TECHNICAL NOTE:

LONGEVITY AND PERFORMANCE OF A SUBSURFACE DRIP IRRIGATION SYSTEM

F. R. Lamm, D. H. Rogers

ABSTRACT. *System longevity is an important economic factor to minimize amortized investment costs for subsurface drip irrigation (SDI), especially when growing lower-value commodity crops such as field corn. Kansas State University established a research site in 1989 at a research center to study SDI. One research study area was used for continuous production of SDI corn for 27 seasons without dripline replacement. Normalized plot flowrates for 23 separate plots after 27 seasons were within ±5% of their first annually measured value. Hydraulic performance of the driplines and emitters was measured* in situ *and in the laboratory for excavated dripline samples after the SDI system was decommissioned in the fall of 2015. There were similar results from both* in situ *and laboratory tests of the used driplines, with excellent coefficients of variation (CV) of approximately 3%, lower quartile distribution uniformities (DU_{lq}) of 96 to 97, and Christiansen uniformity coefficients (U_C) of approximately 98. The performance results of the excavated driplines were as good as or better than the performance of some unused driplines that had been in storage since 1990. Long SDI system life appears possible in the U.S. Central Great Plains when the systems are properly designed, installed, and maintained. The long system life (27 seasons and 26.5 years) improves the economic competitiveness of SDI with alternative irrigation systems such as center-pivot sprinkler systems, which are currently the predominant irrigation system in the region. The SDI system was decommissioned at the end of the 2015 crop growing season due to leaks arising from breakdown in the plastic material, rather than due to any clogging concerns and subsequent lower application uniformity.*

Keywords. *Distribution uniformity, Drip irrigation, Flow variation, Microirrigation, Subsurface drip irrigation.*

The predominant irrigation system for irrigated commodity crop production in the Central Great Plains is center-pivot sprinkler irrigation, which is used on 54%, 99%, and 88% of the total irrigated land area in Colorado, Kansas, and Nebraska, respectively (USDA-NASS, 2014). Although the subsurface drip irrigation (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 by 127% and 176% in Kansas and Nebraska, respectively, in the last five years (USDA-NASS, 2010, 2014). As water stress continues to increase in many parts of the world, including the Great Plains, it can be anticipated that SDI will be increasingly adopted because of its greater efficiency.

SDI is a viable alternative to surface and sprinkler irrigation for commodity cereal, oilseed, and forage crop production in the Great Plains region. Many of the advantages and disadvantages of SDI as compared to alternative irrigation systems are discussed by Lamm and Camp (2007). SDI systems are expensive, and their economic competitiveness against alternative irrigation systems greatly depends on SDI system longevity (Lamm et al., 2015). In 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 lesser-value commodity crops, an 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 is possible with CP systems (i.e., as much as 25% greater land area for SDI as compared to full-circle CP in square fields). Using current economic assumptions for full-sized quarter-section fields (65 ha, 160 acres), SDI systems are not very competitive with CP systems unless they have longevity of more than 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 pro-

Submitted for review in January 2017 as manuscript number NRES 12237; approved for publication as a Technical Note by the Natural Resources & Environmental Systems Community of ASABE in February 2017.

The authors are **Freddie R. Lamm, ASABE Fellow,** Professor, Northwest Research-Extension Center, Kansas State University, Colby, Kansas; **Danny H. Rogers, ASABE Fellow,** Professor, Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, Kansas. **Corresponding author:** Freddie R. Lamm, KSU Northwest Research-Extension Center, P.O. Box 505, Colby, KS 67701; phone: 785-462-6281; e-mail: flamm@ksu.edu.

  ISSN 2151-0032 https://doi.org/10.13031/trans.12237

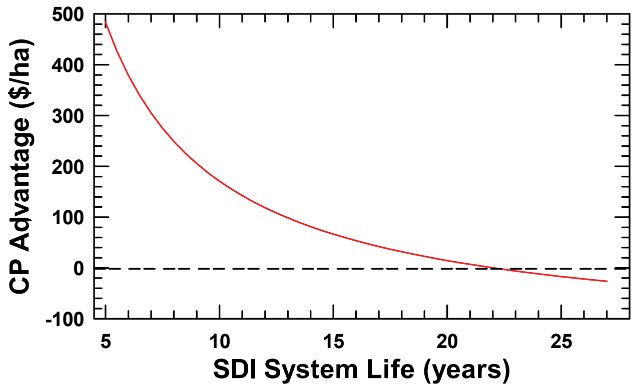

Figure 1. Annual economic advantage of center-pivot sprinkler irrigation over SDI for corn production as affected by the longevity of the SDI system (data from KSU software using 2016 economic assumptions; Lamm et al., 2016).

duction 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).

A few studies in the published literature discuss long-term performance of SDI systems. In a study in the southeastern Coastal Plains of the U.S., Camp et al. (1997) concluded that 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 a greater coefficient of variation (CV = 0.186) for SDI emitters as compared to 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 that an 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 for 8 to 20 years, Enciso-Medina et al. (2011) found that two-thirds of the systems had flow variation (Q_{var}) of less than 20% and lower quartile distribution uniformity (DU_{lq}) greater than 80, which would be rated acceptable (Bralts et al., 1987), and one-third of the systems had Q_{var} less than 10% and DU_{lq} greater than 90, which would be rated good to excellent. 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 (NWREC) in Colby, Kansas, began in 1989 (Lamm and Rogers, 2014), and the first system installed in 1989 was successfully operated for 27 seasons (26.5 years) before being decommissioned in the fall of 2015. Layflat thin-walled collapsible driplines (also known as drip tapes) were starting to fail randomly in the dripline creases in the last 3 to 4 years of the system's life. 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 NWREC failed for similar reasons after 22 years of usage. Industry evaluation of driplines from that earlier field concluded that the bonds in the plastic were beginning to break down after many years of usage. This technical note discusses the long-term performance of the research system installed in 1989 and decommissioned in the fall of 2015 and the implications of the system's longevity.

Procedures

The SDI system was installed in March 1989 at the NWREC in 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 holds approximately 443 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 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 to 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^{-1} at a nominal pressure of 68.9 kPa for a system application rate of approximately 1.22 mm h^{-1}. The emitter exponent as obtained from the manufacture was 0.533. The site was planted to corn during each of the 27 growing seasons (1989 to 2015) with each dripline lateral centered between two corn rows. The 1.2 ha study area was approximately 140 m wide by 90 m long with a land slope of approximately 0.5% and 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 four 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 as the plot area. Irrigated corn field studies conducted on the site had differing objectives throughout the 27 seasons, but all plots received at least some irrigation each year and typically a considerable amount of dormant season irrigation in the fall (150 to 200 mm) to even out plot differences in profile soil water contents before the next cropping season. It is estimated that each emitter had discharged between 2.7 and 5.7 m^3 of water during the 26.5-year period, given the variation in weather conditions and irrigation regimes. 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 mg kg^{-1} of source water near system startup in the spring and in the fall during approximately the first 15 years of the study and only in the fall during the remaining years. It was determined that the system was not experiencing appreciable biological clogging, so the spring chlorine bleach injections were suspended. The water source was the Ogallala aquifer, with a saturated thickness of approximately 30 m and very little annual recharge (<5 mm $year^{-1}$). The SDI system never received any acid injections, although the water quality tests (table 1) suggested moderate chemical clogging hazards according to typical classifications due to bicarbonate concentrations (Rogers et al., 2003a). Because the system was below ground, the emitters did not have an exposed evaporation face, which may have helped to avoid some precipitation clogging hazards.

Pressure and flow tests of the SDI system were conducted annually in the fall. From 1989 through 2002, the pressures at the plot inlet and flushline outlet were measured with Bourdon tube pressure gauges (Senninger brand pressure gauges with accuracy of 0.5% of full scale 205 kPa). Individual gauges were used on each inlet and outlet; to increase accuracy, the gauges were calibrated to a known water column height approximately every two 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 to 205 kPa range) were used with accuracy to approximately 1 kPa; after 2009, GE Druck DPI 104 pressure transducers (0 to 205 kPa range) were used with accuracy to approximately 0.1 kPa. Municipal-grade positive-displacement flow accumulators (nominal size 16 mm × 13 mm) made by Kent/ABB were used from 1989 until 2010; 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 downward from a standardized 138 kPa obtained by using Senninger low-flow 138 kPa pressure regulators (Lamm et al., 1990). Inlet pressure and dripline length are two important factors affecting uniformity (Perea et al., 2013). All measured plot flowrates (Q_m) were normalized back to a standard nominal 68.9 kPa using a manipulation of the emitter discharge equation:

$$Q_n = Q_m\left(P_n^x / P_m^x\right) \quad (1)$$

where Q_n is the normalized plot flowrate at the standard nominal pressure (P_n) of 68.9 kPa, P_m is 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 plot 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 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 that 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 min 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 min period, the water in the inner plastic cup was weighed in the field with an electronic balance to the nearest 0.1 g for emitter discharge calculations. Two 20 min samples were collected and averaged to determine the emitter discharge. Pressure measurements were measured to the nearest millibar by

Table 1. Source water quality for the SDI system at the KSU Northwest Research-Extension Center as measured in 1999.

Parameter or Chemical Constituent	Level
Nitrate-nitrogen	4.4 mg L^{-1} and 0.31 meq L^{-1}
Chloride	7 mg L^{-1} and 0.20 meq L^{-1}
Sulfate	21 mg L^{-1} and 0.44 meq L^{-1}
Sulfate-sulfur	7 mg L^{-1} and 0.44 meq L^{-1}
Carbonate	<1 mg L^{-1} and <0.03 meq L^{-1}
Bicarbonate	228 mg L^{-1} and 3.74 meq L^{-1}
Calcium	46 mg L^{-1} and 2.3 meq L^{-1}
Magnesium	18 mg L^{-1} and 1.48 meq L^{-1}
Sodium	26 mg L^{-1} and 1.13 meq L^{-1}
Potassium	6 mg L^{-1} and 0.15 meq L^{-1}
Iron	0.005 mg L^{-1}
Total dissolved solids	279 mg L^{-1}
Electrical conductivity	0.44 mmho cm^{-1}
Sodium absorption ratio (SAR)	0.8
Adjusted SAR	1.6
Water pH	7.80
Water pHc	7.35

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

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 in the center section 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

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.

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 gently removed with a wet sponge and clean water. A series of up to six of the 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

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

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 min period at both 55. 2 and 68.9 kPa before emitter 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 NWREC in 1990. However, it should be noted that this unused dripline would have been from a different lot of product from the manufacturer.

The 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}):

$$\mathrm{CV} = \left(\frac{Q_{sd}}{Q_{mean}} \right) \tag{2}$$

where Q_{sd} is the standard deviation of emitter discharges, and Q_{mean} is the mean emitter discharge within the test section.

$$DU_{lq} = 100 \left(\frac{Q_{lq}}{Q_{mean}} \right) \tag{3}$$

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

$$U_C = 100 \left(1 - \frac{\Sigma \left| Q - Q_{mean} \right|}{\Sigma Q} \right) \tag{4}$$

where Q is the emitter discharge for each of the emitters.

$$Q_{var} = \left(1 - \frac{Q_{min}}{Q_{max}} \right) \tag{5}$$

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

The 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% (ASABE, 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% (ASABE, 2011). Christiansen uniformity (U_C) 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., 2003). 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 (Wu et al., 2007).

RESULTS AND DISCUSSION

TIME SERIES OF NORMALIZED PLOT FLOWRATES

Results indicate that normalized 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 normalized 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 gauges to electronic pressure transducers in 2004 (year 14) resulted in a marked reduction in plot-to-plot variation, probably indicating a truer representation of plot flowrate variation. Overall, the SDI system 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^{-1} over the life of the SDI system, with the exclusion of the year 2011 when a devastating hailstorm 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.

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^{-1} 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^{-1}), but the coefficient of variation was excellent at less than 3%. All of the uniformity parameters for the *in situ* emitter performance would be evaluated as acceptable or better when based on the ranges noted in the Procedures section.

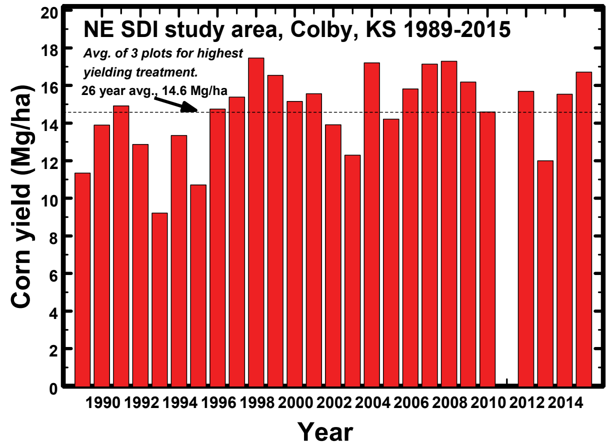

Figure 8. Corn grain yield as affected by years of operation for a research SDI system at the KSU Northwest Research-Extension Center in Colby, Kansas (1989-2015). The crop was destroyed by a devastating hailstorm in 2011.

Table 2. Emitter performance as measured *in situ* for the 23 plots in the research SDI system at the KSU Northwest Research-Extension Center in 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
Max. emitter discharge (L h^{-1})	0.582	0.628
Min. emitter discharge (L h^{-1})	0.522	0.577
Mean emitter discharge (L h^{-1})	0.551	0.605
CV	0.031	0.026
DU_{lq}	96.1	96.6
U_C	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 driplines excavated from the field as compared to the unused driplines (table 3). Uniformity parameters were actually slightly better for the excavated driplines than for the unused driplines. The differences in discharge and uniformity may be due to the different manufacturing

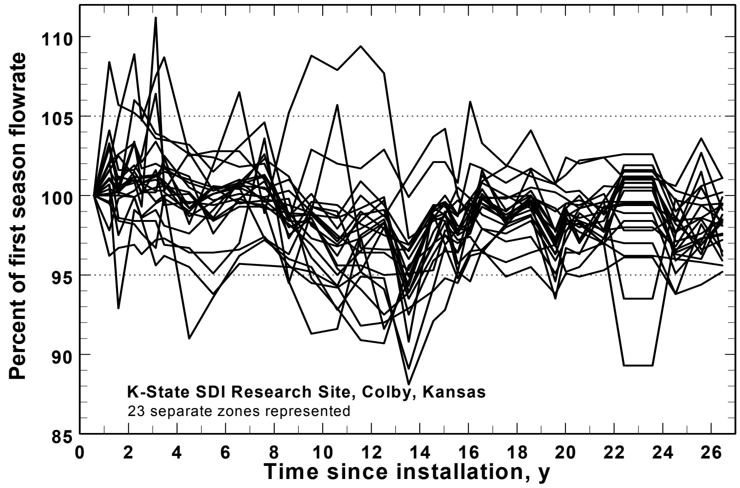

Figure 7. Normalized plot flowrates as affected by years of operation for a 23-zone research SDI system at the KSU Northwest Research-Extension Center in Colby, Kansas (1989-2015).

Table 3. Emitter performance of 26.5-year-old excavated driplines and unused driplines at the KSU Northwest Research-Extension Center in 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
Max. emitter discharge (L h^{-1})	0.613	0.575
Min. emitter discharge (L h^{-1})	0.540	0.495
Mean emitter discharge (L h^{-1})	0.590	0.537
CV	0.026	0.048
DU_{lq}	97.0	94.2
U_C	98.1	95.9
Q_{var}	0.120	0.139

dates or lots or could indicate increased discharge after many years of usage. All of the uniformity parameters for both the excavated driplines and the unused driplines would be evaluated as 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 have a considerable negative affect Q_{var} 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 emitter clogging (Enciso-Medina et al., 2011).

Comparison of *In Situ* and Excavated Emitter Performance

There were little differences in the measured emitter performance between the *in situ* and lab results (table 4). Average emitter discharge was approximately 2.5% greater *in situ* than from the 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 suggests that either methodology can be acceptable for evaluating long-term SDI system performance. However, soil type may have an influence on this conclusion. For a sandy soil in South Carolina, Sadler et al. (1995) reported that removing soil overburden increased emitter discharge by approximately 3% to 4%, but 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 at the KSU Northwest Research-Extension Center in Colby, Kansas. All results are normalized to 68.9 kPa.

Parameter	Driplines Excavated from Field	Lab Results for 20 m Excavated Driplines
Number of measured emitters	23	23 driplines, total of 683 emitters
Max. emitter discharge (L h^{-1})	0.628	0.613
Min. emitter discharge (L h^{-1})	0.577	0.540
Mean emitter discharge (L h^{-1})	0.605	0.590
CV	0.026	0.026
DU_{lq}	96.6	97.0
U_C	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. A few SDI systems in the U.S. 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 remain operational. The ability to make SDI systems last 20 years or longer certainly has positive economic implications for increased adoption of this technology (fig. 1) for lower-value 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). These include:

- 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.
- Train personnel to ensure that connection procedures are understood and followed for 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 replicate successfully 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.
- Establishing a well-thought-out system begins with the decision-making process before purchasing the system (Rogers et al., 2003b).

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 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 Kansas State University Northwest Research-Extension Center in Colby, Kansas, had excellent performance during its 26.5-year life. It was decommissioned in the fall of 2015 because the dripline failed (split) at the crease location, and not because of clogging or uniformity concerns.

Acknowledgements

Funding for this long-term research has come from a variety of sources, such as internal reallocation from Kansas State University, USDA-NIFA and its predecessor through the Special Grants Program, USDA-NIFA Multistate Research Funds, and the USDA-ARS Ogallala Aquifer Program.

References

ASABE. (2011). EP405.1: Design and installation of microirrigation systems. St. Joseph, MI: ASABE.

Ayars, J. E., Phene, C. J., Hutmacher, R. B., Davis, K. R., Schoneman, R. A., Vail, S. S., & Mead, R. M. (1999). Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. *Agric. Water Mgmt., 42*(1), 1-27. https://doi.org/10.1016/S0378-3774(99)00025-6

Bidwell, O. W., Banbury, E. E., Barker, W. L., & Muilenburg, G. E. (1980). The Colby Branch Experiment Station and agriculture in northwestern Kansas, with special mention of soils. KAES Bulletin 635. Manhattan, KS: Kansas Agricultural Experiment Station.

Bralts, V. F., Edwards, D. M., & Wu, I. P. (1987). Drip irrigation design and evaluation based on the statistical uniformity concept. *Adv. Irrig., 4*, 67-117. https://dx.doi.org/10.1016/B978-0-12-024304-4.50005-5

Camp, C. R., Sadler, E. J., & Busscher, W. J. (1997). A comparison of uniformity measures for drip irrigation systems. *Trans. ASAE, 40*(4), 1013-1020. https://dx.doi.org/10.13031/2013.21353

Enciso-Medina, J., Multer, W. L., & Lamm, F. R. (2011). Management, maintenance, and water quality effects on the long-term performance of subsurface drip irrigation systems. *Appl. Eng. Agric., 27*(6), 969-978. https://doi.org/10.13031/2013.40633

Haman, D. Z., Smajstrla, A. G., & Pitts, D. J. (2003). Uniformity of sprinkler and microirrigation systems for nurseries. Bulletin 321. Gainesville FL: University of Florida Cooperative Extension Service.

Lamm, F. R., & Camp, C. R. (2007). Chapter 13: Subsurface drip irrigation. In F. R. Lamm, J. E. Ayars, & F. S. Nakayama (Eds.), *Microirrigation for crop production: Design, operation, and management* (pp. 473-551). Amsterdam, The Netherlands: Elsevier. https://dx.doi.org/10.1016/S0167-4137(07)80016-3

Lamm, F. R., & Rogers, D. H. (2014). SDI for corn production: A brief review of 25 years of KSU research. In *Proc. 26th Annual Central Plains Irrig. Conf.* (pp. 55-66). Colby, KS: CPIA.

Lamm, F. R., Clark, G. A., Yitayew, M., Schoneman, R. A., Mead, R. M., & Schneider, A. D. (1997). Installation issues for SDI systems. ASAE Paper No. 972074. St. Joseph, MI: ASAE.

Lamm, F. R., Manges, H. L., Rogers, D. H., Spurgeon, W. E., & Farmer, M. H. (1990). Design and installation of a drip irrigation system for research purposes. ASAE Paper No. 902530. St. Joseph, MI: ASAE.

Lamm, F. R., O'Brien, D. M., & Rogers, D. H. (2015). Economic comparison of subsurface drip and center-pivot sprinkler irrigation using spreadsheet software. *Appl. Eng. Agric., 31*(6), 929-936. https://doi.org/10.13031/aea.31.11253

Lamm, F. R., O'Brien, D. M., & Rogers, D. H. (2016). Using the K-State center-pivot sprinkler and SDI economic comparison spreadsheet - 2016. In *Proc. 28th Annual Central Plains Irrig. Conf.* (pp. 29-37). Colby, KS: CPIA. Retrieved from https://www.ksre.k-state.edu/sdi/reports/2016/LammUsingCPSDI16.pdf

Perea, H., Enciso-Medina, J., Singh, V. P., Dutta, D. P., & Lesikar, B. J. (2013). Statistical analysis of non-pressure-compensating and pressure-compensating drip emitters. *J. Irrig. Drain. Eng., 139*(12), 986-994. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000644

Rogers, D. H., & Lamm, F. R. (2009). Keys to successful adoption of SDI: Minimizing problems and ensuring longevity. In *Proc. 21st Annual Central Plains Irrig. Conf.* (pp. 140-151). Colby, KS: CPIA. Retrieved from https://www.ksre.k-state.edu/irrigate/oow/p09/Roger09SDI.pdf

Rogers, D. H., Lamm, F. R., & Alam, M. (2003a). Subsurface drip irrigation systems (SDI) water quality assessment guidelines. Irrigation Management Series, MF-2575. Manhattan, KS: Kansas State University Cooperative Extention.

Rogers, D. H., Lamm, F. R., & Alam, M. (2003b). Subsurface drip irrigation (SDI) components: Minimum requirements. Irrigation Management Series, MF-2576. Manhattan, KS: Kansas State University Cooperative Extention.

Sadler, E. J., Camp, C. R., & Busscher, W. J. (1995). Emitter flow rate changes by excavating subsurface drip irrigation tubing. In F. R. Lamm (Ed.), *Proc. 5th Intl. Microirrig. Cong.* St. Joseph, MI: ASAE.

USDA-NASS. (2010). Farm and ranch irrigation survey (2008). In *2007 Census of Agriculture, Vol. 3: Special Studies, Part 1* (AC-07-SS-1). Washington, DC: USDA-NASS.

USDA-NASS. (2014). Farm and ranch irrigation survey (2013). In *2012 Census of Agriculture, Vol. 3: Special Studies, Part 1* (AC-12-SS-1). Washington, DC: USDA-NASS.

Wu, I. P., Barragan, J., & Bralts, V. F. (2007). Chapter 10: Field performance and evaluation. In F. R. Lamm, J. E. Ayars, & F. S. Nakayama (Eds.), *Microirrigation for crop production: Design, operation, and management* (pp. 357-387). Amsterdam, The Netherlands: Elsevier. http://dx.doi.org/10.1016/S0167-4137(07)80013-8