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Long Term Performance of a Research Subsurface Drip Irrigation System

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ABSTRACT. *System longevity of systems is an important economic factor to minimize amortized investment costs for subsurface drip irrigation (SDI) systems, especially when growing lower valued commodity crops. Kansas State University established a research site to study SDI in 1989 and one research study area was used for continuous production of SDI corn for 27 seasons without replacement. This paper discusses the long term performance of this system and the implications of its longevity. The system was abandoned at the end of the 2015 crop growing season due to leaks arising from breakdown in the plastic material.*

Keywords. *drip irrigation, distribution uniformity, flow variation, microirrigation, subsurface drip irrigation,*

Introduction

The predominant irrigation system for irrigated commodity crop production in the Central Great Plains is center pivot sprinkler irrigation [54, 99, and 88% of total irrigated land area in Colorado, Kansas and Nebraska, respectively according to USDA-NASS (2014)]. Although SDI land area in the Central Great Plains is currently less than 1% of the total irrigated area, it is growing at a rapid pace having increased 127 and 176% in Kansas and Nebraska, respectively, in the last 5 years according to the data (USDA NASS, 2010, 2014).

Subsurface drip irrigation (SDI) for commodity cereal, oilseed, and forage crop production is a viable alternative to surface and sprinkler irrigation in the Great Plains region. Subsurface drip irrigation systems are expensive and their economic competitiveness against alternative irrigation systems greatly depends on SDI system longevity. In the spring of 2002, K-State Research and Extension introduced a software spreadsheet for making economic comparisons of center pivot sprinkler irrigation (CP) and SDI systems for corn production (Lamm et al., 2016). Over the years, sensitivity analyses provided by the software indicate that SDI system longevity is a key factor in the economic competitiveness of SDI systems with CP systems (Lamm et al., 2015). Since that time, the spreadsheet has been periodically updated to reflect changes in input data, particularly system and corn production costs. When growing the lesser-value commodity crops, a SDI system that can be amortized over many years is an economic necessity to compete with less expensive CP systems. The competitiveness of SDI increases when a larger proportion of the field is irrigated with SDI than possible with CP systems (i.e., as much as 25% greater land area for SDI as compared to full circle CPs within square fields). Using current economic assumptions for full-sized quarter-section fields (160 acres), SDI systems are not very competitive with CP systems unless they have longevity upward of 15 years (Fig. 1). For SDI longevities of less than 10 years, producers would be facing a significant economic disadvantage by choosing SDI over CP for Great Plains commodity crop production for full-sized fields. With an SDI system life of about 22 years, SDI and CP systems have nearly equal competitiveness using current economic assumptions for full-sized fields (Lamm et al., 2016).

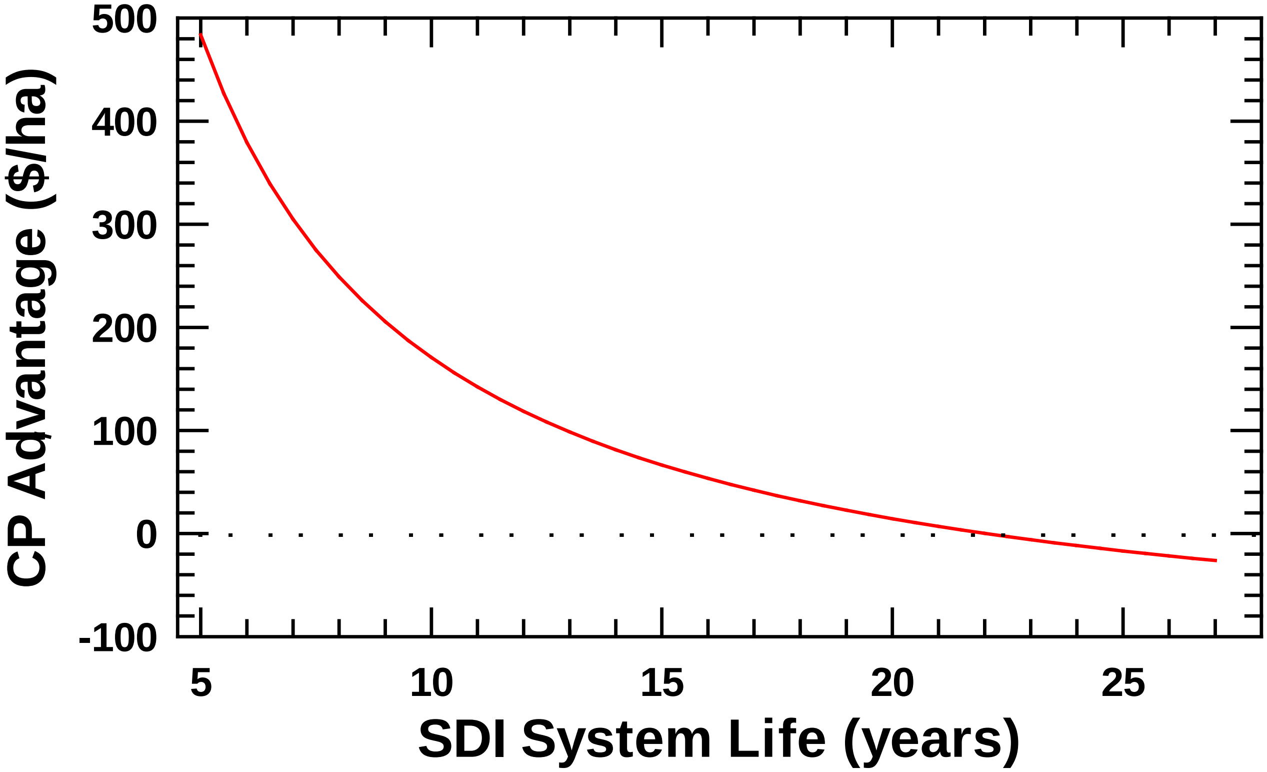


Figure 1. The annual economic advantage of center pivot sprinkler irrigation over SDI for corn production as affected by longevity of the SDI system (Data from KSU software using 2016 economic assumptions, Lamm et al., 2016).

There are a few studies in the published literature which discuss long term performance of SDI systems. In a study in the southeastern Coastal Plains of the USA, Camp et al. (1997) concluded SDI systems could be used with adequate uniformity for at least 10 years without replacement. In their evaluation of two surface drip irrigation (DI) systems and one SDI system, they found greater coefficient of variation (CV=0.186) for SDI emitters as compared to the DI emitters

(CV=0.029). This difference was attributed to greater clogging from soil entrance into the SDI emitters that occurred either at system installation or during system operation over the years. Distribution Uniformity (DU) values of 96.6% and 83.2% were obtained for the DI and SDI systems, respectively with new unused tubing averaging 98.4%. In a study at the University of California West Side Field Station, Ayars et al. (1999) concluded SDI system could be used for at least nine years with Christiansen Uniformity Coefficients greater than 95% as long as measures to prevent root intrusion were employed. In a performance evaluation of 18 commercial SDI systems in west Texas that had been in use between 8 and 20 years, Enciso-Medina et al. (2011) found two-thirds of the systems had flow variation (Q_{var}) less than 20% and lower quartile distribution uniformity (DU_{lq}) greater than 80 which would be rated acceptable, and one-third of the systems had Q_{var} less than 10% and DUlq greater than 90 which would be rated good to excellent uniformity. They reported that lack of adequate operational and maintenance procedures may have exacerbated some of the performance problems.

Research with SDI systems at the Kansas State University Northwest Research-Extension Center at Colby, Kansas began in 1989 (Lamm and Rogers, 2014) and the first system installed in 1989 was successfully operated for 26.5 years before being abandoned in the fall of 2015. Layflat thin-walled collapsible driplines (also known as drip tapes) were starting to randomly fail in the dripline creases. Although, a few more years might have been acceptable with a small proportion of leaks on a producer’s field, the leaks were unacceptable for the research field. Another study field at the Center failed for similar reasons after 22 years of usage. Industry evaluation of driplines from that earlier field concluded the bonds in the plastic were beginning to break down after the many years of usage. This paper discusses the long term performance of the research system installed in 1989 and abandoned in the fall of 2015 and the implications of the system’s longevity.

Procedures

The SDI system was installed in March 1989 at the KSU Northwest Research-Extension Center at Colby, Kansas on a deep, well-drained, loessial Keith silt loam (Aridic Argiustoll). This medium-textured soil, typical of many western Kansas soils, is described in more detail by Bidwell et al. (1980). The 2.4 m soil profile will hold approximately 585 mm of plant available soil water at field capacity as determined from an unpublished drainage study conducted adjacent to this study site in 1990 and 1991. This corresponds to a volumetric soil water content of approximately 0.37 and a profile bulk density of approximately 1.3 gm/cm^3. The climate can be described as semi-arid, with an average annual precipitation of 474 mm and approximate, annual, lake evaporation of 1400 mm.

The SDI system (Lamm et al. 1990) had dual-chamber dripline (Chapin brand Turbulent Twin-Wall IV) with an emitter spacing of 0.3 m installed at a depth of approximately 40-45 cm with a 1.5 m spacing between dripline laterals. The emitter type was a long path labyrinth created by film indentation at manufacturing. The nominal emitter discharge was 0.57 L/h for a system application rate of approximately 1.22 mm/hour. The emitter exponent as obtained from the manufacture was 0.533. The site was planted to corn during each of the 27 seasons (1989 to 2015) with each dripline lateral centered between two corn rows. The 1.2 ha study area was approximately 140 m wide and 90 m long with land slope of approximately 0.5% accommodated 23 research plots that were 6 m wide by 90 m long, running north to south. This corresponds to eight 76 cm rows with driplines spaced every 1.5 m between corn rows. The outer edge plots (plots 1 and 23) on the east and west edges of the study site were not used for research but were constructed, operated and maintained in a similar fashion to the plot area. Irrigated corn field studies conducted on the site had differing objectives throughout the 26.5 year period but all plots received at least some irrigation each year and typically a considerable amount of dormant season irrigation in the fall to even out plot differences before the next cropping season. The average corn yield from three replications of the highest SDI yielding treatment in each year were charted over the 27 seasons as anecdotal evidence of crop performance for the system.

Chemical maintenance treatment was limited to chlorine bleach (5.25% sodium hypochlorite) injections of approximately 50 ml/kl of source water near system startup and in the fall during approximately the first 15 years of the study and only in the fall during the remaining years. It had been determined the system was not experiencing appreciable biological clogging, so the spring chlorine bleach injections were suspended. The system never received any acid injections although the water quality tests (Table 1) would suggest a moderate chemical clogging hazards according to typical classifications due to bicarbonate concentrations (Rogers et al., 2003a). Since the system is below ground the emitters do not have an exposed evaporation face which may help to avoid some precipitation clogging hazards.

Table 1. Water quality for the SDI system water source as measured in 1999, KSU Northwest Research-Extension Center.

Parameter or Chemical Constituent	Level
Nitrate-Nitrogen	4.4 mg/L and 0.31 meq/L
Chloride	7 mg/L and 0.20 meq/L
Sulfate	21 mg/L and 0.44 meq/L
Sulfate-Sulfur	7 mg/L and 0.44 meq/L
Carbonate	<1 mg/L and <0.03 meq/L
Bicarbonate	228 mg/L and 3.74 meq/L
Calcium	46 mg/L and 2.3 meq/L
Magnesium	18 mg/L and 1.48 meq/L
Sodium	26 mg/L and 1.13 meq/L
Potassium	6 mg/L and 0.15 meq/L
Iron	0.005 mg/L
Total Dissolved Solids	279 mg/L
Electrical Conductivity	0.44 mmho/cm
Sodium Absorption Ratio (SAR)	0.8
Adjusted SAR	1.6
Water pH	7.80
Water pHc	7.35

Pressure and flow tests were conducted annually in the fall on the SDI system. From 1989 through 2002, the pressures at the plot inlet and flushline outlet were measured with bourdon tube pressure gages (Senninger brand pressure gages with accuracy of 0.5% of full scale 205 kPa). Individual gages were used on each inlet and outlet and to increase accuracy, the gages were cross calibrated to a known water column height approximately every 2 years. Inlet and outlet pressure measurements were also adjusted to account for small elevation changes within the field. In 2003, it was decided that the pressure measurement accuracy could be improved by using electronic pressure transducers. From 2003 until 2009, PSI-Tronix PG2000 pressure transducers (0-205 kPa range) were used with accuracy to approximately 1 kPa and after 2009, GE Druck DPI 104 pressure transducers (0-205 kPa range) were used with accuracy to approximately 0.1 kPa. Municipal grade positive displacement flow (nominal size 16 mm x 13 mm) made by Kent/ABB were used from 1989 until 2010 and Arkal brand flow accumulators were used after 2011. During approximately the last 15 years of the study the flow accumulators were checked for accuracy during the offseason. Any flow accumulators indicating greater than +/- 1.5% from a known 40 L amount were removed from service. Pressure and flow tests were conducted at both 68.9 and 82.7 kPa in each year with the measurements at the greater pressure serving as a quality control measurement. These pressure changes were accommodated by adjusting a throttling gate valve on each flow control assembly (Lamm et al., 1990). All plot flowrates were normalized back to a standard nominal 68.9 kPa using a manipulation of the emitter discharge equation:

$$Q_n = Q_m \; (P_n{}^x / \, P_m{}^x) \qquad \text{Eq 1.}$$

where Q_n is the normalized flowrate at the standard nominal pressure (P_n) of 68.9 kPa, P_m was the actual measured pressure and x is the emitter exponent of 0.533 as provided by the dripline manufacturer (Chapin). The inlet pressure was used during all the normalized flowrate comparisons although the average inlet and outlet pressures could have been used with very little differences in the results due to the shorter field length (i.e., small friction losses) and the small elevation changes. The normalization process allowed all measurements to be standardized to the nominal pressure and helped to correct for small differences in inlet pressure (e.g., 0.1 to 0.2 kPA) as small fluctuations occurred during the initial adjustment to 68.9 kPa.

Observable leaks were repaired during the life of the system as they occurred. Sometimes small leaks were not discovered until anomalies were seen in annual pressure and flow tests. Leaks were rather uncommon and varied from rodent damage to leaking connectors at the inlet or flushline submains. Some small leaks that were mainly discovered in the first years of the study were related to mechanical damage from the dripline injection shank (e.g., a rough wear spot in the shank). In a few very rare instances, a leak was attributed to wireworm damage. During the final two years of the system operation, random leaks became more common and more difficult to repair as the crease area of the collapsible dripline became more fragile and subject to rupture. However, it is believed these leaks had been repaired at the time of the fall pressure and flow tests. For example, when larger anomalies were discovered in the normalized plot flow measurements, manual observations of the plot area were conducted to look for the cause and attempts to correct it were made before continuing the pressure and flow tests.

After the final pressure and flow tests with a fully intact system were conducted, a hole was excavated around individual emitters in a random selection of one of the four driplines for each of the 23 plots at randomly selected distances of 7.5, 23, 38, 69 or 84 m to allow for in-situ emitter discharge and pressure measurements. The pressure at the plot inlet was standardized at 68.9 kPa for these measurements. Water was collected for a total of 20 minutes in a plastic cup within another cup placed beneath each selected emitter (Fig. 2). A short cotton string was wrapped around both sides of the emitter to direct water droplets into the cup to prevent indiscriminate flow along the dripline. After the 20 minute period the water in the inner plastic cup was weighed in the field with an electronic balance to the nearest 0.1 gm for emitter discharge calculations. Two twenty-minute samples were collected and averaged to determine the emitter discharge. Pressure measurements were measured to the nearest millibar by puncturing the dripline near the emitter with a needle tube attached to a Tensimeter brand pressure transducer (Fig. 3).

After the emitter discharge and pressure measurements at the randomized distances were made, approximately 20 m lengths of dripline were excavated from one of the center two driplines in each plot beginning at approximately 30 m from the plot inlet (i.e., roughly a section in the center of the 90 m length). This was accomplished using a tractor-mounted V-blade ditcher that removed the soil overburden within 5 to 7 cm of the dripline depth (Fig. 4). The dripline was then manually removed by gently tugging the dripline from the remaining soil (Fig. 5). These dripline lengths were carefully folded into 115 L plastic bags for storage until emitter performance measurements were conducted in the laboratory. Immediately prior to laboratory measurements the remaining surface soil residues were carefully removed with a wet sponge and clean water. A series of up to 6 of the total of 23 driplines could be mounted at one time on the laboratory test bench for emitter discharge measurements (Fig. 6). An approximately 9 m section of the 20 m that had been excavated was randomly selected for performance measurements. This is equivalent to 30 contiguous emitters provided that all emitters were functioning. In a few cases, a random split in the dripline crease related to the overall SDI system failure necessitated a repair connection which decreased the emitters by one for each repair. Water was collected for a 20 minute period at both 55. 2 and 68.9 kPa before volume determinations were made from mass measurements on an electronic scale. Both sets of results at the different pressures were normalized to the design pressure of 68.9 kPa.

In addition to measurements on the excavated driplines, performance of three unused sections of the same brand and model dripline was determined from some dripline that had been in storage from a similar SDI installation at the Center in 1990. However, it should be noted that this unused dripline would have been from a different lot of product from the manufacturer.

Figure 2. Arrangement for measuring emitter discharge over a 20 minute period.

Figure 3. Measuring dripline pressure at the emitter by puncturing the dripline with a needle tube attached to a pressure transducer.

Figure 4. Excavating the overburden over driplines selected for laboratory performance measurements.

Figure 5. Careful extrication of the dripline from the remaining 5 to 7 cm of soil overburden.

Figure 6. Laboratory bench arrangement for measuring emitter discharge from 30 contiguous emitters.

Performance measurements selected for discussion are coefficient of variation, CV, distribution uniformity, DU_{lq}, Christiansen Uniformity Coefficient, U_C and emitter flow variation, Q_{var} where

$$CV = (\frac{Q_{stdev}}{Q_{avg}}) \qquad \text{Eq 2.}$$

where Q_{stdev} is the standard deviation of emitter discharges and Q_{avg} is the mean emitter discharge within the test section and

$$DU_{lq} = 100\ (\frac{Q_{lq}}{Q_{avg}}) \qquad \text{Eq 3.}$$

where Q_{lq} is the average emitter discharge of the lower quartile of the measured emitter flows and

$$U_C = 100\ (1 - ((\sum\left|Q - Q_{avg}\right|)/\sum Q) \qquad \text{Eq 4.}$$

where Q is the emitter discharge for each of all the emitters and

$$Q_{var} = (1 - \frac{Q_{min}}{Q_{max}}) \qquad \text{Eq 5.}$$

where Q_{min} and Q_{max} are the minimum and maximum emitter discharges within the test section.

Coefficient of variation for emitters in a line source is consider good when less than 10%, average when between 10 and 20%, and marginal to unacceptable when greater than 20% (ASAE ,2011). The lower quartile distribution uniformity (DU_{lq}) is analogous to a field-measured emission uniformity. The recommended design emission uniformity is 80 to 90 for line source microirrigation laterals on slopes of less than 2% (ASAE, 2011). Acceptable Christiansen Uniformity (UC) values of greater than 87% are typically considered acceptable for microirrigation systems for high value crops or when agrochemicals are being applied through the system (Haman et al., 1997). Emitter flow variation (Q_{var}) of less than 10% is considered desirable, less than 20% is consider acceptable and greater than 20% is considered unacceptable (Bralts et al., 1987). Many of these uniformity terms can be statistically correlated and often it is a matter of personal preference as to which parameter is chosen.

Extensive failure analysis was conducted by Dow Chemical on samples from the 1989 field and the unused dripline from 1990 storage. The entirety of those results will be in a subsequent report but briefly some discussion of photos with a scanning electronic microscope will be included here.

Results and Discussion

Time Series of Plot Flowrates

Results indicate that plot flowrates at the end of the 26.5 year period were within +/- 5% of their initial first annual value (Fig. 7). There were fluctuations in measured plot flowrates over the years with a few higher flowrates representing small leaks that were finally located between annual measurements and some flowrate reductions that were probably short term clogging events that were remediated through maintenance. The transition from bourdon-tube pressure gages to electronic pressure transducers in 2004 (year 14) resulted in a marked reduction in plot to plot variation probably reflective of less true plot flowrate variation. Overall, the SDI system had performed well over this long time series.

Corn Yield throughout SDI System Life

Corn grain yields from the highest yielding SDI treatment for each year were used as further anecdotal evidence of SDI system performance. Corn grain yields averaged 14.6 Mg/ha over the life of the SDI system with the exclusion of the year 2011 when a devastating hail storm resulted in no crop yield (Fig. 8). There was no discernible pattern in grain yields attributable to the system life with notable yield reductions occurring due to poor growing conditions in 1993, some hail damage in 1995 and spider mite insect damage in 2003 and 2013.

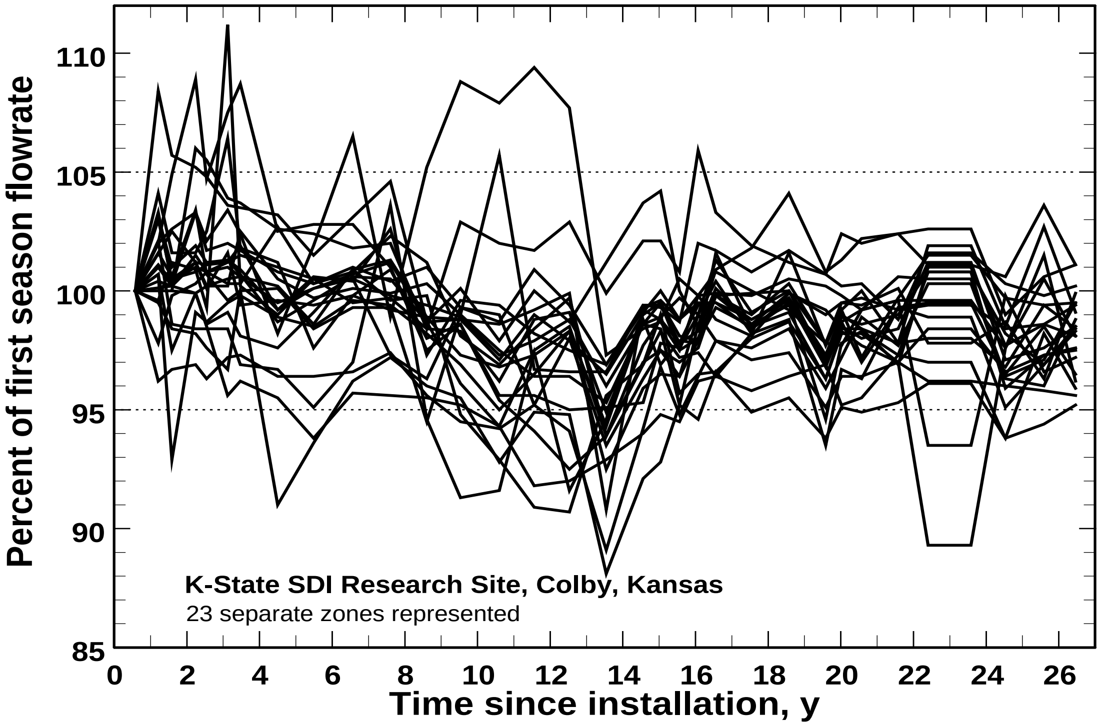


Figure 7. Plot flowrates as affected by years of operation for a 23-zone research SDI system at the KSU Northwest Research-Extension Center, Colby Kansas (1989-2015).

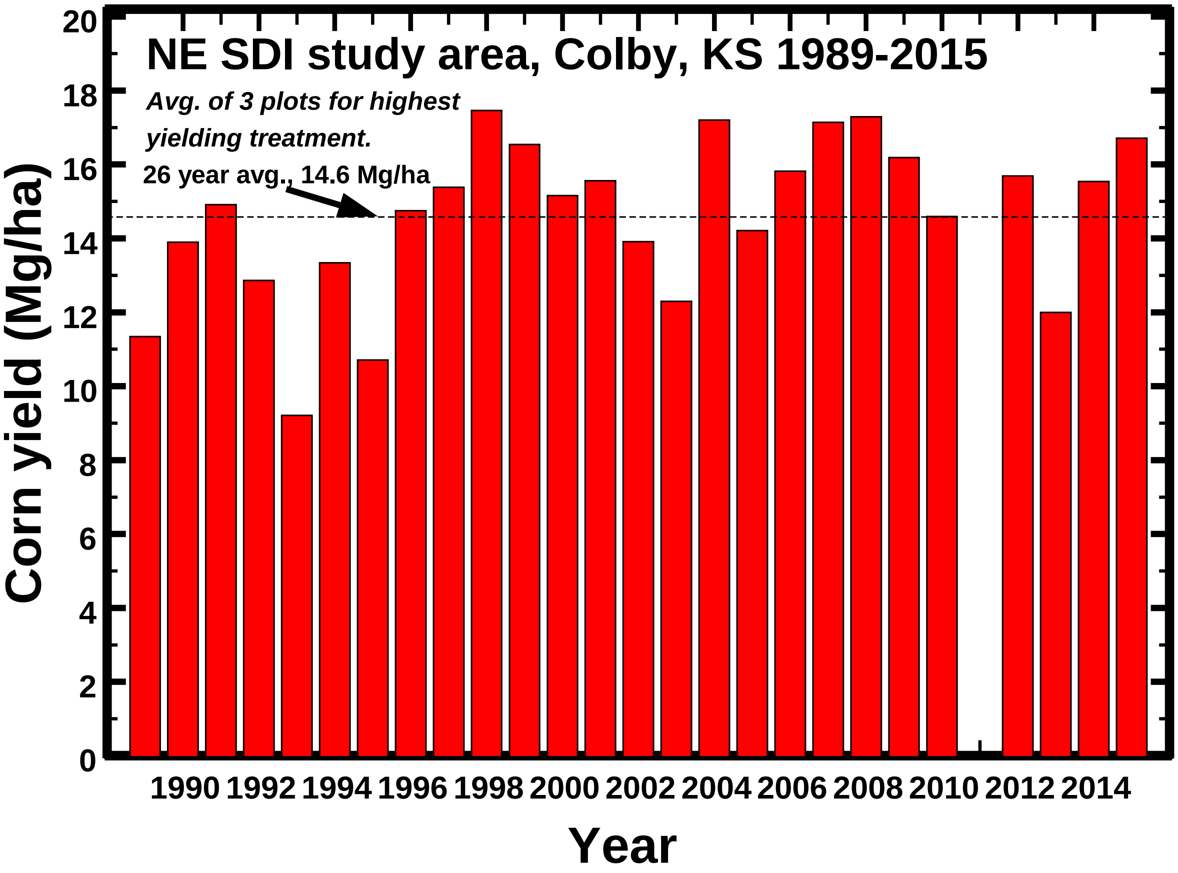


Figure 8. Corn grain yield as affected by years of operation for a research SDI system at the KSU Northwest Research-Extension Center, Colby Kansas (1989-2015). The crop was destroyed by a devastating hail storm in 2011.

In-situ Emitter Performance

Field measurements from 23 exposed emitters indicated that the system was performing well after 26.5 years (Table 2) considering that the nominal emitter discharge from the manufacturer is 0.57 L/h at a pressure of 68.9 kPa. The normalized mean measured emitter discharge was slightly greater (6%) than the nominal discharge (0.605 vs. 0.570 L/h), but the coefficient of variation was excellent at less than 3%. All of the uniformity parameters for the in-situ emitter performance would be in the acceptable or above range that were discussed in the Procedures section.

Table 2. Emitter performance as measured in-situ for the 23 plots in the research SDI system at the KSU Northwest Research-Extension Center, Colby, Kansas after 26.5 years of operation.

Parameter	Raw results at field measured pressure	Results normalized to 68.9 kPa
Number of measured emitters	23	23
Maximum emitter discharge, L/h	0.582	0.628
Minimum emitter discharge, L/h	0.522	0.577
Mean emitter discharge, L/h	0.551	0.605
CV	0.031	0.026
DU_{lq}	96.1	96.6
UC	97.5	97.8
Q_{var}	0.103	0.081

Excavated and Unused Dripline Emitter Performance

Average emitter discharge was approximately 10% greater for the excavated driplines from the field as compared to emitter discharge from the unused driplines. Uniformity parameters were actually slightly better for the excavated driplines than for the unused driplines. The differences in discharge and uniformity may be differences that occurred during the different manufacturing dates or lots or could be indicating increased discharge after many years of usage. All of the uniformity parameters for both the field excavated driplines and unused driplines would be acceptable or above in terms of performance with the exception of emitter flow variation (Q_{var}) which exceeded 10%. This emphasizes the fact that the reduced flow from individual emitters can negatively affect Q_{var} considerably while overall uniformity is still high. The appropriateness of Q_{var} as a uniformity parameter is greater when the minimum emitter discharge is related to lateral hydraulics and not caused by individual emitters clogging (Enciso-Medina et al., 2011).

Table 3. Emitter performance comparison for excavated 26.5 year old and unused driplines, KSU Northwest Research-Extension Center, Colby, Kansas. All results are normalized to 68.9 kPa.

Parameter	Driplines excavated from field	Unused driplines from storage
Number of measured emitters	23 driplines, total of 683 emitters	3 driplines, total of 90 emitters
Maximum emitter discharge, L/h	0.613	0.575
Minimum emitter discharge, L/h	0.540	0.495
Mean emitter discharge, L/h	0.590	0.537
CV	0.026	0.048
DU_{lq}	97.0	94.2
UC	98.1	95.9
Q_{var}	0.120	0.139

Comparison of In-situ and Excavated Emitter Performance

There were very little differences in the measured emitter performance between the in-situ and lab results. Average emitter discharge was approximately 2.5% greater in-situ than from lab results, but CV was identical at 2.6%. Other performance parameters were similar in value with the exception of Q_{var} which was greater (i.e., less desirable) in the lab results because of finding reduced emitter discharge in a few emitters of the large number of measurements (n = 683).

Overall, the small differences are likely the result of experimental variation. The similarity of results suggest that either methodology can be acceptable for evaluating long term SDI system performance. However, soil type may have an influence on this conclusion. On a sandy soil in South Carolina, Sadler et al. (1995) reported that removing soil overburden increased emitter discharge approximately 3 to 4% but indicated they did not expect excavation to cause appreciable errors in uniformity calculations.

Table 4. Emitter performance comparison for in-situ measurements as compared to lab results for longer 20 m excavated driplines, KSU Northwest Research-Extension Center, Colby, Kansas. All results are normalized to 68.9 kPa.

Parameter	Driplines excavated from field	Lab results from 20 m excavated driplines
Number of measured emitters	23	23 driplines, total of 683 emitters
Maximum emitter discharge, L/h	0.628	0.613
Minimum emitter discharge, L/h	0.577	0.540
Mean emitter discharge, L/h	0.605	0.590
CV	0.026	0.026
DU_{lq}	96.6	97.0
UC	97.8	98.1
Q_{var}	0.081	0.120

Potential for SDI System Longevity and its Implications

These results indicate that with a good design, installation, and maintenance protocol, an SDI system can have a long life in the Central Great Plains. There are a few SDI systems in the USA that have been operated for over 25 years without replacement (Lamm and Camp, 2007). There are other SDI systems on commercial farms in Kansas that are approximately 20 years old without replacement and it will be interesting to see how long they will remain operational. The ability to make SDI systems last 20 years or longer certainly has positive economic implications for the increased adoption of this technology (Fig. 1) for lower-valued commodity crops such as corn.

Although the individual “requirements” for long term successful operation of an SDI system would likely vary from one system to the next, attention to some key factors such as water quality, system design and installation, cropping system, and operator maintenance practices would likely increase system longevity (Rogers and Lamm, 2009). Several key installation issues were reported by Lamm et al. (1997). Avoid SDI installation either into excessively dry compacted or wet soils to avoid stretching and other damage to the dripline. Dripline depth should be uniform throughout the field, so that the planned depth of tillage operations can be obtained in all locations. Use quality assurance and control (QA/QC) on the extensive number of dripline connections to submains and flushlines. Choose a dripline connection procedure that is easy to successfully replicate and that will be durable for the anticipated life of the system. Maintenance for a well-thought-out SDI system, design, and installation is not necessarily complicated, but it must be timely and consistent throughout the life of the system. Part of the process in establishing a well-thought out system begins with the decision-making process before purchasing the system (Rogers et al., 2003b).

Failure of the SDI System

During the last few years of the system (2013-2015) a few driplines were starting to randomly fail in the crease. Note: the crease failed, not the seam in this dual-chambered dripline. Although, a few more years might have been acceptable with a small proportion of leaks on a producer’s field, the leaks were unacceptable for the research field. Another study field at the research center failed for similar reasons after 22 years of usage. These particular leaks are difficult to repair as the dripline continues to split in the dripline lateral direction at the failed crease.

Optical microscope images of cross sections of the excavated and unused driplines revealed differences in the wall of the dripline at the crease as compared to other locations within the dripline (Fig 9 and 10). Manufacturing machine direction surface striations were present along the inside of the unused dripline following the edge creases, but were absent in areas away from the crease.

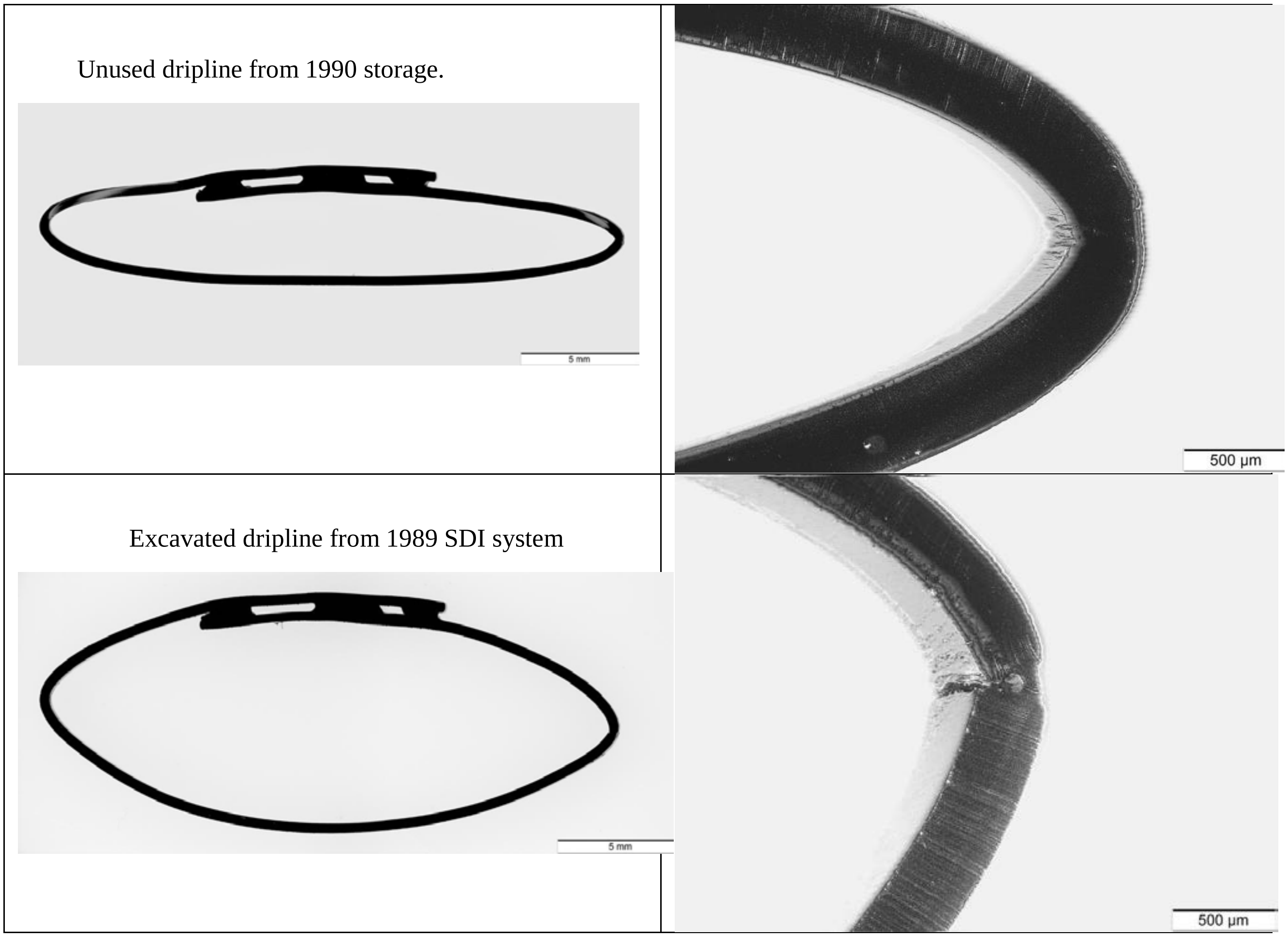
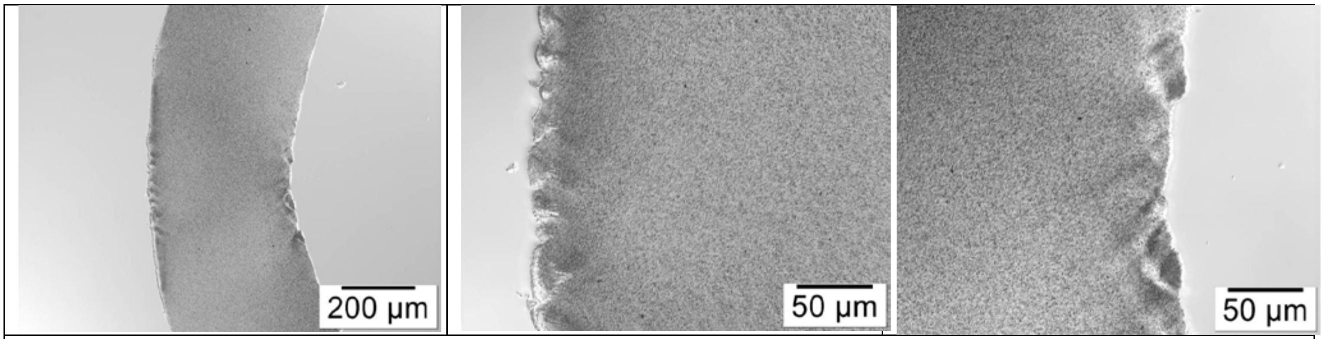


Figure 9. Cross sections of excavated and unused driplines as photographed by an optical microscope. The enlargements at the right indicate striations that existed in both the unused and used driplines, but the striations progressed to cracks in the used driplines.

Figure 10 contains higher magnification views of the cross section of the failure region of both the failed and unused driplines. Surface striations were present along the inner surface of the unused dripline which followed the edge crease. Outer surface deformations were also observed in the unused dripline. Sharp internal cracks were present on the inside surface of the failed dripline in the crease region but not on the outside surface of the dripline or areas away from the crease region.

Figure 11 contains scanning electron microscope images of the inner surface of the unused and excavated driplines in the crease area. The excavated dripline exhibits surface cracks propagating into the wall whereas the unused dripline exhibits only striations. Machine direction striations were observed in the crease area of the unused drip line. It is believed that these striations were caused by strain applied when the tape is collapsed. Since the unused drip line did not fail or exhibit surface cracking, it is concluded that these striations alone did not cause the failure. The failure was likely caused by a combination of factors including exposure to the internal liquid medium, strain and time.



Above: Unused dripline from 1990 storage: cross section, outer, and inner walls

Below : Excavated dripline from 1989 SDI system: cross section, outer, and inner walls

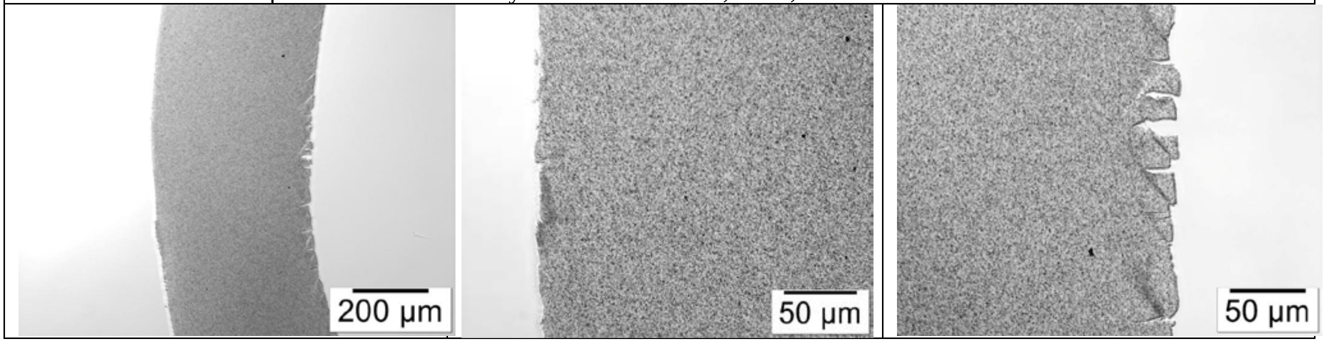
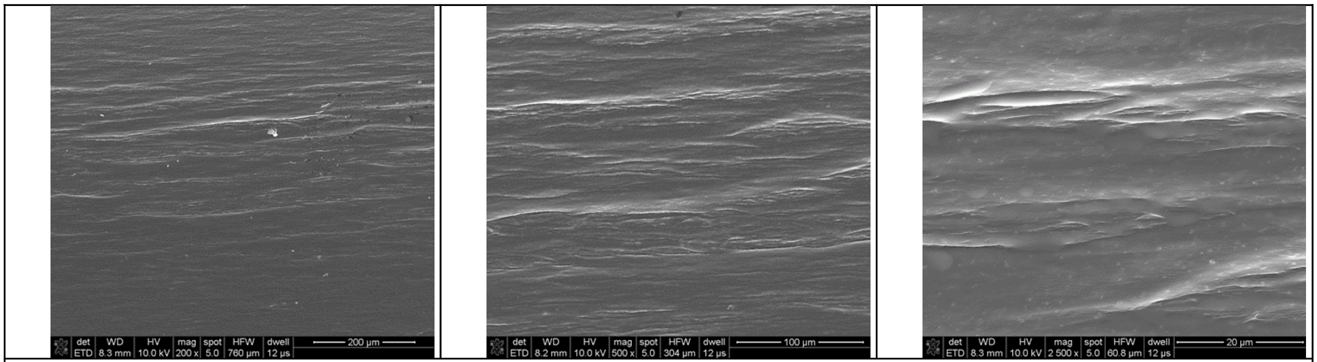


Figure 10. Inner and outer walls of excavated and unused driplines as photographed by a scanning electronic microscope. The striations and defects are more pronounced on the inner walls and are more ragged for the used driplines.



Above: New and unused dripline from 1990 storage showing inner surface at crease location

Below : Excavated dripline from 1989 SDI system showing inner surface at crease location

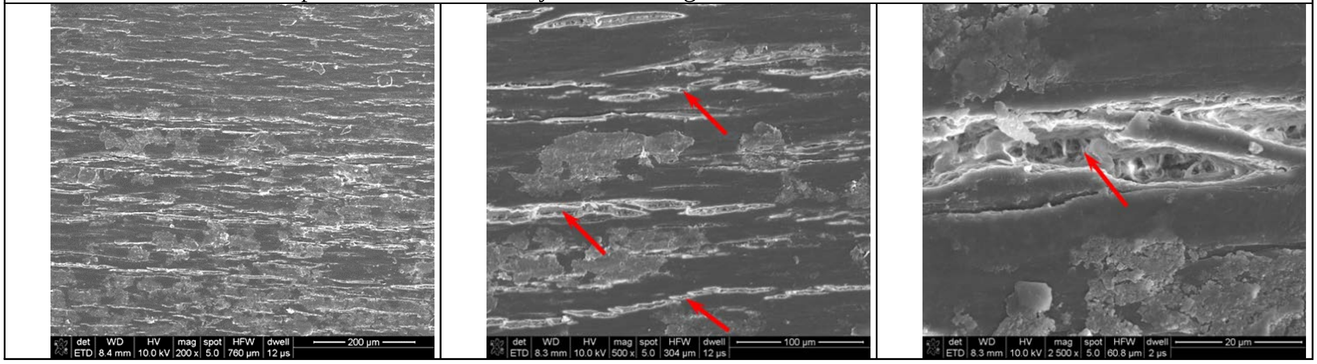


Figure 11. Inner surface of driplines at crease location using scanning electron microscope (SEM). Surface cracking is observed in the excavated dripline at the crease while not in the unused dripline

Summary and Conclusions

The longevity of SDI systems is one of the most important factors in improving the economic competitiveness of SDI with alternative pressurized irrigation systems such as center pivot sprinkler irrigation. The life of an SDI system needs to be upwards of 15 to 20 years to be economically competitive and this appears possible in the Central Great Plains with proper design, installation, and maintenance. A research system installed in 1989 at the KSU Northwest Research-Extension Center in Colby, Kansas had very good performance during its 26.5 year life. It was abandoned in the fall of 2015 not because of clogging and uniformity concerns, but because the dripline itself failed (split) at the crease location.

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