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PERFORMANCE AND LONGEVITY OF A SUBSURFACE MICROIRRIGATION SYSTEM

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Summary:

Three microirrigation systems were installed in 1984, two on the soil surface and one about 0.30 m below the soil surface. These systems were used to apply irrigation water and nutrients to several experiments beginning in 1985 and ending in 1992. Emitter plugging, system uniformity, and overall performance were evaluated for both surface and subsurface systems using several methods, and the results were compared to those obtained for unused tubing purchased at the same time from the same manufacturer.

Keywords:

Drip/trickle irrigation, emitter flow, uniformity coefficient, emitter plugging, simulation

INTRODUCTION

Microirrigation can potentially achieve high application uniformity and provide high application efficiency. This is important in producing uniformly high crop yields and preserving water quality when both water and chemicals are applied through the irrigation system. Subsurface microirrigation offers additional advantages of multiple-year life, lower cost because of a longer amortization period, less interference with cultural operations, and less evaporation loss. Because most system components are located below the soil tillage zone, it is difficult to monitor system operation, especially reduced system performance caused by emitter plugging. Consequently, good management practices and periodic preventive maintenance are required to reduce the potential for emitter plugging.

Evaluation of emitter discharge uniformity and system performance are necessary to determine if water and chemicals are applied uniformly. Application uniformity of microirrigation systems can be expressed by several uniformity parameters; however, most require measurement of emitter discharge for a representative sample of the emitters in a system. Nakayama and Bucks (1986) reviewed several widely used parameters, including uniformity coefficient, *UC*, emitter flow variation, q_{var}, and coefficient of variation of emitter flow, *CV* (Christiansen, 1942; Wu et al., 1979). A method for statistically evaluating microirrigation systems in the field using measured emitter flow rates and pressures for randomly selected emitters and sub-mains was adopted by ASAE (1988) as an engineering practice, EP458. However, determination of these parameter values for field systems requires measurement of emitter flow rate and pressure at selected locations throughout the system. This can be accomplished in a straightforward manner for systems where the emitters are located on the soil surface; however, it is much more difficult for subsurface systems, where the emitters to be evaluated must be excavated to allow collection of water discharged. Models used for design and evaluation of microirrigation systems - Energy Gradient Line (EGL), Revised Energy Gradient Line (REGL), and Step by Step (SBS) - may be useful in the evaluation of application uniformity of subsurface systems (Feng and Wu, 1990; Wu and Yue, 1991; Wu, 1992). Based on measured system uniformity for five different thin-wall tape systems in both surface and subsurface field installations, Phene et al. (1992) found that REGL or SBS models can be used to design or evaluate microirrigation systems when system uniformity is fairly good.

The objectives of this research were (1) to evaluate emitter discharge uniformity for a subsurface microirrigation system that had been used annually during the growing season for eight years, (2) to compare emitter discharge uniformity of the 8-year-old subsurface system with that of unused emitters, (3) to compare measured emitter uniformity values for surface and subsurface systems, and (4) to compare measured emitter discharge uniformity with that predicted by simulation models.

MATERIALS AND METHODS

Field Site

<u>Installation</u>. Microirrigation tubing was installed in the fall of 1984 on a 0.20-ha site of Norfolk loamy sand (Typic Kandiudult) near Florence, South Carolina. Prior to installing the irrigation system, the experimental site was subsoiled to a depth of 0.4 m in two directions, each diagonal

to row direction, and then smoothed with a disk harrow. Thereafter, only a disk harrow and field cultivator were used to remove weeds and incorporate agricultural chemicals. The microirrigation tubing (Lake Drip-In[1]) had in-line, labyrinth-type emitters spaced 0.61 m apart, each delivering 2.5 L/h at 115-kPa pressure. The experimental site included 24 plots: eight with subsurface microirrigation and 16 with surface microirrigation (eight for each of two lateral spacings). All plots were 12 m long and 6.1 m wide. Lateral spacing was 0.76 m for the subsurface system and one of the surface systems, and 1.52 m for the other surface system. A schematic diagram of the three systems is included as Figure 1. In most experiments conducted on this site, the laterals in the 0.76-m spacings were located adjacent to or under each crop row and laterals in the 1.52-m spacings were located in alternate row furrows. In most experiments, there were two irrigation treatments for each lateral spacing (irrigation application modes, scheduling methods, etc.) and four replications of each treatment.

Laterals for the subsurface system were installed using a modified subsoiler shank, and they remained in the soil thereafter. At this depth, the tubing was located below the frost line and at the top of the E horizon; however, much of the E horizon had been mixed by tillage with the adjacent Ap and B horizons. The surface system was installed each year after crop emergence, was removed prior to harvest, and was stored during the off-season. The two surface systems were considered together for the performance evaluation discussed in this paper.

Modifications. All laterals within a plot were connected to a single manifold, in which flow was controlled by a solenoid valve and manifold pressure was regulated at approximately 115 kPa using a pressure-regulating valve. Manifolds were initially installed on the soil surface for both the surface and subsurface systems. In 1987, manifolds for the subsurface system were buried at a depth of about 0.30 m, the same depth as the laterals. Also, two manifolds, including individual pressure-regulating valves, were installed in each plot to allow either separate or combined control of each half plot (four laterals for 0.76-m spacing). Manifolds connecting the discharge end of each lateral (0.3 m deep) and extending to the field edge were also installed in 1987 to facilitate flushing. Previously, each lateral in the subsurface system had extended to the soil surface and was terminated with a removable end cap.

Management and operation. Crops grown on this experimental site were corn during the first three years (1985-87) (Camp et al., 1989), spring and fall vegetables during the next two years (1988-89) (Camp et al., 1993), and corn during the next three years (1990-1992). Vegetable crops included cowpea, green bean, yellow squash, muskmelon, and broccoli. The irrigation water supply was a chlorinated municipal supply during most of the period, supplemented with well water at various times. All water was passed through a 200-mesh cartridge filter, and well water was normally filtered through a sand filter first. At the beginning of and periodically during each growing season, the system was flushed by removing the end caps. At the end of each growing season, a higher-concentration chlorine solution (10-50 mg/kg available chlorine) was injected into the system, allowed to remain in the system for 1 h, and flushed with water.

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[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

This treatment was applied to reduce biological activity and to retard root entry into emitters, particularly during the dormant season.

System operating parameters, including system flow rate and manifold operating pressure, were monitored during the 8-year operation period. Preliminary evaluation of the microirrigation system had been conducted at the end of the growing season in 1989, when 16 emitters were excavated and emitter flow rates were measured. A 10-mg/kg chlorine solution was then injected into the system where it remained overnight. The next day, a 10-percent sulfuric acid and 100-mg/kg chlorine solution was injected into the system and again remained overnight. The system was then flushed, and flow rates were measured for the same emitters. The treatment had a small effect on emitter discharge rate, but did not significantly change emitter discharge uniformity.

The aforementioned discussion describes the history of the field systems. The status at the beginning of the current work was (1) the system was eight years old, (2) on-going monitoring had indicated that there was no major problem, but the monitors may not have been sensitive enough, and (3) a preliminary evaluation of emitter uniformity suggested there may have been some emitter plugging. The work reported here was conducted in 1993.

System Evaluation

Laboratory, every emitter (EE) test. Unused tubing of the same manufacturer and type, and purchased at the same time as the tubing installed in 1984, was evaluated in the laboratory using the same pressure-regulating valves as those used in the field installation. Emitter discharge rate was determined by collecting for a period of 5 minutes the water discharged from every emitter on a single, 12-m length of lateral (total of 20 emitters). This evaluation was repeated for two other laterals of the same length and material. Water volume was determined by measuring its mass using an electronic balance and converted via density. Water flow rate, pressure, and temperature were measured for each test. Each test was conducted three times for each of the three laterals.

Field, every emitter (EE) test. Emitter discharge rate was also determined for every emitter on each of three 12-m laterals selected randomly from the surface system that had been used in the field since its installation in 1984. Measurements were obtained in the same manner as in the laboratory tests, and each test was conducted three times for each lateral.

Field, random emitter (RE) test. Emitter discharge rate was measured for 24 randomly selected emitters from both the surface and subsurface systems that had been in use since 1984. All measurements were made while the system operated in the normal mode, and system flow rate, water pressure, and temperature were measured for each test. The soil was excavated from around each emitter in the subsurface system to accommodate the 500-ml collection container.

Uniformity Parameter Calculations

Traditional methods. Three widely-used parameters for measuring emitter discharge uniformity are emitter flow rate variation, q_{var}, coefficient of variation of emitter flow rate, CV, and emitter uniformity coefficient, *UC* (Nakayama and Bucks, 1986). Emitter flow rate variation, q_{var}, was calculated using the equation

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \tag{1}$$

where q_{max} = maximum emitter flow rate, and

q_{min} = minimum emitter flow rate.

Coefficient of variation of emitter flow rate, *CV*, was calculated using the equation

$$CV = \frac{s}{\bar{q}} \tag{2}$$

where s = standard deviation of emitter flow rates and

$\bar{q}$ = mean emitter flow rate.

Emitter uniformity coefficient, *UC*, as defined by Christiansen (1942) and modified to reflect a percentage, was calculated using the equation

$$UC = 100 \left[1 - \frac{\frac{1}{n} \sum_{i=1}^{n} |q_i - \bar{q}|}{\bar{q}} \right] \tag{3}$$

where n = number of emitters evaluated. In tests where every emitter in the lateral (EE) was evaluated, means of calculated values for each test (replication) are reported for each of the three laterals tested. Measure emitter discharge rates for all three laterals combined (60 emitters) were used to calculate parameter values for each of three tests (replications); means of calculated values are reported. In tests where 24 random emitters (RE) were evaluated, means of the calculated values for all tests are reported.

<u>ASAE EP458 Method</u>. Statistical uniformity, emitter discharge variation, hydraulic variation, and emitter performance variation were calculated using EP458 to evaluate microirrigation systems in the field. Nomenclature used in a pending revision of EP458 is used in this paper. Confidence limits (95%) for calculated uniformity parameters were determined using the procedure in Bralts and Kesner (1983) because confidence limits were not included in EP458 for the number of system emitters tested (24). Most of the calculated values require the determination of mean emitter discharge rate, $\bar{q}$, and standard deviation, S_q, which were calculated using the equations

$$\bar{q} = \frac{1}{n} \sum_{i=1}^{n} q_i \tag{4}$$

$$S_q = \sqrt{\frac{\sum_{i=1}^{n} q_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} q_i\right)^2}{n-1}} \quad (5)$$

The emitter discharge coefficient of variation, V_{qs}, and statistical uniformity, U_s, were calculated using the equations

$$V_{qs} = \frac{S_q}{\bar{q}} \quad (6)$$

$$U_s = 100\,(1 - V_{qs}) \quad (7)$$

The mean hydraulic pressure, $\bar{h}$, and hydraulic design coefficient of variation, V_{hs}, were determined using Eqs. [4], [5], and [6], respectively, with substitution of lateral line pressure, h_i, for emitter discharge, q_i, while all other variables are as previously described. The emitter discharge coefficient of variation due to hydraulics, V_{qh}, was calculated using the equation

$$V_{qh} = x\,V_{hs} \quad (8)$$

where x is the emitter discharge exponent (0.54 according to manufacturer). Likewise, the statistical uniformity of emitter discharge rate due to hydraulics, U_{sh}, was calculated using the equation

$$U_{sh} = 100\,(1 - V_{qh}) \quad (9)$$

The emitter performance variation is a measure of emitter discharge variability due to water temperature, emitter manufacturer's variation, emitter wear, and emitter plugging. The emitter performance coefficient of variation, V_{pf}, was calculated using the previously determined emitter discharge coefficient of variation, V_{qs}, the emitter discharge coefficient of variation due to hydraulics, V_{qh}, and the equation

$$V_{pf} = \sqrt{V_{qs}^2 - V_{qh}^2} \quad (10)$$

Model simulations. System dimensions and operating parameter values only were used in the computer program CEDDIS (Yue et al., 1992) to obtain application uniformity values for these models. These values were then compared with those determined from measured emitter flow rates and lateral operating pressures.

RESULTS

System flow rate and operating pressures monitored during the eight growing seasons indicated that the microirrigation system had been operating in a satisfactory manner. However, the flow meters may not have been sensitive enough to measure small changes in flow rate that may have occurred. Data collected during the initial system evaluation in 1989 suggested some emitter plugging had occurred.

When pressures in several manifolds in the subsurface system exceeded the preset value, the regulating valves for these manifolds were excavated, removed from the system, and examined. Soil particles had accumulated in the pressure regulating valve and had caused the valve to malfunction, which allowed the downstream pressure to exceed the design value. After the valves were disassembled and cleaned, they operated normally. Because the color and texture of soil particles found in the malfunctioning pressure-regulating valves indicated that the soil probably came from the experimental site, we believe that the soil entered the system during construction when the manifolds and pressure regulating valves were buried as part of the system modifications in 1987. Possibly, the manifolds were not flushed sufficiently before the pressure-regulating valves were installed. There was no evidence that the soil particles entered the system via the water supply.

Unused vs. used surface laterals. Uniformity parameter values calculated using the traditional parameters for the unused and used laterals tested in the laboratory and field, respectively, are shown in Table 1. There was slight variation in uniformity parameter values among the three unused laterals when emitter flow rates were measured for all emitters (n=20) on each lateral. The *CV* values were low, ranging from 0.011 to 0.018, with a mean value of 0.015. Similarly, the *UC* values were high, ranging from 98.5 to 99.2, with a mean value of 98.8. Uniformity parameter values for two of three laterals from the surface (field) system were similar to those for the unused laterals, but the third lateral had a higher *CV* value and a lower *UC* value. *CV* values ranged from 0.017 to 0.179 with a mean value of 0.073, and *UC* values ranged from 92.4 to 98.7 with a mean value of 96.4. The degraded performance of the third lateral resulted from one emitter that was partially plugged. Uniformity parameter values were also calculated for all three tubes combined (n=60 emitters) to determine the effect of a larger sample size and for comparison with mean values for testing each lateral separately. The *CV* values were slightly greater and the *UC* values were slightly less for the laterals combined than for the mean values of each lateral tested separately. Based on these measurements, it appears that there has been some degradation in emitter application uniformity during the 8-year period for the surface microirrigation system, but the system uniformity values remain acceptable.

Emitter flow uniformity and system application uniformity parameter values calculated using the EP458 method are shown in Table 1 for the used and unused single-lateral comparisons. As with the traditional parameter values, the unused laterals had greater uniformity than the used laterals; however, two of the used laterals were similar to the unused laterals. Again, the parameter values calculated for the three laterals combined indicated slightly less uniformity than the mean of values calculated for the laterals separately. Although the values were slightly different for the traditional and EP458 methods, ranges and trends were similar. It appears that the EP458 method provides a lower uniformity value than the traditional methods when emitter plugging occurs.

Table 1. Uniformity parameter values calculated for various microirrigation systems using both evaluation methods.

System/ Evaluation Method	No. Emitters	No. Tests	Uniformity Parameter Values*						
					Traditional Methods			EP458 Method	
			$\bar{q}$	S_q	q_{var}	CV	UC	V_{qs}	U_s
EE†, Unused, Lab			L/h	L/h	--	--	%	--	%
Tube 1	20	3	2.325	0.025	0.043	0.011	99.2	0.011	98.9
Tube 2	20	3	2.324	0.040	0.059	0.017	98.8	0.017	98.3
Tube 3	20	3	2.235	0.039	0.055	0.018	98.5	0.018	98.2
Mean	--	-	2.294	0.035	0.052	0.015	98.8	0.015	98.5
Combined‡	60	3	2.294	0.055	0.092	0.024	98.1	0.024	97.6
EE, Used, Field									
Tube 1	20	3	2.331	0.039	0.054	0.017	98.7	0.017	98.4
Tube 2	20	3	2.203	0.048	0.065	0.022	98.0	0.022	97.8
Tube 3	20	3	2.135	0.382	0.765	0.179	92.4	0.179	82.1
Mean	--	-	2.223	0.156	0.295	0.073	96.4	0.073	92.8
Combined	60	3	2.224	0.233	0.775	0.105	96.0	0.105	89.5
RE, Used, Field									
Surface	24	5	2.239	0.074	0.117	0.033	97.6	0.033	96.7
Subsurface	24	5	2.240	0.428	0.873	0.191	91.4	0.191	80.9
Models§	--	--	2.156	0.033	0.075	0.015	98.8	--	--

* Each value is the mean of values calculated for individual tests.

† Emitter selection systems are defined as EE = every emitter (20) on a single lateral and RE = randomly selected emitters (24) from all laterals in a system.

‡ Values calculated using data collected for all three tubes during a given test.

§ Values predicted by the EGL, REGL, and SBS models were equal for the surface and subsurface systems.

<u>Field system tests</u>. When the field surface and subsurface microirrigation systems were evaluated using the traditional evaluation methods and randomly selected emitters (n=24), the *CV* value for the surface system (0.033) was slightly greater than *CV* values for most of the single laterals, and the *CV* value for the subsurface system (0.191) was significantly greater. Likewise, the *UC* value for the surface system (97.6) was similar to values for the single laterals but was significantly greater than that for the subsurface system (91.4). The *CV* value was greater and the *UC* value was less for the subsurface system than for the surface system, possibly indicating a greater degree of emitter plugging. Even though the *UC* value for the subsurface system was much less that the surface system, it remained acceptable.

Results of more extensive evaluation of the surface and subsurface microirrigation systems in the field using the EP458 method for calculating parameters are shown in Table 2. Mean emitter discharge rates for the surface and subsurface systems were similar, but other parameter values were quite different. Confidence limits (95%) based on calculated statistical uniformity values and the number of emitters measured are included immediately below each parameter value in Table 2. The emitter discharge coefficient of variation, V_{qs}, was much less and emitter discharge statistical uniformity, U_s, was much larger for the surface system than for the subsurface system. The surface system would be evaluated 'excellent' according to EP458 EP458, while the subsurface system would be evaluated between 'good' and 'fair'. When values of emitter discharge coefficient of variation due to hydraulics, V_{qh}, were calculated, the value for the surface system (0.019) was half the value for the subsurface system (0.038), indicating less difference between the two systems for this parameter. Likewise, the statistical uniformity of emitter discharge rate due to hydraulics, U_{sh}, indicates less difference between the two systems. Finally, the emitter performance coefficient of variation value, V_{pf}, indicates that the surface system is significantly more uniform than the subsurface system (0.027 vs 0.187).

Model simulations. Parameter values predicted by the EGL, REGL, and SBS models for the surface and subsurface systems were equal, both among models and for the two systems; consequently, single values are reported for each parameter in Table 1. Equality of parameter values among models and systems is not unexpected because these systems are small with little change in elevation when compared to most field systems, and hydraulic design is not a major consideration. Parameter values for the surface system were very similar to those predicted by the models, but those for the subsurface system indicated lower uniformity, probably caused by emitter plugging. All model values were determined with all emitter plugging input values set to zero. When non-zero plugging input values were used, even very small values, model predictions were erratic; consequently, we concluded that the models were useful when plugging is not a factor in system evaluation, which is similar to the conclusion reached by Phene et al. (1992).

In the future, the subsurface system will be treated with acid and chlorine to determine whether emitter plugging can be reduced. The system will then be evaluated again to determine any change in emitter discharge uniformity. Other uniformity evaluation studies and techniques are also planned. Following these studies, some emitters will be excavated and removed for examination, especially if emitter discharge uniformity does not improve significantly following the acid and chlorine treatment. Because soil particles were found in some pressure-regulating valves, some of the emitter plugging may have been caused by soil particles.

CONCLUSIONS

Microirrigation laterals that had been used since 1984 in both surface and subsurface systems were evaluated using both traditional emitter discharge uniformity parameters and a method included in ASAE EP458. These values were compared to those measured for unused laterals of the same type and manufacturer, and purchased at the same time as those that were installed, and to values predicted by three design models. Emitter uniformity values calculated by the

Table 2. Evaluation of emitter uniformity using randomly selected emitters (RE) in field systems and the ASAE EP458 method for calculating parameter values.

Field Microirrigation System	Uniformity Parameter Values* (ASAE EP458)						
	$\bar{q}$	S_q	V_{qs}	U_s	V_{qh}	U_{sh}	V_{pf}
	L/h	L/h	--	%	--	%	--
Surface	2.239	0.074	0.033	96.7	0.019	98.2	0.027
Conf. limit§	--	--	±0.010	±0.99	±0.006	±0.57	±0.008
Subsurface	2.240	0.428	0.191	80.9	0.038	96.2	0.187
Conf. limit§	--	--	±0.059	±5.91	±0.011	±1.14	±0.058

* Each value is the mean of values calculated for five individual tests (replications).
§ Confidence limits (95%) appropriate for statistical uniformity values and evaluation of 24 system emitters based on ASAE EP458.

traditional and EP458 methods were similar for the unused laterals and used laterals from the surface system in the field, however those calculated by the EP458 method indicated lower uniformity values for the used laterals from the subsurface system in the field. The EGL, REGL, and SBS models predicted the same uniformity parameter values for surface and subsurface systems, and all values indicated greater uniformity than did the values based on measured values. However, the input data for the models reflected zero plugging and the models did not provide realistic values when non-zero plugging values were used.

Based on these evaluations, it appears that both the traditional methods and those described in EP458 can be used to evaluate microirrigation systems. Overall procedures and guidance are provided in EP458, but the procedure tends to be somewhat complex. The surface system that had been used for at least eight years retained excellent uniformity, and measured emitter uniformity values were generally comparable to those of unused tubing of the same age. Measured emitter discharge uniformity for the subsurface system was somewhat less and rated between 'good' and 'fair', based on guidelines in EP458. Remedial measures to return the system to a uniformity comparable to the surface system will be attempted in the near future. However, soil particles that probably entered the system while modifications were being installed may have caused some plugging and might not be removed by acid and chlorine solutions. If great care is exercised in the installation and maintenance, subsurface systems should have a useful life of at least 8-10 years.

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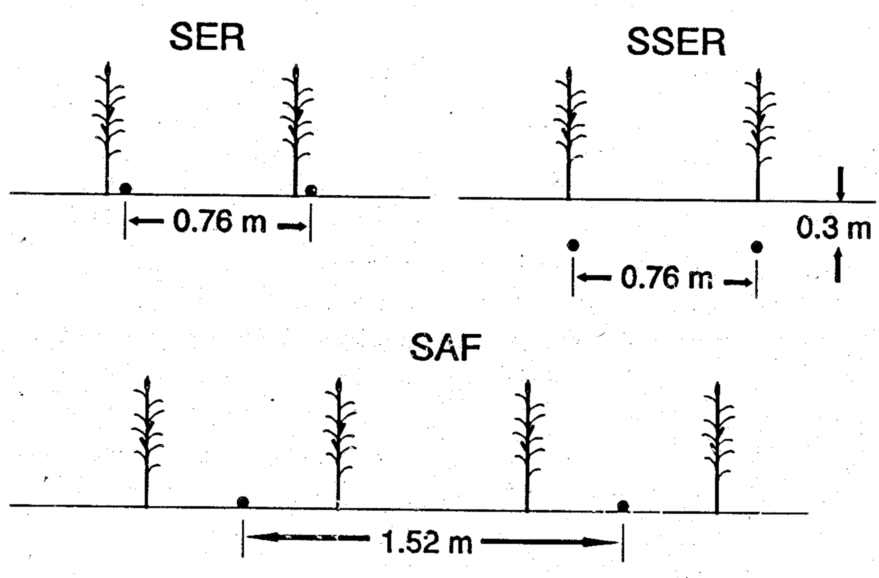

Figure 1. Schematic diagram of microirrigation lateral placements in field systems. Systems are defined as follows: SER = surface every row, SSER = subsurface every row, and SAF = surface alternate furrow.