COMPARISON OF SUBSURFACE DRIP IRRIGATION UNIFORMITY DESIGNS ON COTTON PRODUCTION

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Abstract

One of the biggest obstacles to the widespread adoption of subsurface drip irrigation (SDI) on the High Plains of Texas is the high cost of initial installation. In some cases, SDI costs can be reduced if systems are designed using lower irrigation uniformity standards. The question becomes “what is the cost in terms of cotton lint yield of lowering the uniformity standards for SDI design?” A SDI system was installed in a 16-acre area with drip lines located in alternate furrows on 30-inch rows. The field was divided into four blocks with six treatment areas per block. Within each block, two treatment areas were irrigated with each 0.630-in., 0.875-in., and 0.990-in. diameter drip tape laterals. These three lateral diameters were designed to provide flow variations (FV’s) of 0.71, 0.94, and 0.85 within the respective area. Each of the three drip designs within each block was used to irrigate cotton at two levels, 60% and 100% of a base irrigation amount. The experiment was conducted from 2001 through 2004.

Total cotton lint yield within a zone was not affected by water distribution designs having FV’s between 0.71 and 0.94 during the test period. Conditions other than SDI design had bigger impacts on the spatial yield variability than the design treatments. Cotton yield response tended to follow the trends established by variations in emitter flow rate along the length of a drip tape lateral. Generally higher yields occurred at locations of higher drip emitter discharge, however, the magnitude of the yield change over the length of the lateral did not correspond the magnitude of the emitter flow rate change over the test period. Unusual conditions during the test period may have masked expected differences in SDI design, however, in some instances, SDI installation costs may be reduced by relaxing design specifications.

Introduction

Subsurface drip irrigation (SDI) is the most efficient in-season water application method on the Texas High Plains (Bordovsky and Porter, 2003). One of the biggest obstacles to the widespread adoption of SDI in this cotton producing area is the high cost of initial installation. The turnkey installation cost of a SDI system, including filtration and automated controls, ranges from $700 to $1000 per acre, depending on the size of installation and lateral spacing (Frerich, 2004). Initial SDI costs can be reduced if systems are designed using lower irrigation uniformity standards than those recommended by the Natural Resources Conservation Service (USDA-NRCS, 1997) or ASAE (ASAE, 2000). A practical application of this concept is increasing the length of drip laterals thereby reducing initial installation costs while allowing emitter flow uniformity below the recommended standards. Information concerning yield, lint quality, and water use efficiency resulting from irrigation with a range of SDI uniformity designs could be used to justify designs for less uniform systems and therefore lower SDI installation costs.

One of the chief advantages of an automated SDI system is the ability to irrigate and apply plant nutrients at very frequent intervals, as often as three times per day. Deficit irrigated cotton has shown a positive yield response to light, frequent irrigations (Bordovsky et al., 1992, Radin et al., 1992). However, on sloping fields, water uniformity within a SDI zone can be adversely affected by frequent irrigation cycles when water within the irrigation network flows to the lower elevations at the end of each irrigation cycle. Uniformity advantages of a well-designed SDI system may be reduced by irrigating too frequently.

A field experiment is being conducted to evaluate the effect of water distribution by three SDI designs having field variations (FV’s) of 0.71, 0.85, and 0.94 over 1300-ft lengths in terms of emitter flow rates and cotton lint yields. Evaluations of irrigation water discharge from selected emitters following zone valve closure is also being conducted. This paper describes these field experiments and reports the preliminary results.

Methods and Materials

The field experiment is being conducted at the Texas Agricultural Experiment Station's Helms Research Farm, 2 miles south of Halfway, TX (1071 m elev., 34^0 9'N, 101^0 56' W). The field is located adjacent to a playa in a transitional soil changing from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) at high elevations to an Olton loam (fine, mixed, thermic Aridic Paleustolls) at lower elevations. In 2001, a SDI system was installed in a 16-acre area with drip lines located in alternate furrows on 30-inch rows with N-S orientation. The field dimensions are 520' x 1300' and the cross slope is approximately 1% from southwest to northeast. The field is divided into four blocks with six sub-zones per block, each sub-zone is 1300 ft long by 8 rows wide. Within each block, two sub-zones are irrigated with each 0.630-in., 0.875-in., and 0.990-in. diameter drip tape laterals. These three lateral diameters are designed to provide flow variations of 0.71 (poor), 0.94 (very good), and 0.85 (acceptable) within the respective sub-zones when operated at 10, 12, and 6.5 psi pressure (Netafim, 2001). Each of the three drip designs within each block were used to irrigate cotton at two levels, 60% and 100% of a base irrigation (BI) amount. A schematic of the field installation is given in Figure 1.

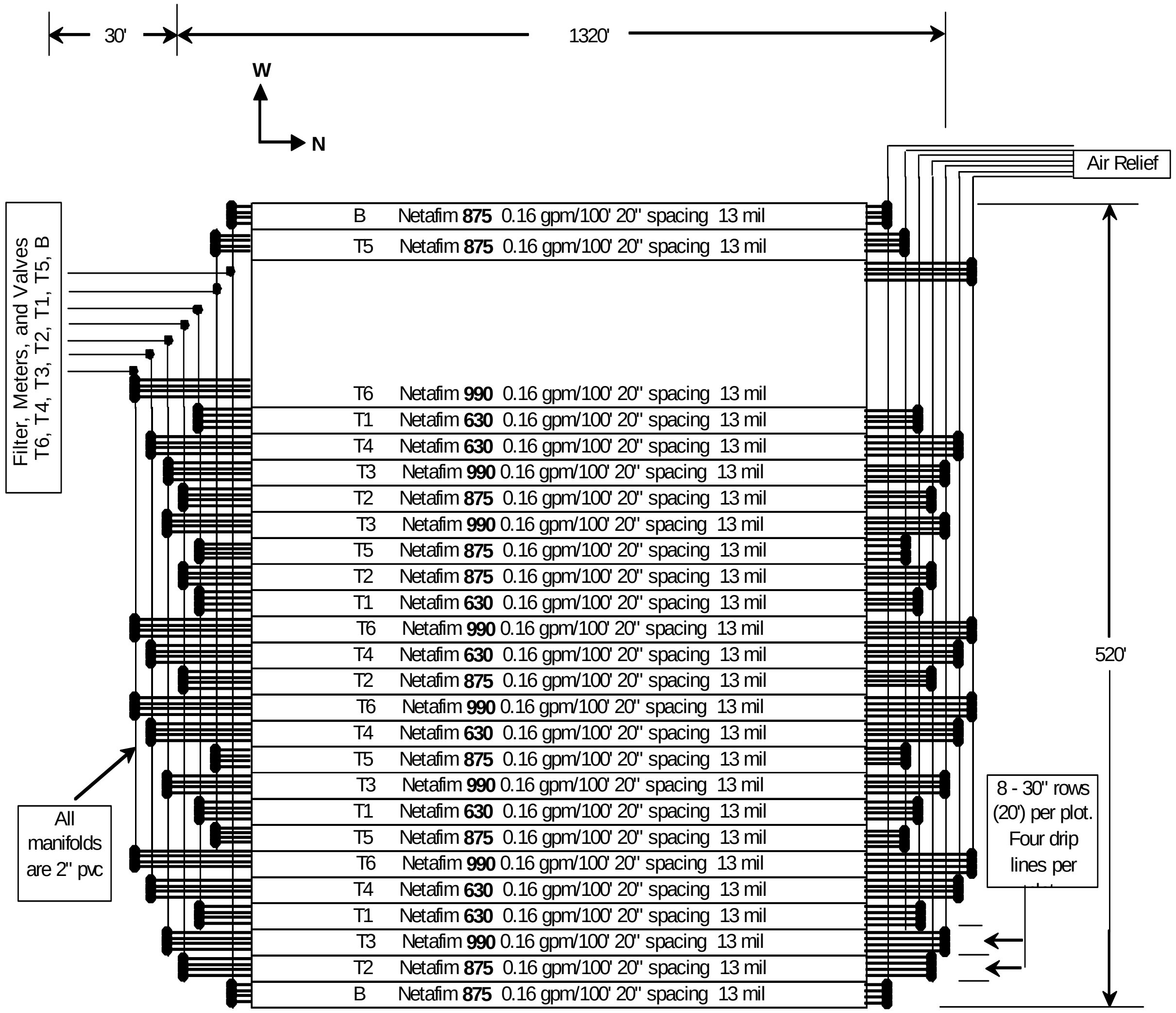

Figure 1. Schematic of SDI drip installation. The three drip tape diameters were installed so that cotton lint yield can be related to poor, acceptable, and very good uniformity of water delivery with SDI at the TAES, Helms Farm.

In 2003 and 2004, drip tape from each of the designs was excavated at 150, 650, and 1150 feet from the irrigation supply manifold along laterals in Blocks 1 and 4. Emitter flow rates were measured (Sadler et al., 1995) at these locations while zones were at design operating pressure and again following zone valve closure as water drained to the lower elevations. Field uniformity of each irrigation design was calculated for comparison to manufacturer's specifications. Flow measurements following zone valve closure were made to determine the time required for emitter flow to stop and to evaluate the pattern of water redistribution due to elevation.

Cotton was planted and irrigated on the experimental area in each year from 2001 to 2004. Yield goals were 1200 and 1500 lb lint/ac for the 60% and 100% BI irrigation treatments. Cotton varieties planted were PM2326RR in 2001 and FM989RR in 2002 through 2004. Based on 24-inch soil fertility sampling, phosphorus and approximately 50% of the required nitrogen was banded on the sides of seed beds in the furrow containing the drip tape. The remaining nitrogen was applied in-season by injection into SDI zones while irrigating from mid July to early August. Therefore, differences in irrigation uniformity caused by the design treatments also affected nitrogen placement within the field. Furrow dikes were placed in non-wheel traffic furrows which were also the furrows containing the drip tape and applied fertilizers. Irrigations were applied daily in 2001 and 2002 and at 2-day intervals in 2003 and 2004 with amounts determined from evapotranspiration (ET) demand estimated from local climatic data and a crop growth function. The 100% BI treatment was equivalent to approximately 80% of ET demand, but varied from year to year based on available irrigation capacity and effective rainfall received in a particular year. Irrigations of the 60% BI treatment equaled approximately 60% of the 100% BI treatment. Cotton was harvested from five locations in each treatment plot, 150, 400, 650, 900, and 1150 feet from the irrigation supply manifold, along the length of the plot. Hand harvested areas in 2001 and 2002 and machine harvest areas in 2003 and 2004 were approximately 80 and 150 ft^2 in size, respectively. Cotton lint yield at each sample site was determined by ginning samples in a small plot gin.

Results

In three of the four test years unusual situations occurred that may have impacted results. The first year of the test, 2001, had the best growing conditions with early, timely rains and open fall weather. In 2002, severe emitter plugging was caused by manganese (Mn) oxide deposits derived from moderate levels of Mn in the irrigation water. A process was developed to clean the emitters and treat the irrigation water to prevent further problems with Mn, however, cotton growth in 2002 was severely affected by this problem and yield data from this year could not be used to evaluate differences in SDI design. In 2003 severe weather in late May and June that included heavy rain, cool temperatures, hail, and blowing sand resulted in abandonment of over half the cotton acres planted in the county (TASS, 2003). Although plant populations were reduced and irregular, the SDI experimental protocol was completed and, with a long, open fall, cotton yields and experimental results were reasonable. The 2004 growing season was noted for record rainfall. Total rain exceeded 34 inches for the year compared to the long-term average of 18 inches. Redistribution of rainfall runoff occurring in the experimental area may have masked the spatial yield variation expected with the different SDI designs.

Flow variation (FV) is a design standard used in the SDI industry and is an indicator of uniform water distribution within a drip lateral, a zone, or a field. Theoretical FV's provided by drip tape manufacturers are a function of emitter design, length of run, tape diameter, and anticipated elevation differences and are determined by dividing the lowest emitter flow rate to the highest emitter flow rate within an area of concern. Table 1 summarizes the treatments used in this experiment along with the manufacturers theoretical FV's and measured FV's for the three SDI designs and operating conditions in 2003. Measured FV's for the POOR and ACC designs were higher than the theoretical values, 0.80 verses 0.71 and 0.94 verses 0.85, respectively. The measured FV's are generally higher than theoretical values due in part to the excavated emitters not being located at the extreme ends of the drip lateral, but rather 150 ft from the ends of the field. FV's determined in 2004 were similar to 2003, thus supporting the concept that manufacturer's FV values are good, conservative estimates of the flow variations that will occur after installation.

Table 1. Treatments, design criteria, and design and measured emitter flow variations from SDI design experiment, Helms Farm, 2003.

Treatment	Irrigation Level	Irrigation Uniformity	Tape Diam. (in.)	Design Pressure (psi)	Design FV	Measured FV
POOR$_{0.6}$	60% BI	Poor	0.650	10.0	.71	.80
VGOOD$_{0.6}$	60% BI	Very Good	0.875	12.0	.94	.92
ACC$_{0.6}$	60% BI	Acceptable	0.990	6.5	.85	.94
POOR $_{1.0}$	100%BI	Poor	0.650	10.0	.71	.80
VGOOD $_{1.0}$	100%BI	Very Good	0.875	12.0	.94	.92
ACC$_{1.0}$	100%BI	Acceptable	0.990	6.5	.85	.94

Non-uniform water discharge following zone valve closure was very significant. Figure 2 shows emitter flow rates over time at six locations on the outer perimeter of the 16-acre test area of the ACC$_{1.0}$ design following zone valve closure. Water continued to flow from low elevation emitters for over 6 hours following the end of an irrigation cycle. Similar results occurred in 2004. The data in Figure 2 suggests that SDI irrigations at multiple irrigation cycles per day on sloping fields would result in poor water distribution. For example, by integrating the area under the "NE" curve in Figure 2, the volume of water deposited by the emitter on the NE corner of the field when irrigating twice per day would equal an additional 0.12 inches of irrigation per day, or over irrigation by 60% of a 0.2 inch irrigation demand. Therefore, benefits of high frequency cotton irrigation with SDI need to be weighed against the effects of poor water distribution caused by frequent zone valve cycling. On sloping fields, SDI irrigation on 2-day intervals might be a reasonable compromise.

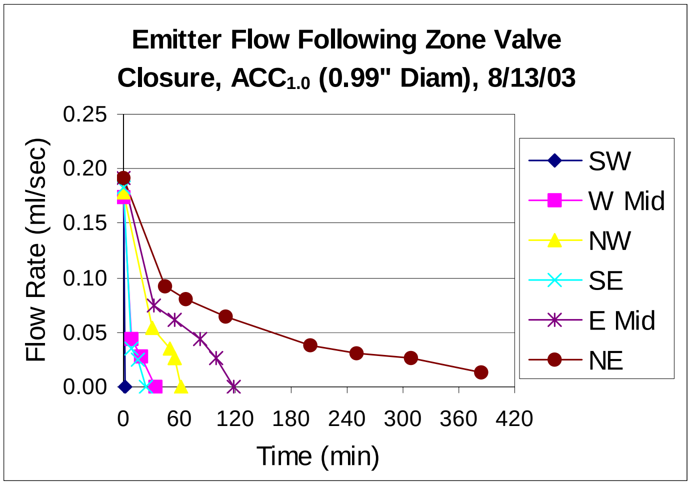

Figure 2. Measured emitter flow rates at six locations in the field following zone valve closure of the large (0.99") diameter drip tape zones, Helms Farm, 2003.

Yield variation statistics and average overall cotton lint yield at the two irrigation levels using the three SDI designs for 2001, 2003, and 2004 are given in Table 2. Christiansen's uniformity coefficient (CU) was determined from the 20 yield values (5 locations per plot x 4 replicates) of each treatment each year. Within an irrigation level, the CU values were not different among the SDI designs ranging from 90 to 92 at the 60% BI level and 85 to 86 at the 100% BI irrigation level. Yield variation is the difference between the highest and lowest yield (of the 20 sample sites) divided by the lowest yield. Within an irrigation level, averaged over the three years, the VGOOD design had

Table 2. Yield variation statistics and average overall cotton lint yield at two irrigation levels using three SDI designs at the Texas Agricultural Experiment Station, Halfway, TX.

Parameter	Irrigation Level	Design Treatment	Year			Averages
			2001	2003	2004	
CU (%)[1]	60% BI	POOR$_{0.6}$	84	92	95	90
		VGOOD$_{0.6}$	92	89	95	92
		ACC$_{0.6}$	92	91	94	92
	100% BI	POOR$_{1.0}$	77	88	94	86
		VGOOD$_{1.0}$	75	88	93	85
		ACC$_{1.0}$	75	88	95	86
Yield Variation[2]	60% BI	POOR$_{0.6}$	1.39	0.65	0.26	0.77
		VGOOD$_{0.6}$	0.45	1.60	0.33	0.79
		ACC$_{0.6}$	0.45	0.58	0.30	0.44
	100% BI	POOR$_{1.0}$	1.02	1.31	0.39	0.91
		VGOOD$_{1.0}$	0.51	2.91	0.40	1.27
		ACC$_{1.0}$	1.09	1.84	0.40	1.11
Lint Yield (lb/ac)	60% BI	POOR$_{0.6}$	1011 a	1293 ab	1602 ab	1302
		VGOOD$_{0.6}$	1035 a	1197 bc	1666 a	1299
		ACC$_{0.6}$	975 a	1356 a	1581 b	1304
	100% BI	POOR$_{1.0}$	1285 b	1090 c	1677 a	1350
		VGOOD$_{1.0}$	1334 b	1100 c	1629 ab	1354
		ACC$_{1.0}$	1300 b	1175 c	1602 ab	1359

[1] CU = Christiansen's uniformity coefficient.

[2] Yield Variation = (max. yield – min yield) / min. yield

numerically higher yield variations (more variability) than either the ACC or POOR designs. When comparing differences in total yield caused by SDI designs, the average yields over the three years were virtually the same within an irrigation level ranging from 1299 to 1304 lb lint/ac at 60% BI and 1350 to 1359 lb/ac at 100% BI. In no year did the SDI design have an effect on total lint yield at the higher irrigation level. SDI design made significant differences in yield in 2003 and 2004 within the 60% BI irrigation level with higher yields in the ACC treatment than those in the VGOOD treatment in 2003 (1356 lb/ac - ACC vs. 1197 lb/ac - VGOOD) and the opposite occurring in 2004 (1581 lb/ac - ACC vs. 1666 lb/ac - VGOOD). The lack of differences in total yield between irrigation levels are attributed to the unusual events previously mentioned.

A visual example of spatial lint yield variation in 2004 is shown in Figure 3. This figure contains lint yields at five distances from the SDI supply manifold in four replicated blocks resulting from the six treatments in 2004. Yield variability occurs in each treatment, but does not appear to be pronounced in one treatment more than the others.

Yields are expected to be higher at locations of higher emitter flow rates, particularly at the 0.6BI irrigation level. Figure 4 shows average cotton yields and emitter flow rates as a function of the distance from the SDI supply manifold in the 0.6 BI irrigation treatments. The POOR treatment was irrigated with small diameter drip tape, and resulted in reduced emitter flows away from the supply manifold as friction losses reduce pressures at the emitters (18% decrease in flow rate along lateral). Yields tended to follow the water, generally decreasing away from the supply manifold, but increasing at the distal location. The VGOOD treatment was irrigated with an optimum size drip tape that compensated for friction losses in the tape with the change in elevation along the length of the plot (2% increase in emitter flow along lateral). Lint yields were fairly level, or increased slightly as a function of distance away from the manifold. The ACC treatment used large diameter drip tape and low operating pressure resulting in larger emitter flows at locations farther from the supply manifold (15% increase along lateral). Yields, again, were fairly level along the length of the plots showing only slight increases with distance away from the supply line in 2003 and 2004. Although yield variations away from the supply manifold were not as pronounced as changes in emitter flow rates, yield response tended to follow the emitter output of the three drip designs.

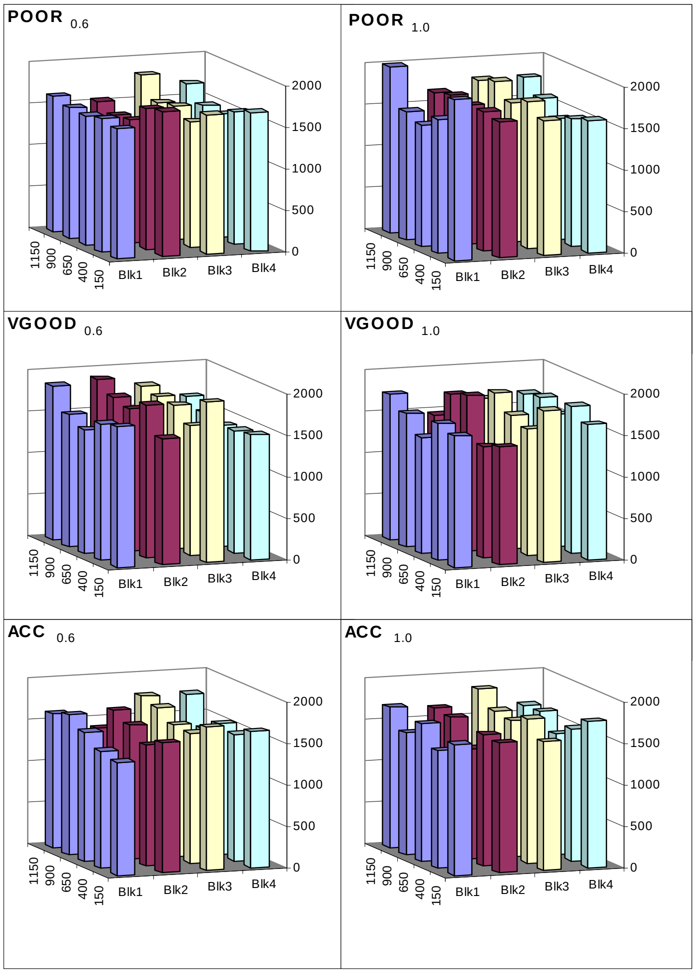

Figure 3. Spatial variation in cotton lint yield at five distances from the SDI supply manifold of four replicated blocks resulting from three SDI uniformity designs irrigated at two irrigation levels in 2004.

Conclusions

Based on measured emitter flow rates, theoretical flow variation values provided by manufacturers for design purposes are conservative estimates of actual flow variations observed in the field. Water remaining in a SDI distribution network following zone valve closure can result in significant redistribution to lower elevations within a zone with frequent valve cycling. Total cotton lint yield within a zone was not affected by water distribution designs having FV's between 0.71 and 0.94. During the test period, conditions other than SDI design had a greater impact on the spatial yield variability than did the design treatments. Cotton yield response tended to follow the trends established by variations in emitter flow rate caused by elevation and friction losses along the tape lateral. Generally higher yields occurred at locations of higher drip emitter discharge, however, the magnitude of the yield change over the length of the lateral did not correspond the magnitude of the emitter flow rate change over the test period. In some instances, SDI installation costs could be reduced by relaxing design specifications.

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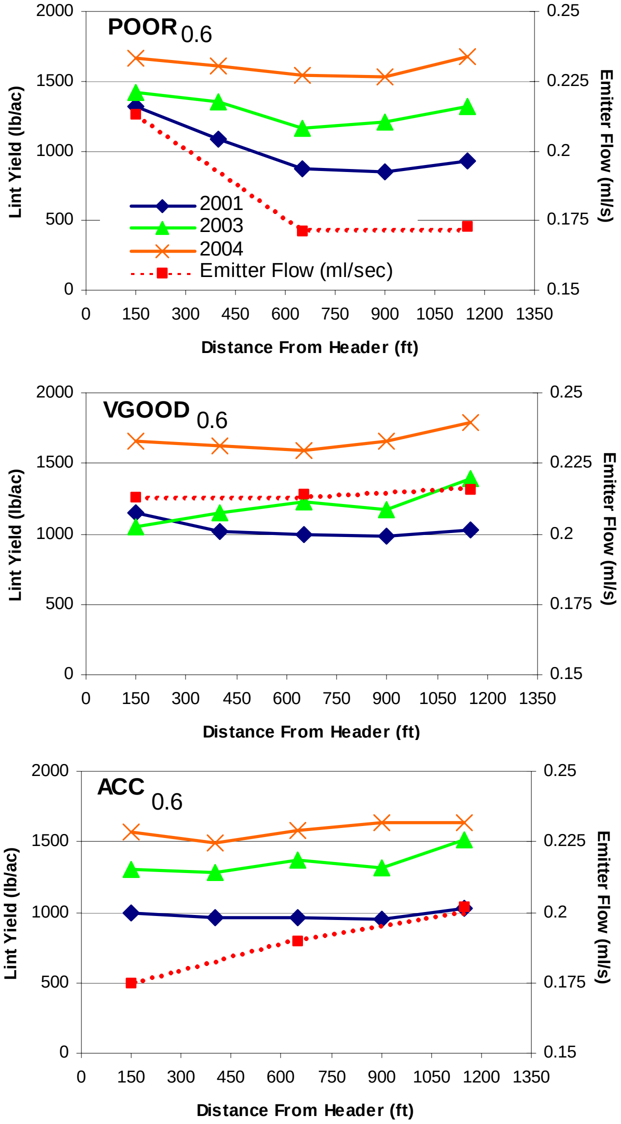

Figure 4. Comparison of 2001, 2003, and 2004 cotton lint yields to SDI emitter flow rates at multiple locations along drip laterals of three drip uniformity designs.

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