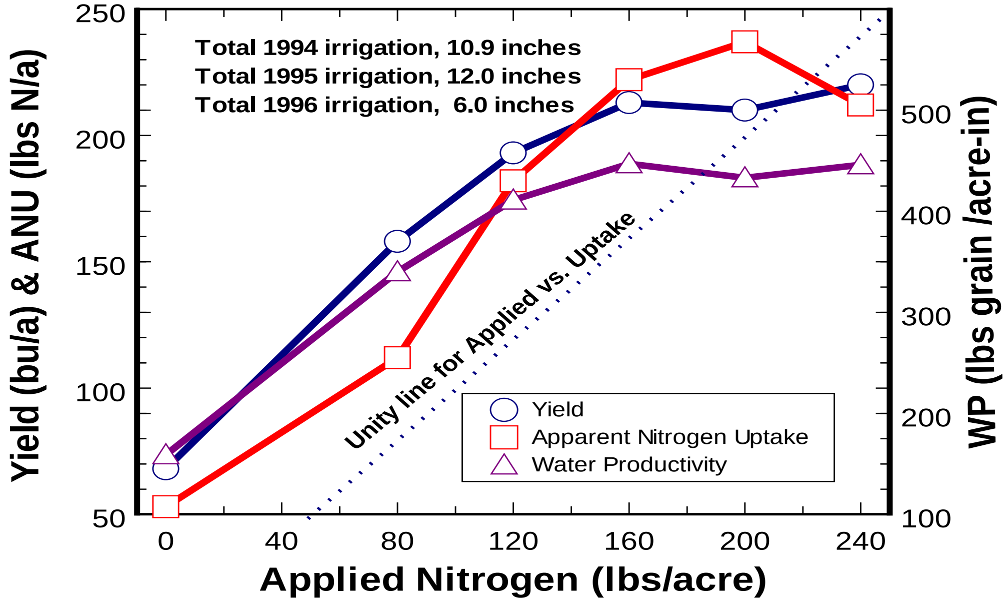

Figure 11. Average (1994-96) corn yield, apparent nitrogen uptake in the above-ground biomass, and water productivity as related to the total applied nitrogen (preseason amount, starter fertilizer, fertigation, and the naturally occurring N in the irrigation water). Total applied nitrogen exceeded fertigation applied nitrogen by 30 lb/acre.

After 4 years of continuous application of the fertigation treatments (Figure 12), 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).

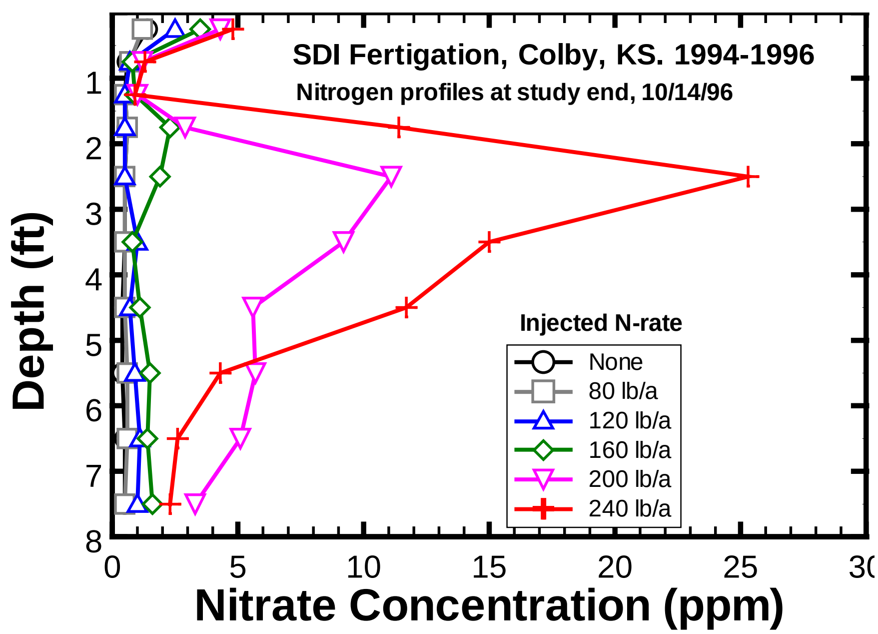

Figure 12. Nitrate concentrations within the 8 ft soil profile as affected by SDI fertigation N rate after four years of continuous application, KSU Northwest Research-Extension Center, Colby Kansas.

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). All treatments received a pre-plant broadcast surface application of 125 lbs N/acre in the form of UAN 32-0-0. Additional targeted SDI N fertigation events of 70 lbs N/acre (UAN 32-0-0) 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 3).

Table 3. 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 Kernels/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

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. Averaged over the two years, supplemental nitrogen fertigation at the V6 stage was most beneficial to grain yield response when the crop was fully irrigated, particularly in 2010. In contrast, timing of the nitrogen fertigation had little effect on the deficit irrigated treatments. When supplemental nitrogen fertigation was not added to the base 125 lbs/acre preplant-applied nitrogen, corn grain yields were greatly reduced with a 44% reduction in the more normal year, 2010 and a 25% reduction in the drought year, 2012. The lack of supplemental nitrogen fertigation greatly reduced grain yields and water productivity in both years.

Differences in the intermediate yield component, kernels/area (i.e., plants/area x ears/plant x kernels/ear) could explain the corn grain yield differences for the fully irrigated V6 treatment in 2010 and for the non-fertigated treatment in both years (Table 3 and Figure 13). Generally, the potential kernel number is set between V6 and V9, while the actual kernel number is finalized by about 2 weeks after pollination (R1 growth stage). The lack of the supplemental nitrogen fertigation had the greatest effect on the kernels/area value in the more normal year 2010.

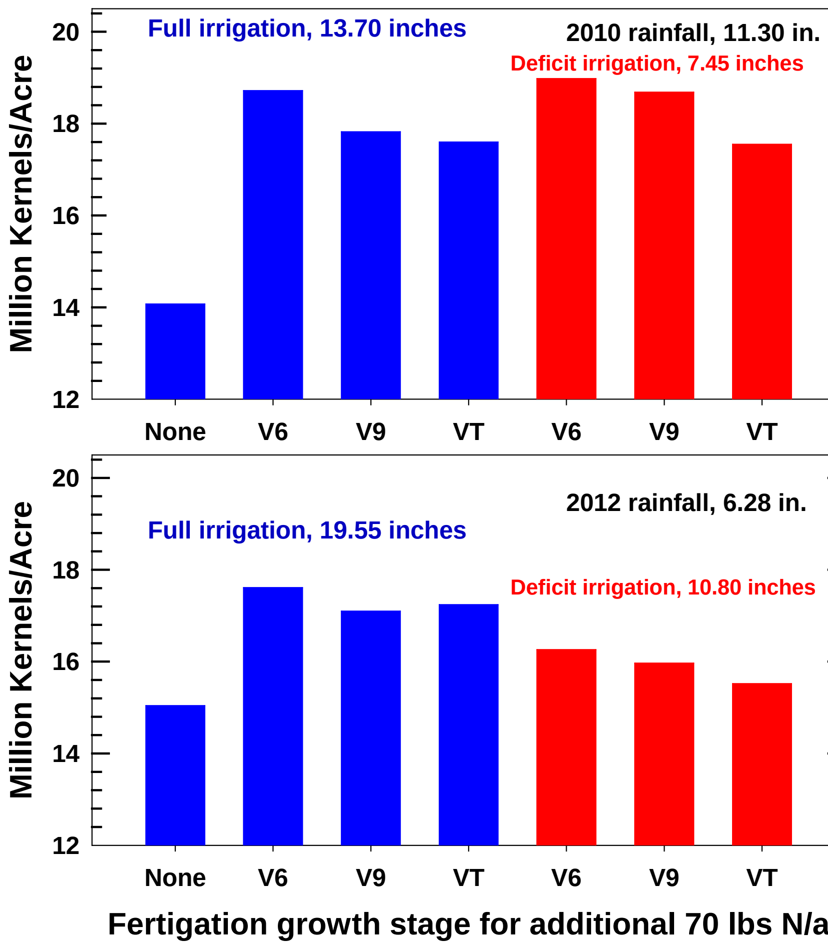

Figure 13. Kernels per unit land area as affected by irrigation regime and supplemental nitrogen fertigation timing for a subsurface drip irrigated corn study at the KSU Northwest Research-Extension Center, Colby, Kansas, 2010 and 2012.

Kernel mass was greatest for the fully irrigated V6 fertigation treatment in 2010 and was much lower when there was no supplemental fertigation in both years (Table 3 and Figure 14). Timing of fertigation had little or no effect on kernel mass in the drought year 2012. The lack of the supplemental fertigation had the greatest effect on kernel mass in the more normal year 2010.

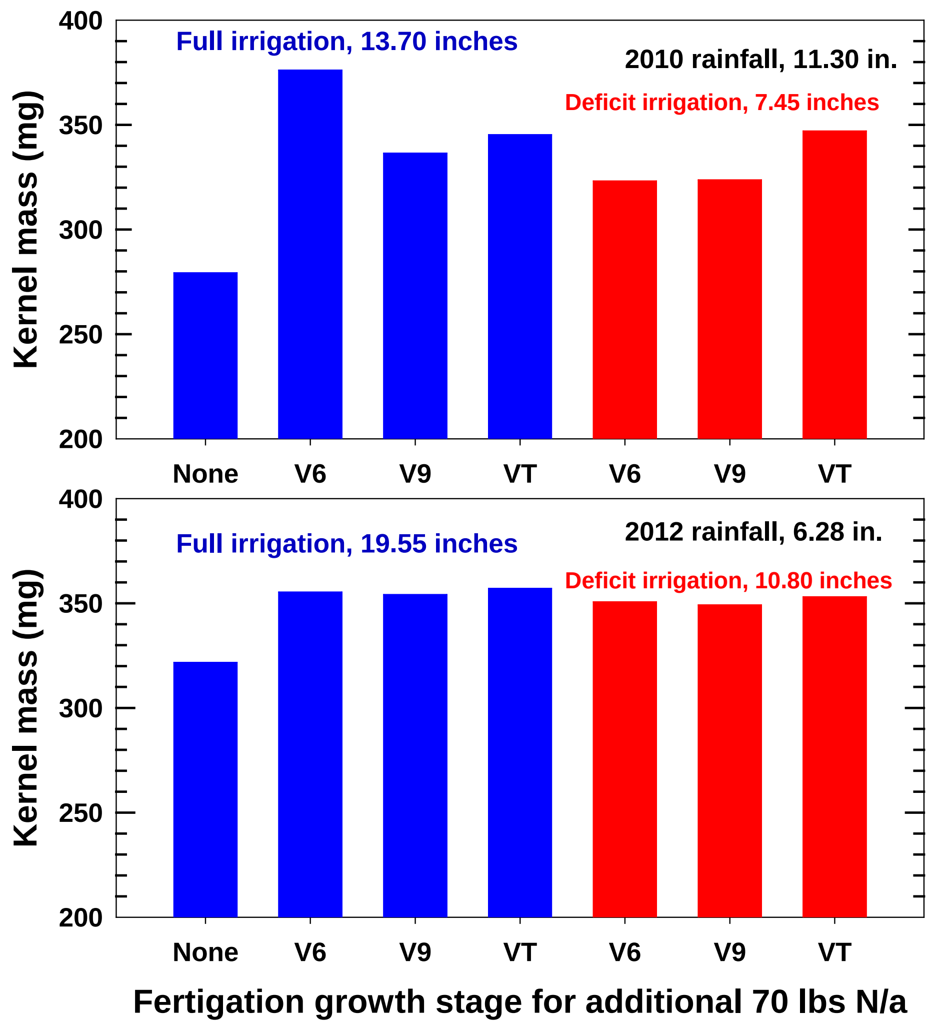

Figure 14. Kernel mass as affected by irrigation regime and supplemental nitrogen fertigation timing for a subsurface drip irrigated corn study at the KSU Northwest Research-Extension Center, Colby, Kansas, 2010 and 2012.

Appropriate timing of N fertigation had the greatest positive effect under full irrigation in the more normal year 2010, because of both greater kernels/area and much greater kernel mass. Conjunctive management of both irrigation and in-season N fertigation are important for corn production with SDI.

PHOSPHORUS FERTIGATION FOR SDI CORN

A study was conducted at the KSU Northwest Research-Extension Center at Colby, Kansas from 2015 to 2017 to examine timing of in-season phosphorus fertigation for corn production using SDI. The fertilizer treatments, yield and water use results are shown in Table 4.

Table 4. Fertilizer treatments, corn yield and water use parameters in a phosphorus fertigation study using SDI at KSU-NWREC, Colby, Kansas from 2015 to 2017. Note: All treatments received a total of 220 lbs N/acre and 40 lbs P/acre in each year.

Fertilizer Treatment	Applied at Planting	In-season Fertigation		
		5 to 10 Leaves	11 Leaves to Tasseling	Tasseling to Blister Kernel
1 No P fertigation	44 lbs N/a, 40 lbs P/a + banded Zinc	66 lbs N/a	66 lbs N/a	44 lbs N/a
2 P Fertigation Trt 1	44 lbs N/a, 24 lbs P/a + banded Zinc	66 lbs N/a, 4 lbs P/a	66 lbs N/a, 8 lbs P/a	44 lbs N/a, 4 lbs P/a
3 P Fertigation Trt 2	44 lbs N/a, 16 lbs P/a + banded Zinc	66 lbs N/a, 8 lbs P/a	66 lbs N/a, 12 lbs P/a	44 lbs N/a, 4 lbs P/a
4 P Fertigation Trt 1	44 lbs N/a, 24 lbs P/a + 50% banded Zinc	66 lbs N/a, 4 lbs P/a + 25% foliar Zinc	66 lbs N/a, 8 lbs P/a	44 lbs N/a, 4 lbs P/a
5 P Fertigation Trt 2	44 lbs N/a, 16 lbs P/a + 50% banded Zinc	66 lbs N/a, 8 lbs P/a + 25% foliar Zinc	66 lbs N/a, 12 lbs P/a	44 lbs N/a, 4 lbs P/a

Fertilizer Treatment No.	Yield (bu/a)	Plant Density (plants/a)	Ears /Plant	Kernels /Ear	Kernel Mass (mg)	Crop Water Use (in)	Water Productivity (lb/acre-in)
Crop Year, 2015							
1	246	34412	0.97	562	332	28.97	476
2	278	33541	1.00	609	346	28.68	544
3	260	33323	0.99	595	336	29.13	501
4	273	33977	0.99	623	332	27.53	555
5	266	33541	0.99	607	337	27.69	539
Crop Year, 2016							
1	258	33323	1.00	536	368	25.16	575
2	276	33323	0.99	591	361	25.26	612
3	284	33106	1.00	600	362	25.44	624
4	274	33759	0.99	590	354	25.52	602
5	272	33541	0.98	568	370	25.60	595
Crop Year, 2017							
1	286	34195	0.99	587	364	27.62	579
2	288	34195	1.01	585	364	27.20	593
3	295	34412	1.01	583	368	28.28	584
4	295	34630	1.01	584	368	27.67	597
5	301	34412	1.00	607	366	28.01	601
Mean of All Years							
1	**263 B**	33977	0.99	561	35.5	27.25	**543 B**
2	**281 A**	33686	1.00	595	35.7	27.05	**583 A**
3	**280 A**	33614	1.00	593	35.6	27.61	**570 AB**
4	**281 A**	34122	0.99	599	35.1	26.91	**585 A**
5	**280 A**	33832	0.99	594	35.7	27.10	**578 A**

Column data followed by different levels are significantly different at P<0.05.

All treatments received the same amount of nitrogen and phosphorus fertilizer (220 lbs N/acre and 40 lbs P/a, respectively), but Treatments 4 and 5 missed a 25% addition of fertigated Zinc at the 11 leaves to tasseling stage in all three years of the study.

Overall grain yields were excellent (Table 4) and although there were no statistically significant differences (P<0.05) in yields in individual years, there was a strong numerical trend for greater yield for in-season phosphorus fertigation. When the data was analyzed over all three years, there was a statistically significant grain yield increase with in-season phosphorus fertigation. There were no significant differences in crop water use, but water productivity was significantly greater for in-season phosphorus fertigation when averaged over the three years. There was no appreciable effect of how the fertigated phosphorus was applied within the three growth stages.

CONCLUDING STATEMENTS

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.

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.

OTHER AVAILABLE INFORMATION

Subsurface Drip Irrigation website: www.ksre.ksu.edu/sdi

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