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Using Time Domain Reflectometry to Measure

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ABSTRACT

The purpose of this project was to determine whether the use of soil moisture content measured by time domain reflectometry (TDR) could be used to estimate microirrigation uniformity based on traditional volumetric measurements. Experimental methods were designed such that various levels of uniformity were tested for both volumetric discharge and soil moisture content at three distances from the emitter. Despite volumetric statistical uniformities ranging from 0.64 to 0.91, soil moisture uniformity values only ranged from 0.80 to 0.88. These results indicate that redistribution of soil water leads to a relatively uniform soil moisture condition within the range of system uniformities tested.

INTRODUCTION

Microirrigation (sometimes referred to as drip or trickle irrigation) has the potential for increased efficiency in both water and energy use. According to the 2000 Irrigation Survey (Irrigation Journal, 2001), microirrigation accounts for nearly 5% of all irrigated acreage nationwide. The high efficiency achieved by these systems is due to reduced flow rate and pressure requirements. Water is directly applied to the root zone, which lessens the total volume of irrigation water needed to sustain the crop. However, the efficiency of this method is largely dependent on the uniformity of the water distribution and management.

Irrigation uniformity is a measure of how evenly water is distributed to different areas of the field. At high uniformity, water can be applied adequately with little excess. However, at low uniformity, some portions of the field will be deprived of water while other locations will be over-irrigated. Therefore, the effects of high uniformity are improved yield, reduced water and energy use, and decreased environmental impacts. These benefits become more significant when chemicals are being injected through the irrigation lines.

In drip irrigation, distribution uniformity is affected by emitter conditions and hydraulic factors within the system. Emitter conditions include manufacturing variation, clogging (due to sediment or biological growth), and general deterioration. Because pressure variation will impact the flow rate of the emitters, hydraulic conditions in the system also influence uniformity. These conditions include pressure variation in the laterals, topography, and wear inside the pipes (Clemmens, 1987). Uniformity should be tested as part of the system maintenance. Problems within the system such as clogging and pressure variations can be diagnosed using the results from the uniformity test.

Irrigation uniformity has been quantified in several different equations. Low-quarter distribution uniformity (DU_{lq}) is defined as the ratio of the average of the lowest quarter of samples to the average of all samples:

$$DU_{lq} = \frac{d_{lq}}{d_{avg}} \qquad \text{(Kruse, 1978)} \qquad [1]$$

where d_{lq} = the average of the lowest-quarter depths (or volume)

d_{avg} = the average depth (or volume)

Another measure of uniformity that is defined with the coefficient of variation is statistical uniformity.

$$U_s = (1 - CV) \qquad \text{(ASAE, 1997)} \qquad [2]$$

$$\text{where} \quad CV = \frac{s}{\bar{x}} \qquad [3]$$

CV = the coefficient of variation

s = standard deviation

$\bar{x}$ = sample average

Current guidelines for uniformity determination are based on volumetric flow from the emitters. The water discharged over a constant time is caught from several emitters throughout the sample area. These data are analyzed according to the above equations to determine the uniformity of the irrigation system or subunit (ASAE, 1997).

It is becoming increasingly popular for drip irrigation to be installed below the soil surface or under plastic mulch in vegetable production. As such, it is inconvenient and destructive to evaluate these systems in the field using the existing procedures described above. Additionally, these results only represent the distribution from the emitter without accounting for the water's movement through the soil.

A method of determining the soil volumetric moisture content could provide a more practical method for conducting uniformity tests. Time domain reflectometry, which indicates this soil property, could provide a solution.

Time domain reflectometry (TDR) was initially used to find breaks in coaxial transmission lines, but has been used in the last two decades to determine the soil moisture content of soils. Electromagnetic waves are propagated along a wave guide. By timing their return, the dielectric constant of the soil is determined. It has been shown that the dielectric constant is strongly correlated to soil moisture content, with little effects from texture, material, temperature or salinity. Thus, water content in the surrounding media can be determined (Topp et.

al., 1980).

The objective of this study was to determine if TDR could be used to accurately quantify the uniformity of drip irrigation systems. Uniformity was calculated using both soil moisture and volumetric measurements, then the results were compared.

MATERIALS AND METHODS

Field Preparation

This project was conducted at the Irrigation Research and Education Park on the University of Florida campus in Gainesville, FL. The test area was first tilled, disked, and leveled. Landscaping fabric was installed to prevent weeds from growing, which could disturb the results. A plumbing setup was constructed that consisted of pressure regulators to maintain the desired head in the drip tape, pressure gauges before and after the manifold, and an injection point for clogging the lines **(figure 1**). Four 30 m sections of drip tape (RoDrip 16mm, 300 lph/100m at 55 kPa, 30cm emitter spacing, Roberts Irrigation, San Marcos, CA) were installed for each assembly. Typical operating pressures for the system varied between 55 to 69 kPa.

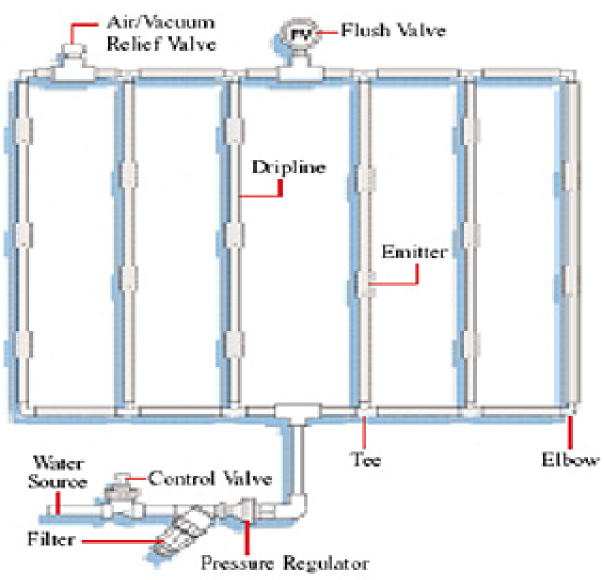

Figure 1. Typical microirrigation system layout.

Testing Procedure

The goal of this project was to determine the relationship between soil moisture content uniformity and conventional volumetrically measured uniformity. In a given soil, the volumetric soil moisture content due to drip tape is a function of the irrigation time and the distance from the emitter. To properly assess the usefulness of soil moisture content in measuring distribution uniformity, both

of these variables must be taken into account. Soil moisture measurements were taken at irrigation times of 0, 10, 20, 40, 80, and 120 minutes, at distances of 5, 10, and 15 centimeters from the emitter being tested. Treatments were arranged in a completely randomized block design with four replicates. These data were collected using the Spectrum Field Scout soil moisture sensor (Spectrum Technologies, Inc., Plainfield, Illinois), which is equipped with a CS620 water content reflectometer (Campbell Scientific, Inc., Logan, UT). A wooden template was created to make TDR measurements accurately and uniformly (fig. 2). There is also a gentle slope in the test area. To eliminate the effect of the slope, the orientation of the template was rotated 90÷ for each tape per irrigation time.

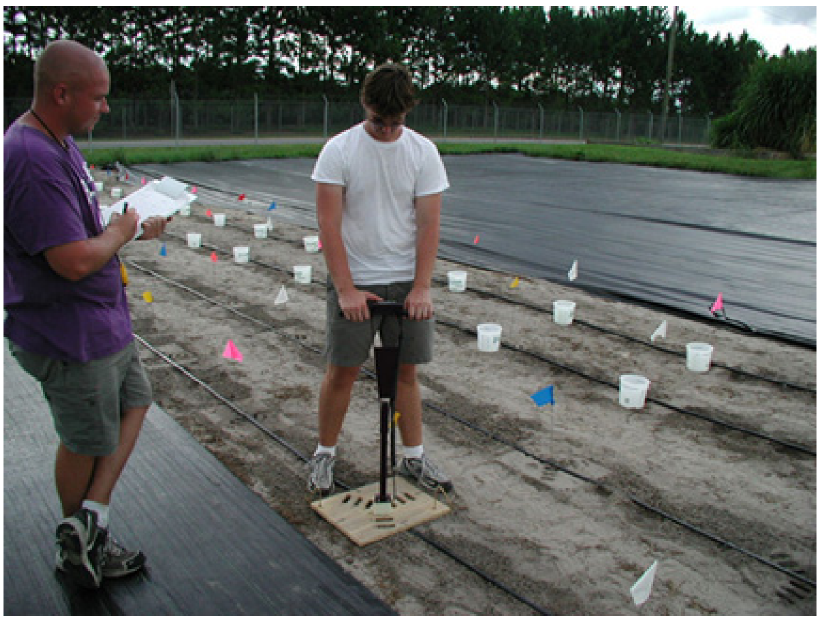

Figure 2. Taking soil moisture measurements with the TDR probe during a test.

It was necessary to test the TDR method for a range of DU values. To accomplish this, the drip tapes were artificially clogged by injecting a solution of bentonite and soil mixture at varying levels. The procedure above was then repeated four times at subsequently higher clogging intensities. The five tests resulted in volumetric DU_{lq} of 0.87, 0.82, 0.82, 0.64, and 0.42. At each emitter tested, the volumetric discharge was also measured to compare with the soil moisture uniformity.

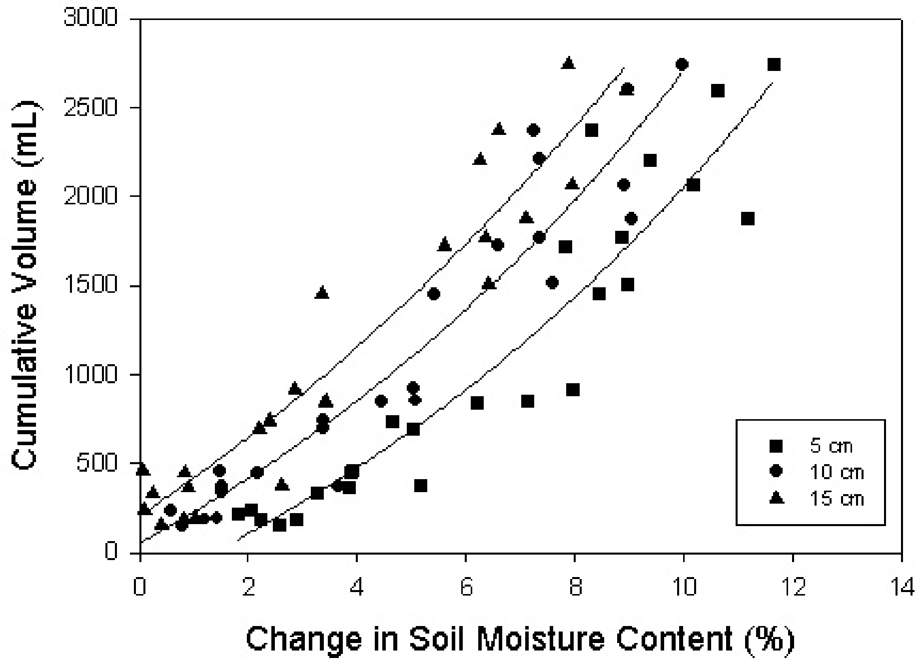

Figure 3. Relationship between volume emitted and the change in soil moisture at 3 distances from the emitter.

RESULTS

Statistical analysis of the data resulted in no correlation between the TDR values and the volumetric measurements. As seen in figure 3, there is a good correlation between the volume applied and the change in soil moisture content (average r^2 of 0.872). However, variability in the data prevented prediction of a DU_{lq} equivalent to that calculated from volumetric data. Also, the regression has less resolution at the high and low ends of the spectrum.

Distribution uniformity based on soil moisture data and volumetric data was calculated according to equation 1 and graphed for each time and distance combination for a total of 18 graphs. According to figure 4, which shows all of these graphs, there is no consistent relationship between the DU_{lq} calculated from soil moisture content and the DU_{lq} based on volumetric data. Although the volumetric DU_{lq} varied between 0.42 and 0.87, there was no predictable variation from the DU_{lq} calculated from TDR data.

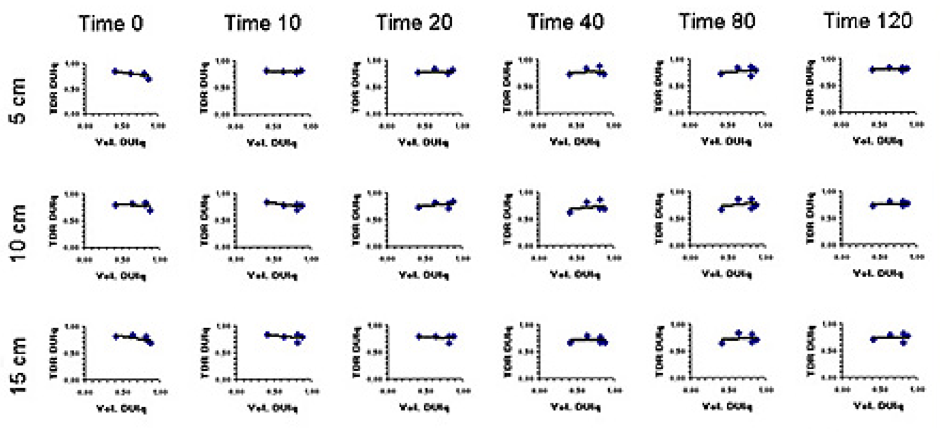

Figure 4. Comparison of low-quarter distribution uniformity calculated by soil moisture content (TDR DU_{lq}) and volumetrically (Vol. DU_{lq}).

Similar results can be seen in figure 6 using a different measure of uniformity. The Statistical Uniformity (Us) calculated from the volumetric data ranged from 0.91 to 0.65. However, the soil moisture based statistical uniformity values ranged from 0.80 to 0.88, except one value of 0.58. This is a further indication that the variation in soil moisture is not impacted to the degree expected from the non-uniform water distribution.

Uniformity is a measure of the error in the irrigation application. By trying to calculate the uniformity using soil properties, additional error is introduced due to the error associated with soil moisture measurement and from the natural variation of the soil.

The TDR probe manufacturer provides an equipment error of ±3% soil moisture content. This is especially noteworthy since the majority of the measurements were between 7-22% soil moisture content. Even in a perfect system, the inherent variability of the probe will produce flawed values for uniformity. Additionally, the probe only measures the volume of soil close to it (approximately 1100 cm3 with the 20cm probe). The portion of this volume influenced by the irrigation water is small, especially at the 15 centimeter distance with short irrigation times (figure 5). All of these errors are then reflected in the soil moisture uniformity.

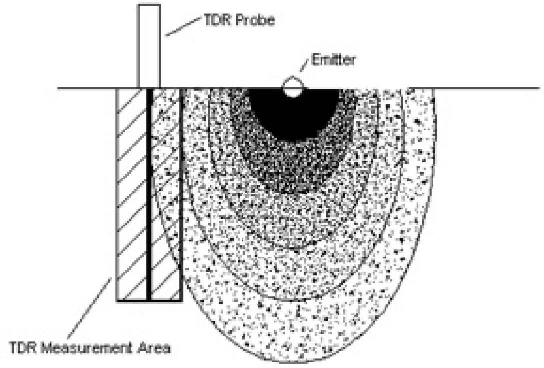

Figure 5. Wetting front of the drip emitter compared to the measurement area of the TDR probe at the 15 cm distance.

Also, soil water will redistribute during and after an irrigation event such that non-uniformity of water application will not necessarily result in the same magnitude of non-uniform soil moisture, particularly at longer irrigation intervals.

The statistical uniformity calculated from the TDR values should not be used to judge the performance of the microirrigation system, but it might still be useful. TDR Us is consistently in the 0.8-0.9 range, even when volumetric Us is a nearly unacceptable 0.64 (figure 6). The simplest conclusion is that even in a clogged or poorly designed system, water redistribution within the soil can improve the uniformity of the irrigation application. To take full advantage of this effect, the proper emitter spacing should be selected based on the soil type and the planting density.

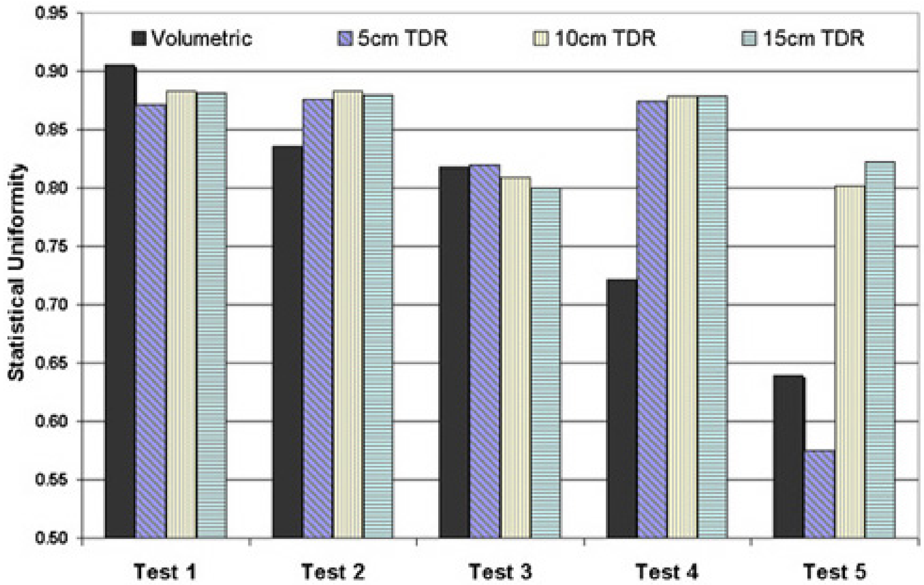

Figure 6. Statistical uniformity calculated by equation 4 for volumetric measurements and soil moisture measurements at three distances from the emitter.

Further studies in this direction could produce beneficial results. A similar experiment could be conducted with various soil types and various emitter spacings. Also, plants could be introduced in a future study to determine the effects of uniformity of microirrigation systems on yield. It may be that a new uniformity classification system needs to be developed for microirrigation that takes soil type into account.

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