EMITTER FLOW RATE CHANGES CAUSED BY EXCAVATING SUBSURFACE MICROIRRIGATION TUBING

E. John Sadler, Carl R. Camp, and Warren J. Busscher*

ABSTRACT

Design criteria for irrigation systems are heavily optimized for uniformity of application. Therefore, measuring application uniformity is an important tool to evaluate system operation and longevity. Measuring uniformity for sprinkler systems involves catch cans located within the irrigated area. Measuring uniformity for surface microirrigation systems is a straightforward adaptation of this technique. Extending the adaptation for subsurface microirrigation systems requires that individual emitters be excavated, which presumes that the effect of soil around the emitter is negligible. The objective of the research was to measure the effect of excavating subsurface emitters on flow rate. This was done by measuring flow rate for a section of tubing, then sequentially excavating emitters and measuring flow from them with catch cans. The combined measurements allow both regression of flow rate on number of exposed emitters and the computation of the effect of excavating single emitters. Excavating an emitter increased flow rate between 2.8% and 4.0% (extremes over four laterals). Only about half of this increase could be explained by the 0.3-m head postulated to exist in soils that exhibit upwelling above subsurface emitters. The effect of excavating emitters to measure uniformity is not expected to cause significant errors in the uniformity calculation.
Keywords. Subsurface microirrigation, Excavation, Uniformity

INTRODUCTION

Subsurface microirrigation systems have potential for conserving water while providing plant roots with water and nutrients in a direct manner. Field uniformity of water and nutrient applications are particularly difficult to determine for subsurface systems. For overhead spray systems, catch cans can be placed at predetermined locations in a field. For subsurface microirrigation systems, researchers are required to excavate individual emitters, place cans under them, and catch the flow. This procedure is tedious, destructive, and labor intensive. Alternatives to this procedure have been proposed, including evaluation before installation and using a computer model (Phene et al., 1992).

Camp et al. (1989, 1993a) described the uniformity of an 8-yr-old subsurface microirrigation system using the traditional method of excavating buried emitters and catching flow in cans for weighing. The system design included microirrigation lines buried 0.3 m below the surface in each row, as well as two surface placements. Camp et al. (1993b) concluded that the uniformity of the surface system was essentially the same as that of the unused tubing retained from the original lot. Buried tubing uniformity was slightly lower than surface uniformity, but was still rated good by the appropriate standard (ASAE, 1988).

In addition to the difficulties mentioned above, excavating the emitters brings into question two procedural assumptions. First, it is assumed that the flow from the buried emitter is the same as flow from the emitter when excavated. Second, even without the first assumption, it

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* Authors are Soil Scientist, Agricultural Engineer, and Soil Scientist, respectively, U.S. Dept. of Agric., Agric. Res. Service, Coastal Plains Soil, Water, and Plant Research Center, Florence, SC.

is assumed that whatever the effect of the soil were to be, it would be the same for each emitter. The objective of this research is to place confidence limits on the implications of these procedural assumptions required to evaluate subsurface microirrigation systems.

METHODS AND MATERIALS

The subsurface irrigation system described by Camp et al. (1989, 1993a, 1993b) was used for this study. The soil at the 0.20-ha installation was Norfolk loamy sand (Typic Kandiudult). In 1984 irrigation tubing (Lake Drip-in**) with labyrinth, in-line emitters on 0.6-m spacing was buried at the 0.3-m depth beneath rows spaced 0.76 m apart. The system included four replications, each with two plots of 8 rows, 12 m long. The original installation had 20 emitters per line. The flow from an individual emitter was nominally 1.9 L/hr (0.5 gph), for a line flow rate of 38 L/hr.

The basis of the measurements was that if excavating an emitter made a consistent difference in flow rate, this difference could be measured as the slope of the flow rate as a function of number of excavated emitters. The flow rate from an entire, single line could be measured by installing a flow meter upstream from the emitters. Sequential runs could be made, each with one additional emitter excavated. By the end of the sequence, the slope could be determined and, because all emitters were now exposed so that the outflow could be caught and weighed, the calibration of the flow meter could be confirmed. Initial tests suggested that one of the inexpensive flow meters was not reliable. Nevertheless, it appeared there was a small but consistent increase in flow rate as each emitter was excavated. Although the line pressure was regulated at 100 kPa (15 psi), the regulator was not completely successful in eliminating line pressure variations caused by source pressure variations. Therefore, a means of correcting pressure was developed to interpret the flow results.

Bernoulli's equation, with continuity and assumed incompressibility of flow, provides that the flow rate through an orifice is proportional to the square root of the pressure drop across the orifice.

$$Q = CA\sqrt{\frac{2}{\rho}(P_o - P_i)} \tag{1}$$

where Q is flow in L/hr, C is a coefficient for the orifice, A is area of the orifice in m^2, ρ is density in kg/m^3, and P is pressure at the outlet and inlet in kPa. Gathering all terms but Q and P into a single coefficient, K, and assuming the pressure at the outlet is negligible, we have a constant for an emitter.

$$K = \frac{Q}{\sqrt{P}} \tag{2}$$

One could argue that a labyrinth cannot be described as a simple orifice. Nakayama and Bucks (1986) report that empirical studies of turbulent-flow, non-pressure-compensated, labyrinth emitters could be described by the above equation, but with an exponent of 0.56.

$$K = \frac{Q}{P^{0.56}} \tag{3}$$

Pressure-corrected flow was defined using the value K in equation 3, and calculating the flow at 100 kPa.

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Field and laboratory measurements were conducted in a similar manner. A section of irrigation tube was removed to allow insertion of a pressure regulator (nominally @ 115 kPa), a pressure transducer (Model PX302, Omega Engineering, Inc., Stamford, CT), a thermocouple, and two flow meters in series (model TI0175, Kobold Instruments Inc., Pittsburgh, PA) between the lateral and the first emitter to be measured. The field setup was too close to insert all this without sacrificing one emitter on the supply end. The opposite end, which in the field was connected to a collection manifold, was isolated from the pressurized system so that the flow meters recorded all flow.

The outputs from the transducers were interrogated and stored on 5-s intervals by a CR7X datalogger (Campbell Scientific, Inc, Logan, UT) connected to a laptop computer. Flow totals caught under each excavated emitter were weighed on a platform balance, also connected to the laptop. Flow and weight files for each of the sequential runs were analyzed and plotted using software written for the purpose in SAS (SAS, 1990).

When effects of pressure variations were removed for a preliminary field run, regression with 0, 1, 2, 3, 9, and 10 emitters excavated resulted in a slope that produced a 14% increase in flow rate when an emitter was excavated. Examination of the data showed that the run for the last emitter appeared anomalous. Deletion of that one point reduced the effect to 3%. This difficulty emphasized the necessity for more confidence in the flow meter. Observations of flow meter failure in sunlit conditions, but acceptable operation in the laboratory, suggested that the photodetectors were being saturated by direct sunlight penetrating the translucent housing. A simple shield solved this problem.

During the runs, and consistent with prior experience with subsurface irrigation on these and other soils (Zimmer et al., 1988), the water rose to the surface over several of the emitters. If this soil were acting as a containment vessel, then the assumption of zero outlet pressure would be invalid. A head of 0.3 m reduces the nominal pressure difference by 3%. Using the square root of that difference, the hydraulic effect alone would be about 1.5%. We decided to conduct a lab test to check this theory while recalibrating the two flow meters.

Enclosures for emitters were constructed to provide 0.3-m head at the outlet. A lab apparatus that allowed flow rate to be measured for each emitter was modified to accommodate seven enclosures out of 18 emitters in a line. As the enclosures were sequentially added to random emitters, flow rates were measured for 5 min. This made an analog to burying emitters sequentially, but with catch-can data from the 'buried' emitters being available. Two flow meters were installed in series for the test.

The lab setup was re-installed in the field, with new calibrations for the flow meters. Emitters were sequentially excavated for two entire lines, with measurements made for each configuration from 0 to 19 emitters excavated. Measurements of flow rate and pressure were made by the datalogger for the 5-min duration for each emitter. To relieve the labor requirement for 19 persons moving catch cans, placement and removal of catch cans were accomplished in a 10-s stagger, in pairs, within 20 s of the 5-min limit. All calculations and regression of flow rate on number of exposed emitters were performed using the SAS statistical package.

RESULTS

Lab Test and Calibration

A graph of pressure-corrected flow rate against number of emitters with 0.30-m head impressed on the outlet is shown in fig. 1. The slope of the equation represents the average increase of an emitter when the head is removed. The mean effect of exposing the emitters was 3%.

Field Test

A graph of pressure-corrected flow rate for both runs and both flow meters is also shown in fig. 1. The slope of the regression line represents the average marginal increase in flow measured as an emitter was excavated. For lateral 1, where the regression line slope and intercepts were identical to 3 significant figures, the average flow for an emitter when buried, as determined from the intercept, was 2.02 L/hr. The slope was 79.8 mL/hr/emitter, which is a 3.95% increase when an emitter is excavated. Corresponding numbers for lateral 2, flowmeter 1, were 1.93 L/hr average flow, 53.4 mL/hr/emitter slope, and 2.77% average effect of excavating the emitter. Flow meter 2 on lateral 2 was intermediate, with 3.26% average effect of excavation. Inspection prior to run 2 had isolated an oxidized bridge between contacts on flow meter 2, which was disassembled to correct the problem. It is unknown whether the performance of the flow meter was altered as a result of this correction.

The means and standard deviations of individual emitters, as determined by weighing catch cans, are shown in table 1. The effect of excavating an emitter on its flow rate, as found by subtracting successive measurements by flow meter 1, is shown in column six. The rightmost column is the calculated flow rate that prevailed when the emitters were still buried. For lateral 1, the effect on individual emitters ranged from a decrease of 0.118 L/hr (-5.2%) to an increase of 0.154 L/hr (+7.7%), with all but the one difference positive. Note that 4 emitters were nonfunctional, which was determined to be the result of an earlier breach that allowed soil intrusion that was not completely flushed after the repair. For lateral 2, the range was from a low of -0.023 L/hr (-1.0%) to a high of 0.138 L/hr (7.1%), with all but 2 values positive.

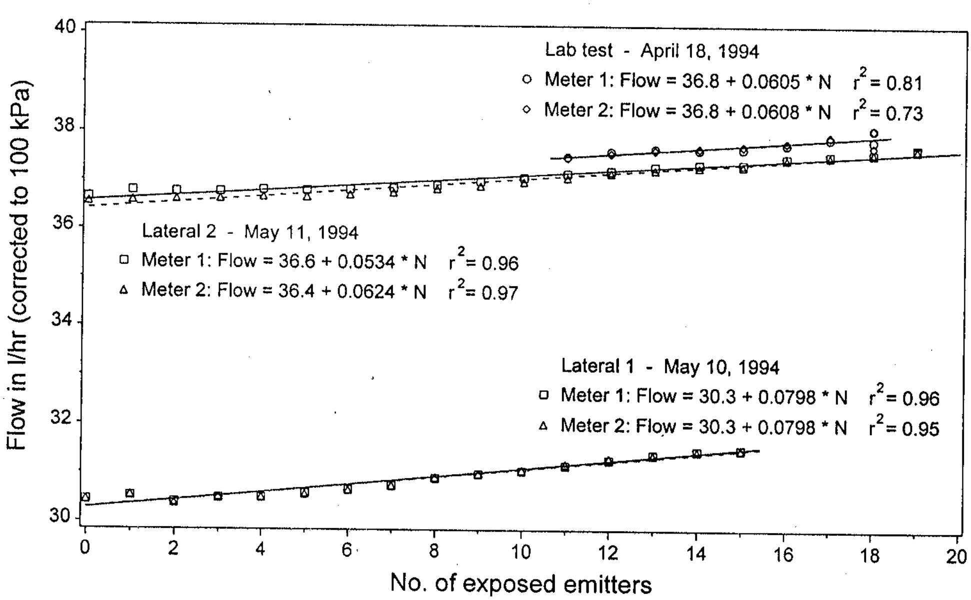

Figure 1. Results of laboratory test of effect of 0.3-m head on flow rates from emitters, and of field tests of effect of excavation on flow rates from buried irrigation emitters.

Table 1. Mean measured flow of excavated emitters, calculated increase because of excavation, and calculated flow rate of buried emitters.

Lateral	Emitter #	Mean flow L/hr	Std dev L/hr	N	Increase L/hr	Buried flow L/hr	
1	1	2.147	0.0103	16	0.0856	2.061	
1	2	2.159	0.0091	15	-0.1185	2.277	
1	3	2.041	0.0069	14	0.0809	1.960	
1	4	2.145	0.0069	13	0.0067	2.138	
1	5	1.977	0.0125	12	0.0938	1.883	
1	6	2.134	0.0054	11	0.0708	2.064	
1	7	2.135	0.0028	10	0.0869	2.048	
1	8	2.091	0.0054	9	0.1535	1.938	
1	9	2.126	0.0060	8	0.0861	2.040	
1	10	2.013	0.0061	7	0.0677	1.946	
1	11	2.056	0.0023	6	0.1079	1.948	
1	12	2.092	0.0045	5	0.1164	1.976	
1	13	2.001	0.0046	4	0.1086	1.892	
1	14	2.041	0.0003	3	0.0787	1.962	
1	15	0				0	
1	16	0				0	
1	17	2.127	0.0014	2	0.0315	2.0955	
1	18	0				0	
1	19	0				0	
		Mean	Std dev			Mean	Std dev
With clogged emitters		1.646	0.852			1.591	0.826
Without clogged emitters		2.086	0.058			2.015	0.100

Lateral	Emitter #	Mean flow	Std dev	N	Increase	Buried flow	
2		2.070	0.0044	20	0.1376	1.933	
2	2	2.130	0.0046	19	-0.0226	2.153	
2	3	2.112	0.0049	18	0.0008	2.112	
		1.993	0.0041	17	0.0412	1.952	
	5	2.043	0.0045	16	-0.0107	2.054	
	6	2.074	0.0063	15	0.0153	2.058	
2	7	2.061	0.0049	14	0.0317	2.029	
2	8	2.084	0.0042	13	0.0605	2.024	
	9	2.115	0.0041	12	0.0810	2.034	
	10	2.102	0.0048	11	0.0798	2.023	
2	11	2.058	0.0036	10	0.0808	1.977	
2	12	0.650	0.0088	9	0.0613	0.589	
2	13	2.159	0.0046	8	0.0850	2.074	
	14	2.108	0.0037	7	0.0465	2.061	
	15	1.845	0.0044	6	0.0119	1.833	
2	16	1.725	0.0090	5	0.1265	1.598	
2	17	2.133	0.0045	4	0.0505	2.082	
2	18	2.065	0.0034	3	0.0463	2.019	
2	19	2.125	0.0084	2	0.0935	2.032	
			Std dev				Std dev
With emitter #12			0.330				0.336
Without emitter #12			0.105				0.120

The scatter in the calculated effect of excavating individual emitters suggested that calculation of buried emitter uniformity would be prone to more noise than that of excavated emitters, thus complicating the comparison of uniformity before and after excavation. Standard deviations of the emitter flow rates for both excavated and buried states are shown in table 1. The values for lateral 1, which had nonfunctioning emitters, were calculated both with and without the plugged emitters included. The standard deviation for the excavated functioning emitters was 0.0577 L/hr, and for the corresponding buried emitters, was 0.100 L/hr, or almost twice as high. For lateral 2, emitter 12 flowed at about one-third nominal flow rate. Inclusion of this emitter tripled the variance calculation, so calculations with and without it are shown. The standard deviation of the other emitters was about 15% higher when buried than when excavated.

CONCLUSION

The average flow rate of buried (0.3-m depth) trickle irrigation emitters increases about 3% when they are excavated for measurement of uniformity. This value is about twice that calculated for the theoretical explanation of 0.3-m hydraulic head causing the change, indicating some effect of resistance to flow in the soil around the emitter. The practical effects of this overestimate of flow are not immense in the measurement of emitter uniformity, but may be more important when calculating total flow into a main, sub-main, and lateral field. It is unlikely, though, that 3% reduction in flow in buried emitters will be important except possibly when buried and surface applications are compared.

The dependence of the uniformity calculation on the measurement of flow rate reduced the confidence that could be placed on the calculated buried flow rate. Although it appears some decrease in variance occurred when the emitters were excavated, this increase was likely the result of measurement technique rather than an emitter characteristic.

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