SUNFLOWER, SOYBEAN, AND GRAIN SORGHUM CROP PRODUCTION AS AFFECTED BY DRIPLINE DEPTH

F. R. Lamm, A. A. Abou Kheira, T. P. Trooien

ABSTRACT. *A 5-year field study (2004-2008) using irrigation water from an unlined surface reservoir was conducted to examine the effect of dripline depth (0.2, 0.3, 0.4, 0.5, or 0.6 m) on subsurface drip-irrigated rotational crop production of sunflower, soybean, and grain sorghum on a deep silt loam soil in western Kansas. Additional years (1999-2003) of data were included in the analysis of long-term dripline flowrates as affected by dripline depth. Crop seed germination and plant establishment with the subsurface drip irrigation system was not examined in this field study. There were no significant differences in crop yields or yield components in any year of the study with the exception of the number of soybean pods/plant in 2007. In that year, the number of pods/plant was significantly greater for the deeper dripline depths, but this improvement was not reflected in significantly greater soybean yield due to compensation from the other yield components. Measured crop water use and calculated water productivity (yield/water use) also were not significantly affected by dripline depth for any crop in any year. Crop water use varied less than 4% and water productivity varied less than 8% with dripline depth from the mean values for a given crop within a given year, but water productivity tended to be greater for the intermediate 0.4 m dripline depth. There was a tendency for the deeper dripline depths to have greater amounts of plant available soil water and this tendency was stronger as the crop season progressed and for deeper portions of the crop root zone. However, there were neither significant differences in plant available soil water in the upper (0 to 0.9 m) and lower root zones (0.9 to 2.4 m) at physiological maturity of the crop in any year, nor in the total 2.4 m soil profile. The lack of significant differences in crop yields, water use, water productivity and plant available soil water at physiological maturity suggests that dripline depths ranging from 0.2 to 0.6 m are acceptable for crop production of these three crops on the silt loam soils of the region. Measurements of plot dripline flowrates during the period 1999 through 2008 indicated a tendency for deeper driplines to have reduced flowrates and these flowrate reductions were statistically significant in 2001, 2006, 2007, and 2008. Although the reason for these plot flowrate reductions cannot be fully ascertained, it seems likely they were caused by emitter clogging related to an interaction between dripline depth and irrigation water quality for which the rationale was not determined.*

Keywords. *Subsurface drip irrigation, Microirrigation, Yield components, Irrigation management.*

Subsurface drip irrigation (SDI) is the fastest growing segment of microirrigation in the United States with an estimated increase of nearly 60% from the 2003 to 2008 (USDA-NASS, 2009). Although the estimated U.S. irrigated land area using SDI (260,000 ha) is only 17% of the total microirrigated area, its rapid growth suggests that more producers are seeking to adapt this technology to their own farms. In Texas alone, the estimated SDI land area increased from 8800 ha in 2000 to over 100,000 ha by 2004 primarily for cotton production (Bordovsky and Porter, 2008; Colaizzi et al., 2009). In some regions, SDI systems are installed at a shallow depth less than 0.2 m and are installed and retrieved annually (Lamm and Camp, 2007). Often these systems are referred to as surface drip irrigation in research reports, and the term SDI is reserved for systems intended for multiple-year use that are installed below tillage depth (Camp and Lamm, 2003). In the U.S. Great Plains region, most SDI systems are used for relatively low value commodity crops such as the cereal grains, forages, and fiber crops and thus deeper multiple-year use SDI systems are desirable so that system and installation costs can be amortized over a long time period. A few systems in the United States have been used for periods longer than 20 years without replacement (Lamm and Camp, 2007) and more systems are approaching that milestone.

Some of the primary reasons for deeper dripline placement is to help producers avoid mechanical damage to driplines caused by crop cultural practices and to reduce soil water evaporative losses (Lamm and Camp, 2007), whereas the primary reasons for shallower dripline placement are for crop germination and establishment and for production of shallow-rooted crops such as many of the horticultural crops. Although crop germination and establishment are important aspects for all crops and can be strongly affected by dripline depth, it was not the focus, nor was it a limiting factor during this study. Readers are referred to Lamm and Camp (2007) for a more detailed discussion of the effects of dripline depth

---

Submitted for review in February 2010 as manuscript number SW 8430; approved for publication by the Soil & Water Division of ASABE in April 2010.

The authors are **Freddie Ray Lamm, ASABE Member Engineer,** Professor, Research Irrigation Engineer, Kansas State University, Northwest Research Extension Center, Colby, Kansas; **Abdrabbo A. Abou Kheira,** Visiting Scientist, Research Irrigation Engineer, Kansas State University, Northwest Research Extension Center, Colby, Kansas; and **Todd P. Trooien, ASABE Member Engineer,** Professor, Water Resources Engineer, South Dakota State University, Brookings, South Dakota. **Corresponding author:** Freddie Ray Lamm, Kansas State University, Northwest Research Extension Center, 105 Experiment Farm Road, Colby, KS 67701; phone 785-462-6281; fax 785-462-2315; e-mail: flamm@ksu.edu.

ISSN 0883-8542

on crop establishment and germination. A number of lower value commodity crops have been successful with dripline depths between 0.2 and 0.5 m. Most of these crops have extensive root systems that will continue to function properly at these greater depths. In an earlier study on the same field site (as is the subject of this report), corn yields were unaffected by dripline depths ranging from 0.2 to 0.5 m and there was only a slight yield reduction at the 0.6-m depth on a deep silt loam soil (Lamm and Trooien, 2005). Safflower seed and oil yields were greater for SDI at 0.25- and 0.35 m dripline depths than at shallower 0.15-m or deeper 0.45-m depths on a loamy sand in Saudi Arabia (Al-Nabulsi et al., 2000). Cotton lint yields were 1292, 1380, and 1465 kg/ha for dripline depths of 0.2, 0.3, and 0.4 m, respectively, on a Varina loamy sand with a clay hardpan at the 0.25- to 0.32-m depth in South Carolina (Khalilian et al., 2000). Although not statistically significant, greater lint yield and net returns were obtained for cotton in a 3-year study in southern Texas with dripline depth at 0.3 m rather than 0.2 m (Enciso et al., 2005). Using results from a soil-column study with a loessial brown loam soil examining root development, Plaut et al. (1996) suggested that a reasonable dripline depth for cotton would be 0.4 to 0.5 m. However, in a study on a fine sandy loam soil in a semiarid region, cotton root development and distribution was not affected by dripline depths ranging from 0 to 0.45 m (Kamara et al., 1991). Their results suggest that in regions that typically receive precipitation during the growing season, dripline depth will not be the overriding factor in cotton root development and distribution. Similarly, in a discussion of the history of drip irrigation of cotton in Texas, Henggeler (1995) concluded that SDI installation depth did not appear to be an appreciable factor in lint yield or SDI system longevity. In Australia, edible soybean pod yield was generally unaffected by dripline depth (0 to 0.35 m) when the irrigation water was oxygenated, but was reduced with deeper depth due to poor aeration when oxygenation was not practiced on a black cracking clay soil (Bhattarai et al., 2008). Alfalfa forage yields were unaffected by dripline depths of 0.3 and 0.45 m in a 2-year study on a sandy loam soil in southwest Kansas (Alam et al., 2002).

There are a number of factors related to dripline depth that can influence long-term SDI system performance and emitter discharge. Two major factors can be soil compaction and soil overburden that can result in deformation of the typical dripline shape, thus increasing pipe friction losses and subsequently reducing system flowrate (Chase, 1985; Hills et al., 1989; Sadler et al., 1995; Steele et al., 1996). Soil overburden is usually associated with non-bridging soils (i.e., soils that have little structure), such as some of the sands, while compaction problems that affect SDI performance are usually confined to shallower installations in heavy-textured soils. Root intrusion is another problem that can reduce emitter discharge and SDI system uniformity. Although root intrusion has long been recognized as a problem that can plague SDI (Lamm and Camp, 2007), few published and detailed research studies are available. In a literature review of SDI, Camp (1998) cited only 4 of 61 reports that provided management guidelines discussing root intrusion. Some crops tend to cause more root intrusion problems than others. For example, perennials may present root intrusion problems when roots continue to grow and utilize some water in winter or semi-dormant periods when irrigation is usually not practiced (Schwankl et al., 1993; Hanson et. al., 1997). In heavier-textured soils or those soils with reduced water hydraulic conductivity, back pressure on the emitter can occur and reduce emitter discharge and SDI system uniformity. This can be particularly the case when emitter discharge is excessive with respect to soil water redistribution capabilities. Soil type, emitter flowrate, presence of cavities around the emitter, and SDI system hydraulic properties were listed by Shani et al. (1996) as the controlling factors for the existence of backpressure and the subsequent emitter discharge reduction. In a preliminary study, they reported that emitter flow reductions of as much as 50% were attributable to back pressure. This back pressure phenomenon can be exacerbated when the irrigation source has biological contaminants. Application of biological effluent increased soil water retention, decreased the number of large-radius pores, and decreased saturated soil hydraulic conductivity significantly on a sandy loam soil, but had only a minimal effect on a silty clay loam soil (Jnad et al., 2001). Further discussion of these four phenomena (compaction, overburden, root intrusion, and soil water backpressure) and their interaction with SDI system performance is provided by Lamm and Camp (2007).

As some of the earliest barriers to microirrigation adoption, the lack of adequate long-term system performance and emitter clogging continue to plague systems and shorten system life (Nakayama and Bucks, 1991; Pitts et al., 1990; Nakayama et al., 2007). As with all microirrigation systems, water filtration, chemical treatment of the irrigation water, and system maintenance are critical in ensuring proper SDI system operation and system longevity. In many cases, SDI may require more extensive system design features, more complex water quality management, and more frequent system flushing than surface microirrigation systems because there are no opportunities to clean emitters manually (Lamm and Camp, 2007). Little or no literature exists that directly discuss long-term SDI system performance as related to the interaction of dripline depth and irrigation water quality, although the earlier report on the effect of dripline depth on corn production at this same study site (Lamm and Trooien, 2005) did discuss some possible rationale for such effects. Both biological and chemical clogging hazards are temperature dependent (Nakayama and Bucks, 1985; Pitts et al., 1990; Capra and Scicolone, 1998) and there can be differences in dripline water temperatures as affected by dripline depth (Lamm and Trooien, 2005). Diel or seasonal temperature swings can also affect the growth and decay of bacteria within the dripline and thus affect emitter clogging. Chemical precipitation reduced emitter discharge 7%, 2%, and 2% for driplines depths of 0, 0.15, and 0.30 m, respectively, in a 2-year greenhouse study in China (Li et al., 2008). They attributed the greater clogging of the surface driplines to greater temperature. Although there was no mean differences in emitter discharge for the 0.15- and 0.30-m dripline depths, there was greater variation in emitter discharge reduction for the deeper dripline depth. Recovery in reduced SDI system flowrates following winter idle periods were reported for each year of a 4-year beef biological effluent study by Lamm et al. (2002). In an earlier report of this same study, Trooien et al. (2000) suggested that the flowrate recoveries might be related to longer residence-time periods of the acid and chlorine water treatments, cooler winter temperatures allowing improved chemical control, or desiccation and reduction in size of the biological contaminants.

In 1999, Kansas State University initiated a field study to evaluate the effect of dripline depth on field corn production (Lamm and Trooien, 2005). Although corn is the primary irrigated crop in Kansas, growers sometimes want to rotate their fields to the other minor irrigated crops (sunflowers, soybean, and grain sorghum). In 2004, a 5-year, follow-on study was initiated on the same field site to examine sunflower, soybean, and grain sorghum production and long-term SDI system performance under weather and soil conditions where crop germination and establishment would not be anticipated to be affected by dripline depth.

PROCEDURES

EXPERIMENTAL SITE DESCRIPTION

This experiment was conducted at the Kansas State University Northwest Research-Extension Center at Colby, Kansas, during the period 2004 to 2008. Additional years (1999-2003) of data were included in the analysis of long-term dripline flowrates as affected by dripline depth. The deep silt loam soil as described in more detail by Bidwell et al. (1980) can supply about 445 mm of plant available soil water (difference between field capacity and wilting point) from a 2.4-m soil profile. The climate can be described as semi-arid with a summer precipitation pattern and a long-term average annual rainfall of approximately 480 mm. Average precipitation is approximately 300 mm during the 15 May through 11 September (120-day) growing period.

The treatments were five microirrigation dripline depths (0.20, 0.30, 0.41, 0.51, and 0.61 m) replicated four times in a randomized complete block design. The four blocks of five dripline depth each were arranged in a west to east direction with the crop row direction running north to south. Plot length was 42 m and plot width was approximately 6 m (8 crop rows spaced 0.76 m apart with driplines spaced at 1.5 m between alternate pairs of crop rows).

The subsurface drip irrigation (SDI) system was installed in the spring of 1999 preceding a 4-year study (1999 through 2003) examining dripline depth effects on corn production (Lamm and Trooien, 2005). Low-flow (0.0455 L s^{-1} 100 m^{-1}) Toro Ag dripline with a 0.3-m emitter spacing and 22-mm inside diameter (Aquatraxx EA7XX1222) was installed with a 1.5-m dripline spacing using a shank-type injector at the specified treatment depths. The emitter exponent for this dripline was 0.54. There were four driplines in each plot. Additional details about the dripline study site and the other components in the SDI system are provided by Lamm and Trooien (2005). Each plot was instrumented with a municipal-type flowmeter to record accumulated flow.

CROPS AND CULTURAL PRACTICES

Sunflower was planted to the study area in both 2004 and 2007. In 2005 soybean was planted to the entire study site while in 2007 soybean shared the study site area with the sunflower crop. Grain sorghum was the third rotational crop being planted in 2006 and 2008. Crop varieties and hybrids, dates for cultural practices, fertilization, and water parameters are listed in table 1. Pest (weeds and insects) control was accomplished using standard practices for the region for each crop. The fertilizer rates for each crop can be described as non-limiting for high crop yields. The crops were planted parallel with the dripline with each crop row approximately 0.38 m from the nearest dripline. A raised bed was used in crop production which allowed centering the crop rows on the dripline and also limited wheel traffic to the furrow. This controlled traffic allowed shallow cultivation procedures.

IRRIGATION WATER MANAGEMENT

Irrigation was scheduled using a weather-based water budget each year and all dripline treatments received the

Table 1. Cropping and water use parameters from a dripline depth study, 2004 through 2008, KSU Northwest Research-Extension Center, Colby, Kansas.

	Crop Year					
Study Cropping and Data Parameters	2004	2005	2006	2007a	2007b	2008
Crop	Sunflower	Soybean	Grain Sorghum	Soybean	Sunflower	Grain Sorghum
Hybrid	Mycogen 8377NS	Pioneer 93M50	Pioneer 84G62	Pioneer 93M50	Mycogen 8377NS	Pioneer 84G62
ETc calculation period (d)	101	125	105	125	101	105
Planting date	14-Jun	10-May	28-May	15-May	21-Jun	3-Jun
Emergence date, beginning of ETc calculation period	22-Jun	20-May	5-Jun	30-May	29-Jun	9-Jun
Physiological maturity, end of ETc calculation period	30-Sep	21-Sep	17-Sep	7-Oct	1-Oct	21-Sep
Harvest date	12-Oct	4-Oct	5-Oct	7-Oct	15-Oct	27-Sep
Nitrogen (UAN 32-0-0) (kg/ha)	140	55	175	140	140	225
Phosphorous (ammonium superphosphate, 10-34-00) (kg/ha)	50	0	50	0	50	50
Total irrigation (mm)	309	321	222	282	282	179
Calculated ETc (mm)	414	609	428	399	511	400
Long-term average (1972-2009) calculated ETc	442	589	437	424	567	430
Precipitation during ETc calculation period (mm)	155	307	197	202	243	253
Long-term average (1972-2009) precipitation during period (mm)	215	300	244	209	299	246

same amount of irrigation water within a given year. The weather-based water budget was constructed using data collected from a NOAA weather station located approximately 600 m northeast of the study site. The reference evapotranspiration (ETr) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ETr calculations used in this study are fully described by Lamm et al. (1987). A 2-year (2005 and 2006) comparison using weather data from Colby, Kansas, of this estimation method to the ASCE standardized reference evapotranspiration equation which is based on FAO-56 (Allen et al., 1998) indicates that the modified-Penman values are approximately 1.5% to 2.8% lower. This is well within the accuracy of the resultant scheduling and irrigation application procedures. Crop coefficients (Kc) were generated using FAO-56 (Allen et al., 1998) as a guide with periods adjusted to northwest Kansas growing period lengths (fig. 1). Crop evapotranspiration (ETc) was calculated as the product of Kc and ETr. This method of calculating water use has been acceptable in past studies at Colby (Lamm and Rogers, 1983, 1985). In constructing the irrigation schedules, no attempt was made to modify ETc with respect to soil evaporation losses or soil water availability as outlined by Kincaid and Heermann (1974). Alfalfa-based ETr is considered to give better estimates than short-grass ETo in this region (Howell, 2007). In 2007, sunflower crop coefficients were used to schedule both soybean and sunflower with the emergence date for the soybean used in the water budget. This was a necessary compromise to allow both crops to be examined in the same field area but did result in overirrigation of the sunflower and slight underirrigation of soybean for a portion of the summer. A post-study reconstruction of appropriate irrigation schedules (i.e., irrigation schedules that water budget would have indicated had there been only one crop) for the two crops indicates that the soybeans might have benefited from approximately 35 mm of irrigation during the period 5 July through 18 July while the sunflowers were overirrigated by approximately 80 mm during the period 18 July through 28 July. Neither the slight underirrigation of the soybean, nor the overirrigation of the sunflower, was thought to have appreciably affected the results. Typically, daily or every-other-day irrigations were scheduled whenever the calculated soil water depletion in the profile exceeded approximately 25 mm. Exceptions to the daily or every-other-day events were related to the unavailability of the pumping water source due to its concurrent use on another study site. Irrigation amounts ranged from approximately 6 to 13 mm for each event, depending on availability of pumping capacity for the given event. The crops were fully irrigated throughout the season.

CROP AND WATER EXPERIMENTAL DATA

Crop production data collected during the growing season included irrigation and precipitation amounts, weather data, yield components (yield, plant density, pods or seed heads per plant, seeds per head or pod, individual seed mass), and periodic soil water content. Plant density data for the grain sorghum was not measured at harvest and so the number of heads per unit area was the first yield component. Yield component data were measured by hand-harvesting a 6-m section of row near the center of the plot with the exception of the number of soybean pods/plant, which was determined by counting the number of pods and plants in a representative 1-m length of crop row. The number of seeds per pod or crop head was not measured but was calculated by algebraic closure with the remaining yield components. Soil water content was measured weekly or every two weeks in each of the 20 plots with a neutron attenuation moisture meter in 0.3-m increments to a depth of 2.4 m at the crop row (approximately 0.38 m horizontally from the dripline). These soil water measurements extended from emergence through physiological maturity. Values calculated after final data collection included seasonal water use and water productivity. Crop water use was calculated as the sum of soil water depletion between the initial and final soil water measurements, precipitation, and irrigation between the initial and final soil water measurements. Calculating crop water use in this manner would inadvertently include any deep percolation and rainfall runoff. Although deep percolation and rainfall runoff are not considered to be large losses in this study they would increase these crop water use values over calculated ETc. Water productivity was calculated as crop grain yield corrected to a standardized grain moisture content (soybean, 13% wet basis; grain sorghum, 12.5% wet basis; and sunflower, 10% wet basis) divided by total crop water use.

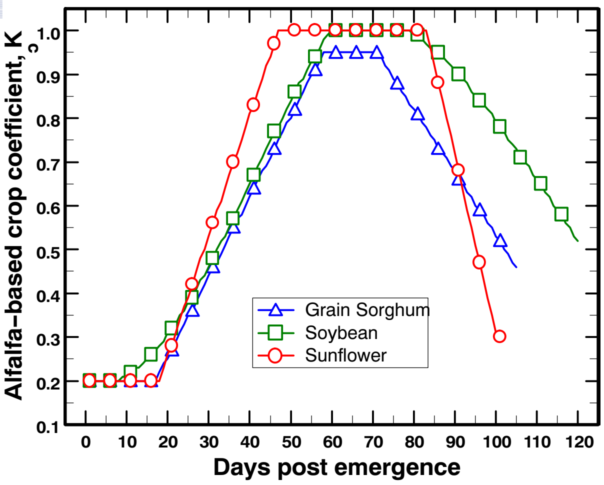

Figure 1. Crop coefficients used with reference evapotranspiration in the study to calculate crop evapotranspiration for irrigation scheduling water budgets. Crop coefficients (Kc) were generated using FAO-56 (Allen et al., 1998) as a guide with periods adjusted to northwest Kansas growing period lengths.

PLOT DRIPLINE PRESSURE AND FLOW MEASUREMENTS

Pressure and flow measurements were made at the time of the study site initiation in May 1999 and also at the end of each subsequent irrigation season using municipal grade flowmeters for approximately 20 min and recording the pressure at the inlet and tail end of the plots. Senninger brand 0- to 207-kPa (0.1-m diameter face) pressure gauges with approximate full scale accuracy of ±1% were used from 1999 to 2002. PSI-tronix brand pressure transducers with a range of 0 to 207 kPa with ±0.5% of full scale were used from 2003 through 2008. The measured flowrates were normalized from the average inlet/outlet pressure to a standard pressure of 69 kPa using the emitter exponent and the following equation,

$$Q_n = Q_o \left(\frac{P_n^x}{P_o^x} \right) \quad (1)$$

where Q_n and Q_o are the normalized and original measured flowrate, respectively, P_n and P_o are the normalized (69 kPa) and original measured pressure (average of dripline inlet and flushline outlet pressure), and x is the emitter exponent of 0.54. This normalization was done to allow direct comparisons between years and to remove the effects of small pressure variations between measurement events.

STATISTICAL ANALYSIS

The experimental data was analyzed as a single factor (dripline depth) analysis of variance using Proc GLM (general linear models) procedure of the SAS statistical package (SAS Institute, Cary, NC, USA) at a significance level of P = 0.05. Means separation was obtained with the Duncan's Multiple Range option.

RESULTS AND DISCUSSION

WEATHER CONDITIONS AND IRRIGATION REQUIREMENTS

Weather conditions during the five years of the study were generally favorable for crop production. The calculated crop ETc for sunflower averaged approximately 8% less than the long-term (1972-2009) calculated values for the same growing periods (table 1). Evapotranspiration for soybean was slightly greater (3%) than the long-term average in 2005 but was nearly 10% less than the long-term average in 2007. Grain sorghum ETc averaged approximately 4% less than the long-term average for its crop growing period. Growing season precipitation averaged 23% less for the sunflowers than the long-term average while the soybeans had near normal precipitation in the two years of its study and grain sorghum had one dry year (2006) and one near normal year (2008). Irrigation requirements were moderate during the study ranging from a low of 179 mm for grain sorghum in 2008 to a high of 321 mm for soybean in 2005.

CROP YIELD AND YIELD COMPONENTS

Crop yields were excellent compared to regional norms in all five crop years (table 2). There were neither statistically significant differences, nor consistent numerical trends in crop yields for any crop as affected by dripline depth (table 2, fig. 2). Similarly, there were no significant differences in any of the crop yield components with the exception of the number of pods/plant for soybean in 2007. In that year the number of pods/plant was significantly greater at the deeper depths, but this improvement was not reflected in significantly greater soybean yield due to compensation from the other yield components. The nonsignificant yield results from these three crops as affected by dripline depth are similar to earlier results from a 4-year study with corn at the same study site from Lamm and Trooien (2005). All four of these crops have reasonably extensive root systems that can extract water at depths greater than 2 m on this soil type, in this region, so the lack of yield differences as affected by dripline depths from 0.2 to 0.6 m might be anticipated. Camp (1998) indicated that dripline depth is often optimized for the local site by using knowledge and experiences about the crop for the soils of the region. Shallow-rooted crops in combination with coarse-textured soils were reported to be most sensitive to variations in dripline depth.

CROP WATER USE AND WATER PRODUCTIVITY

Measured crop water use and water productivity (WP) were not significantly affected by dripline depth for any crop in any year. Crop water use for a given crop in a given year varied with dripline depth less than 4% from the mean value and was generally less than 2%. Water productivity varied less than 8% from mean values for a given crop and year, but tended to be greater for the intermediate 0.4-m dripline depth. This tendency may be explained by less soil water evaporation at this depth than at shallower depths on this soil type. Greater root activity at this depth, compared to deeper depths, may have partitioned more water use to transpiration, thus maintaining a good overall crop yield.

PLANT AVAILABLE SOIL WATER

Although not entirely consistent for all crops and years, there was a tendency for the deeper dripline depths to have more plant available soil water (PASW) and this tendency was stronger as the crop season progressed and for deeper portions of the crop root zone (figs. 3, 4, and 5). The temporal effect may be explained by less soil water evaporation for irrigation water applied at the deeper depths and also perhaps by greater infiltration of precipitation into drier surface soil layers. The deeper portions of the crop root zone could be expected to have greater PASW because of the deeper irrigation application by deeper driplines. There would also likely be less plant water uptake from the deeper portions of the crop root zone, though the differences for deep-rooted crops grown on this soil type may not be great (Lamm et al., 1994). Although these temporal and spatial trends in PASW existed, there were neither significant differences in PASW in the 0- to 0.9-m and 0.9- to 2.4-m depth increments of the root zone at physiological maturity of the crop in any year, nor in the total 2.4-m soil profile (table 3). The lack of significant differences in PASW at physiological maturity which is typically the driest period of the season for summer crops grown in this semi-arid region coupled with no significant differences in crop water use or water productivity suggest that there are little or no appreciable differences in crop water uptake as affected by dripline depths of 0.2 to 0.6 m for sunflower, soybean, or grain sorghum production.

LONG-TERM PLOT FLOWRATE MEASUREMENTS

Although this three-crop study began in 2004, the SDI system was installed in 1999 and plot flowrate measurements were periodically made since installation. Some plot flowrate measurements from the earlier 1999-2003 corn study were reported by Lamm and Trooien (2005) but are also included in this summary for completeness of topical discussion. In the earlier report, Lamm and Trooien (2005) did not observe any consistent effect of dripline depth, though they did report wide fluctuations in plot dripline flowrates, which they largely attributed to differences in dripline maintenance (chemical treatment of the water and dripline flushing procedures) when using water from this unlined surface reservoir. Subsequent analysis of pressure measurements that compared dripline inlet and outlet pressures using the standard pressure gauges (1999 through 2002) with the pressure transducers (2003 through 2008)

Table 2. Crop yield components and water use parameters in a dripline depth study, 2004-2008, KSU Northwest Research Extension Center, Colby, Kansas.

Crop	Year	Dripline Depth (m)	Yield (Mg/ ha)	Plant Density (p/ha)	Heads / plant[a]	Seeds / head	Seed Mass (mg)	Water Use (mm)	Water Productivity (Mg/ha⋅mm)
Sunflower	2004	0.2	3.5	52742	0.98	1294	52	577	0.00607
		0.3	3.2	48975	0.97	1293	52	571	0.00558
		0.4	3.3	52204	0.97	1256	52	566	0.00582
		0.5	3.4	48975	0.99	1302	53	550	0.00610
		0.6	3.3	48437	0.98	1267	55	541	0.00610
		Mean	3.3	50266	0.98	1282	53	561	0.00593
	2007	0.2	3.9	47898	1.00	1800	45	544	0.00718
		0.3	3.7	47360	1.00	1738	46	549	0.00676
		0.4	4.0	47360	1.00	1728	49	526	0.00764
		0.5	3.9	47898	0.99	1692	49	521	0.00752
		0.6	3.9	45746	1.00	1728	50	529	0.00742
		Mean	3.9	47253	1.00	1737	48	534	0.00730
					Pods / plant	Seeds / Pods			
Soybean	2005	0.2	5.4	294207	47	2.29	176	721	0.00748
		0.3	5.5	290619	51	2.11	178	700	0.00783
		0.4	5.4	243977	63	2.11	179	720	0.00751
		0.5	5.4	251152	49	2.56	173	700	0.00768
		0.6	5.2	261916	48	2.59	176	700	0.00746
		Mean	5.4	268374	52	2.33	176	708	0.00759
	2007	0.2	5.1	545360	23b	2.22	186	561	0.00906
		0.3	4.8	581239	21b	2.16	181	573	0.00836
		0.4	5.1	574063	22b	2.19	184	554	0.00924
		0.5	5.0	505893	27ab	2.04	189	558	0.00893
		0.6	5.3	495129	30a	1.95	183	590	0.00895
		Mean	5.0	540337	25	2.11	185	567	0.00891
				Heads / ha		Seeds / head			
Grain sorghum	2006	0.2	10.4	195899	–	2263	24	525	0.01986
		0.3	10.0	199128	–	2139	24	524	0.01905
		0.4	10.4	209892	–	2131	23	519	0.02005
		0.5	10.0	211506	–	2029	23	512	0.01953
		0.6	9.7	198052	–	2172	23	523	0.01865
		Mean	10.1	202895	–	2147	23	521	0.01943
	2008	0.2	9.6	463914	–	868	24	543	0.01766
		0.3	9.7	455303	–	867	25	552	0.01757
		0.4	10.6	460685	–	912	25	564	0.01889
		0.5	9.9	462838	–	891	24	558	0.01773
		0.6	8.9	484904	–	787	23	547	0.01623
		Mean	9.7	465529	–	865	24	553	0.01762

[a] Dripline depth means (the table columns) that are followed by different letters are significantly different at $P < 0.05$.

indicated that the use of pressure transducers greatly reduced experimental variation (data not shown). Plot dripline flowrates during the latter years (2003 through 2008) indicated a more consistent effect, with deeper driplines having reduced flowrates (fig. 6). These flowrate reductions were statistically significant in 2001 from the previous study (Lamm and Trooien, 2005) and for 2006, 2007 and 2008 from this study (table 4).

Neither soil compaction nor soil overburden are thought to be important factors in the flowrate reductions in this study because there was very little difference in dripline inlet and outlet pressures for these 42-m driplines in the latter years of the study (data not shown). Root intrusion is also discounted as a strong factor in the present study because, generally, root distribution for these three crops would typically be greater for the shallower dripline depths and in this study, the driplines for the deeper depths experienced greater reductions in flowrate. Additionally, in anecdotal observations of excavated SDI driplines at this and adjacent sites at the KSU Research-Extension Center, there have been

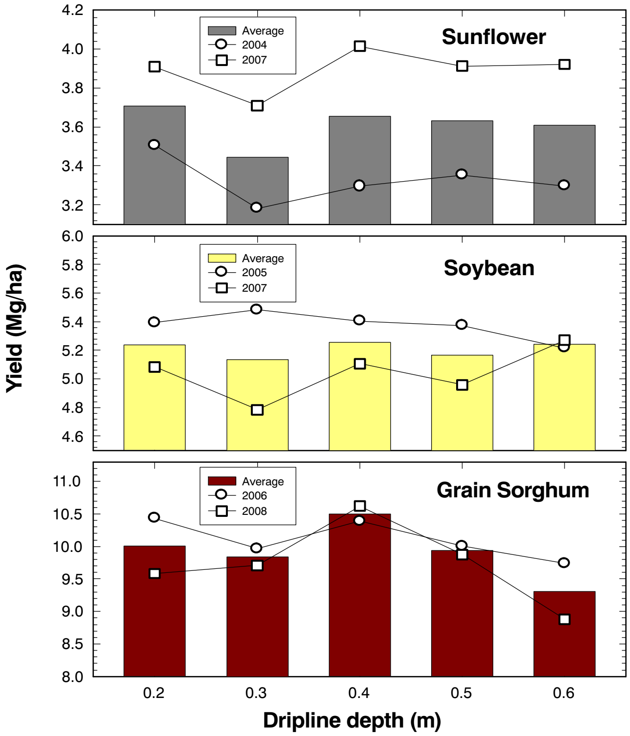

Figure 2. Crop yield as affected by dripline depth, KSU Northwest Research-Extension Center, Colby, Kansas.

no cases of root intrusion for corn, sunflower, soybean, or grain sorghum. Lamm et al. (2009) reported flowrates for 22 of 23 research plots with a dripline depth of 0.4 to 0.45 m from an adjacent SDI site using a freshwater source within ±5% of their initial first-year flowrate after 20 years of use

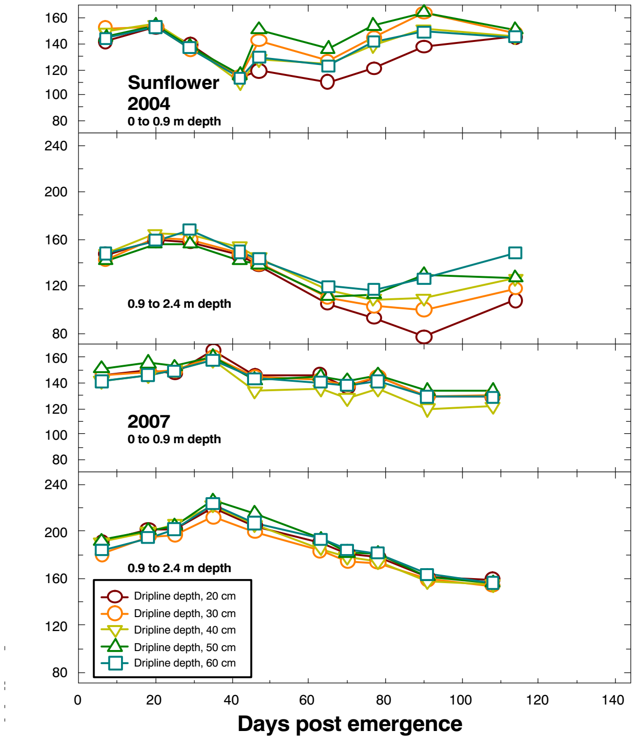

Figure 3. Plant available soil water for sunflower in the 0- to 0.9-m and 0.9- to 2.4-m root zone increments throughout the season as affected by dripline depth, KSU Northwest Research-Extension Center, Colby, Kansas.

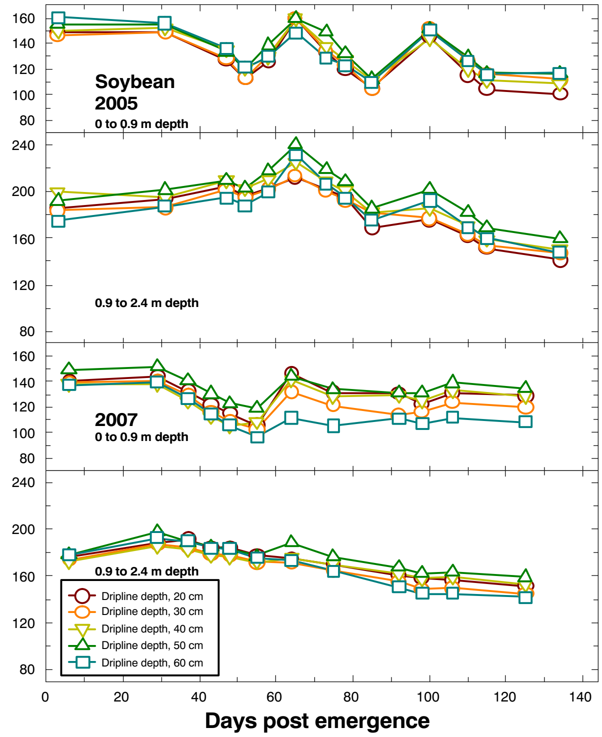

Figure 4. Plant available soil water for soybean in the 0- to 0.9-m and 0.9- to 2.4-m root zone increments throughout the season as affected by dripline depth, KSU Northwest Research-Extension Center, Colby, Kansas.

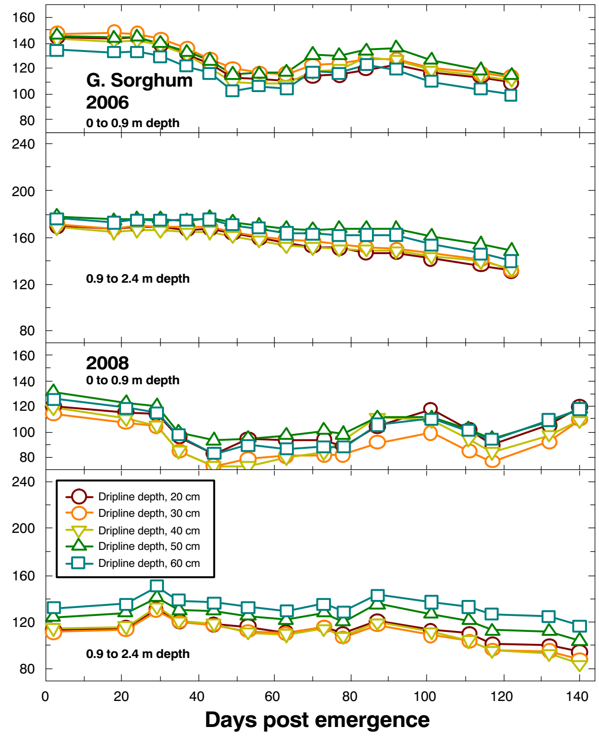

Figure 5. Plant available soil water for grain sorghum in the 0- to 0.9-m and 0.9- to 2.4-m root zone increments throughout the season as affected by dripline depth, KSU Northwest Research-Extension Center, Colby, Kansas.

Table 3. Plant available soil water (PASW) at crop physiological maturity in various portions of the soil profile as affected by dripline depth, KSU Northwest Research-Extension Center, Colby, Kansas.

Crop	Year	Dripline Depth (m)	PASW in 0- to 0.9-m Increment (mm)[a]	PASW in 0.90- to 2.4-m Increment (mm)	Total PASW in 2.4-m Profile (mm)
Sun-flower	2004	0.2	145	108	253
		0.3	148	117	265
		0.4	145	126	272
		0.5	151	127	278
		0.6	145	148	293
		Mean	147	125	272
	2007	0.2	129	159	288
		0.3	130	153	283
		0.4	122	155	277
		0.5	134	156	290
		0.6	129	156	285
		Mean	129	156	285
Soy-bean	2005	0.2	100	142	242
		0.3	112	148	260
		0.4	109	150	259
		0.5	117	160	276
		0.6	117	147	264
		Mean	111	149	260
	2007	0.2	129	152	281
		0.3	120	145	264
		0.4	128	153	281
		0.5	135	159	294
		0.6	108	142	250
		Mean	124	150	274
Grain sorghum	2006	0.2	109	131	240
		0.3	114	132	245
		0.4	111	133	244
		0.5	114	149	263
		0.6	99	140	239
		Mean	110	137	246
	2008	0.2	119	94	214
		0.3	109	88	197
		0.4	109	84	193
		0.5	118	104	222
		0.6	118	116	234
		Mean	115	97	212

[a] There were no significant differences in PASW at physiological maturity for any crop in any year.

for corn production. In general, it is thought that emitter backpressure, as affected by soil differences, is not the cause of the plot flowrate reductions at the deeper depths in this study. The soil is a well-drained silt loam soil that has a decrease in bulk density with increasing depth (Bidwell et al., 1980). However, as stated earlier, application of waters containing biological contaminants, silts, and clays can cause blockage of the soil pores in the immediate vicinity of the emitter and can also cause the backpressure phenomenon (Lamm and Camp, 2007). In an adjacent site to the current study, using water from the same irrigation reservoir, Puig-Bargués et al. (2010) measured total suspended solids (TSS) in the irrigation water ranging from 3.9 to 41.9 mg/L for periodic sampling during the summer of 2004. Although this TSS load would be considered minor according to water quality criteria for emitter clogging proposed by Bucks and Nakayama (1980), in conjunction with biological organisms, the contaminants may conglomerate and clog soil pores or emitters. Application of biological effluent decreased saturated soil hydraulic conductivity significantly on a sandy loam soil, but had only a minimal effect on a silty clay loam soil in Texas (Jnad et al., 2001). Considering the well-drained soil texture it seems more likely that the cause of the plot flowrate reductions was related to emitter clogging instead of clogging of the soil pores.

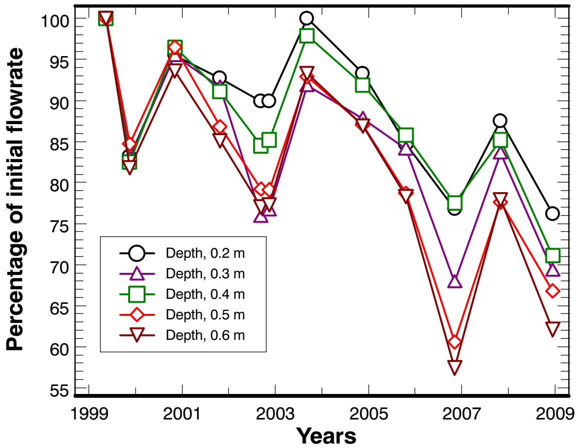

Figure 6. Plot dripline flowrate as percentage of initial flowrate as affected by dripline depth using water from an unlined irrigation reservoir, 1999 through 2008, KSU Northwest Research-Extension Center, Colby, Kansas.

As mentioned in the introduction both biological activity and chemical precipitation are often temperature dependent and can affect emitter clogging. Generally, within the range of typical irrigation water temperatures, chemical insolubility increases with reductions in water temperature, while biological activity increases with increased water temperature. During the earlier dripline depth study with corn, Lamm and Trooien (2005) reported shallower dripline depths having greater temperatures (by as much as 3°C) at the beginning of the irrigation season when crop canopy was less developed but very little temperature difference later in the season as canopy developed and total applied water amounts became greater. If the results of this earlier study are applicable in this study, then temperature differences among dripline depths during the nonirrigated period (fall through late spring) may be more influential on emitter clogging than the summer period. It is possible that the deeper driplines by having greater temperatures during the colder period (long-term, average ambient air temperature in January of -3°C) had more stable and continuing biological activity or more chemical precipitation than the shallower driplines or that the shallower driplines may be experiencing more overwinter recovery in emitter discharge similar to Trooien et al. (2000). None of stated rationale for the plot flowrate reductions with increased depth can be fully proven or discounted with the available data set and this particular SDI system no longer exists at the study site, so no further examination of the emitters and driplines is possible.

Table 4. Plot flowrate over time as percentage of initial plot flowrate (14 May 1999) as affected by dripline depth, KSU Northwest Research Extension Center, Colby Kansas.

	Month and Year[a]										
	Nov-99	Nov-00	Oct-01	Sep-02	Nov-02	Sep-03	Nov-04	Oct-05	Nov-06	Oct-07	Dec-08
	Elapsed Years										
Depth	0.5	1.5	2.5	3.3	3.5	4.3	5.5	6.4	7.5	8.5	9.6
0.2	83	95	93 a	90	90	100	93	85	77 a	87 a	76 a
0.3	83	96	92 a	76	77	92	88	84	68 ab	84 a	69 ab
0.4	83	97	91 a	85	85	98	92	86	78 a	85 a	71 ab
0.5	85	96	87 b	79	79	93	87	79	61 b	78 b	67 b
0.6	82	94	85 b	77	77	93	87	78	57 b	78 b	62 b

[a] Dripline depth means (the table columns) that are followed by different letters are significantly different at $P < 0.05$.

CONCLUSIONS

Crop production of sunflower, soybean, and grain sorghum was not significantly affected by dripline depths ranging from 0.2 to 0.6 m in terms of crop yields, total water use or water productivity under weather conditions when crop germination and establishment are not limiting. This was similar to the earlier results of Lamm and Trooien (2005) for corn production. There were also no significant differences in soil water within the profile at physiological maturity of the crops as affected by dripline depth. Producer preference in choosing dripline depths in this range of values should be acceptable for crop production of these predominant summer crops in this region.

Plot dripline flowrates were strongly and significantly affected over time by dripline depth with greater flowrate reductions with greater dripline depth. Soil compaction and soil overburden were discounted as possible causes of the flowrate reductions because of lack of pressure differences between dripline inlet and outlet. Root intrusion was also discounted due to lack of observed cases. Backpressure caused by poor soil water redistribution was discounted because of the well-drained nature of this soil. The authors believe the most likely cause of the dripline flowrate reductions is increased emitter clogging caused by some interaction of water quality and dripline depth, probably through some water or soil temperature effect. More research is warranted to determine the cause of the flowrate reductions with dripline depth.

ACKNOWLEDGEMENTS

This is a joint contribution of Kansas State University, Manhattan, Kansas, and South Dakota State University, Brookings, South Dakota. Contribution No. 10-224-J from the Kansas Agricultural Experiment Station. This research was supported in part by the Ogallala Aquifer Program, a consortium between USDA Agricultural Research Service, Kansas State University, Texas AgriLife Research, Texas AgriLife Extension Service, Texas Tech University, and West Texas A&M University.

REFERENCES

Alam, M., T. P. Trooien, D. H. Rogers, and T. J. Dumler. 2002. An efficient irrigation technology for alfalfa growers. *J. of Extension* 40(3): 1-9.

Allen, R. G., L .S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration, guidelines for computing crop water requirements. FAO Irrig. and Drain. Paper 56. Rome, Italy: Food and Agric. Organ. United Nations.

Al-Nabulsi, Y. A., A. M. Hilalia, O. A. Al-Tahir, S. H. Mahmoud, A. A. Al-Jasim, and A. H. Al-Arfaj. 2000. Subsurface drip irrigation technology for safflower production and water conservation in Saudi Arabia. In *Proc. 4th Nat'l. Irrigation Symp.,* 647-653. St. Joseph, Mich.: ASAE.

Bidwell, O. W., E. E. Banbury, W. L. Barker, and G. E. Muilenburg. 1980. The Colby Branch Experiment Station and agriculture in northwest Kansas with special mention of soils. KAES Bulletin 635. Manhattan, Kans.: Kansas Agric. Expt. Sta.

Bhattarai, S., D. Midmore, and L. Pendergast. 2008. Yield, water-use efficiencies and root distribution of soybean, chickpea and pumpkin under different subsurface drip irrigation depths and oxygation treatments in vertisols. *Irrig. Sci.* 26(5): 439.

Bordovsky, J. P., and D. Porter. 2008. Effect of subsurface drip irrigation system uniformity on cotton production in the Texas High Plains. *Appied Eng. in Agric.* 24(4): 465-472.

Bucks, D. A., and F. S. Nakayama. 1980. Injection of fertilizers and other chemicals for drip irrigation. In *Proc. Agri-Turf Irrig. Conf.,* 166-180. Silver Spring, Md.: Irrigation Association.

Camp, C. R. 1998. Subsurface drip irrigation: A review. *Trans. ASAE* 41(5): 1353-1367.

Camp, C. R., and F. R. Lamm. 2003. Irrigation Systems, Subsurface Drip. In *Encyclopedia Water Science,* 560-564. New York, N.Y.: Marcel Dekker.

Capra, A., and B. Scicolone. 1998. Water quality and distribution uniformity in drip/trickle irrigation system. *J. Agric. Eng. Res.* 70(4): 355-365.

Chase, R. G. 1985. Subsurface trickle irrigation in a continuous cropping system. In *Proc. 3rd Intl. Drip/Trickle Cong.,* 909-914. St. Joseph, Mich.: ASAE.

Colaizzi, P. D., P. H. Gowda, T. H. Marek, and D. O. Porter. 2009. Irrigation in the Texas High Plains: A brief history and potential reductions in demand. *Irrig. and Drain.* 58(3): 257-274. DOI: 10.1002/ird.418.

Enciso, J. M., P. D. Colaizzi, and W. L. Multer. 2005. Economic analysis of subsurface drip irrigation lateral spacing and installation depth for cotton. *Trans. ASABE* 48(1): 197-204.

Hanson, B., L. Schwankl, S. R. Grattan, and T. Prichard. 1997. Drip irrigation for row crops. Davis, Calif.: Coop. Ext., Dept. Land, Air, and Water Res., Univ. of Calif.

Henggeler, J. C. 1995. A history of drip-irrigated cotton in Texas. In *Proc. 5th Intl. Microirrigation Congress,* 669-674. F. R. Lamm, ed. St. Joseph, Mich.: ASAE.

Hills, D. J., M. A. M. Tajrishy, and Y. Gu. 1989. Hydraulic considerations for compressed subsurface drip-tape. *Trans. ASAE* 32(4): 1197-1201.

Howell, T. A. 2007. Personal communication concerning alfalfa-based reference evapotranspiration. 19 April 2007.

Jnad, I., B. J. Lesikar, A. Kenimer, and G. Sabbagh. 2001. Subsurface drip dispersal of residential effluent: II. Soil hydraulic characteristics. *Trans. ASAE* 44(5): 1159-1165.

Kamara, L., R. Zartman, and R. H. Ramsey. 1991. Cotton-root distribution as a function of trickle emitter depth. *Irrig. Sci.* 12: 141-144.

Khalilian, A., M. J. Sullivan, and W. B. Smith. 2000. Lateral depth placement and deep tillage effects in a subsurface drip irrigation system for cotton. In *Proc. 4th Natl. Irrigation Symp.,* 641-646. St. Joseph, Mich.: ASAE.

Kincaid, D. E, and D. F. Heermann. 1974. Scheduling irrigation using a programmable calculator. USDA Publication ARS-NC-12. Washington D.C.: USDA.

Lamm, F. R., and C. R. Camp. 2007. Chapt. 13: Subsurface drip irrigation. In *Microirrigation for Crop Production - Design, Operation and Management,* 473-551. F. R. Lamm, J. E. Ayars, and F. S. Nakayama, eds. Amsterdam, The Netherlands: Elsevier Publications.

Lamm, F. R., and D. H. Rogers. 1983. Scheduling irrigation using computed evapotranspiration. ASAE Paper No. MCR 83-109. St. Joseph, Mich.: ASAE.

Lamm, F. R., and D. H. Rogers. 1985. Corn yield response to different irrigation regimes. ASAE Paper No. MCR 85-131. St. Joseph, Mich.: ASAE.

Lamm, F. R., and T. P. Trooien. 2005. Dripline depth effects on corn production when crop establishment is nonlimiting. *Applied Eng. in Agric.* 21(5): 835-840.

Lamm, F. R., D. A. Pacey, and H. L. Manges. 1987. Spreadsheet templates for the calculation of Penman reference evapotranspiration. ASAE Paper No. MCR 87-106. St. Joseph, Mich.: ASAE.

Lamm, F. R., D. H. Rogers, and H. L. Manges. 1994. Irrigation scheduling with planned soil water depletion. *Trans. ASAE* 37(5): 1491-1497.

Lamm, F. R., D. H. Rogers, M. Alam, D. M. O'Brien, and T. P. Trooien. 2009. Summary of twenty years of Kansas SDI research. In *Proc. 2009 Irrigation Association Technical Conference.* Falls Church, Va.: Irrigation Assn.

Lamm, F. R., T. P. Trooien, G. A. Clark, L. R. Stone, M. Alam, D. H. Rogers, and A. J . Schlegel. 2002. Using beef lagoon wastewater with SDI. In *Proc. Irrigation Assn. Intl. Irrigation Technical Conf.* Falls Church, Va.: Irrigation Assn.

Li, J., L. Chen, Y. Li, and Y. Liu. 2008. Field evaluation of emitter clogging in subsurface drip irrigation systems. ASABE Paper No. 083512. St Joseph, Mich.: ASABE.

Nakayama, F. S., and D. A. Bucks. 1985. Temperature effect on calcium carbonate precipitate clogging of trickle emitters. In *Proc. 3rd Intl. Drip/Trickle Irrigation Congress,* 45-49. St. Joseph, Mich.: ASAE.

Nakayama, F. S., and D. A. Bucks. 1991. Water quality in drip/trickle irrigation: A review. *Irrig. Sci.* 12: 187-192.

Nakayama, F. S., B. J. Boman, and D. J. Pitts. 2007. Chapt. 11: Maintenance. In *Microirrigation for Crop Production - Design, Operation and Management,* 389-430. F. R. Lamm, J. E. Ayars, and F. S. Nakayama, eds. Amsterdam, The Netherlands: Elsevier Publications.

Pitts, D. J., D. Z. Haman, and A. G. Smajstrla. 1990. Causes and prevention of emitter plugging in microirrigation systems. Univ. of Florida IFAS Extension, Bul. 258.

Plaut, Z., A. Carmi, and A. Grava. 1996. Cotton root and shoot responses to subsurface drip irrigation and partial wetting of the upper soil profile. *Irrig. Sci.* 16: 107-113.

Puig-Bargués, J., F. R. Lamm, T. P. Trooien, and G. A. Clark. 2010. Effect of dripline flushing on subsurface drip irrigation systems. *Trans ASABE* 53(1): 147-155.

Sadler, E. J., C. R. Camp, and W. J. Busscher. 1995. Emitter flow rate changes by excavating subsurface drip irrigation tubing. In *Proc. 5th Intl. Microirrigation Cong.,* 763-768. F. R. Lamm, ed. St. Joseph, Mich.: ASAE.

Schwankl, L., B. Hanson, and T. Prichard. 1993. *Low-Volume Irrigation.* Davis, Calif.: Coop. Ext., Dept. Land, Air, and Water Res., Univ. of Calif.

Shani, U., S. Xue, R. Gordin-Katz, and A. W. Warrick. 1996. Soil-limiting flow from subsurface emitters: I. Pressure measurements. *ASCE J. Irrig. Drain. Eng.* 122(5): 291-295.

Steele, D. D., R. G. Greenland, and B. L. Gregor. 1996. Subsurface drip irrigation systems for specialty crop production in North Dakota. *Applied Eng. in Agric.* 12(6): 671-679.

Trooien, T. P., F. R. Lamm, L. R. Stone, M. Alam, D. H. Rogers, G. A. Clark, and A. J. Schlegel. 2000. Subsurface drip irrigation using livestock wastewater: Dripline flow rates. *Applied Eng. in Agric.* 16(5): 505-508.

USDA-NASS. 2009. Farm and Ranch Irrigation Survey (2008). Census of Agriculture, 2007. Vol. 3, Special Studies, Part 1. Washington, D.C.: USDA-NASS.