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Evaluating Water Distribution Uniformity in Micro-Irrigation Systems

General Description

Micro-irrigation systems are designed to apply water directly to plants at low flow rates and low pressures over relatively long time periods and at frequent intervals, generally daily. By targeting individual plants and wetting only within the root zone, properly operating micro-systems save significantly on water and energy bills. These systems can often accomplish the job of irrigation using as little as half the water and energy used by systems that apply large volumes of water across a field under high pressure.

The heart of the micro-irrigation system is the water application device or emitter, delivering water in small amounts to individual plants rather than broadcasting water over the whole field area. Application of only a small quantity of water to each plant means that **uniform distribution of water is extremely critical** for micro-irrigation success.

A micro-system that delivers the proper total amount of water needed by a crop in a given field can still be a poor system if it under-waters many plants and over-waters many others. That is, the system must be designed and operated so that plants all receive (within reasonable limits) the same amount of water during any irrigation cycle. **A system that does this has an acceptably high uniformity of water application.**

This publication explains one way to quickly and accurately estimate and evaluate the water distribution uniformity of a system and what to do if it is below acceptable limits.

Using these procedures can also give a good estimate of system flow and a check on flow meter data. Knowing system emission uniformity and flow rate will tell the system operator when problems are present and when maintenance procedures should be undertaken to insure continued satisfactory performance from the micro-irrigation system.

Controlling Factors

The amount of water that flows from micro-irrigation devices depends on the operating pressure and the response of the device (emitter) to that pressure. Operating pressure variations along the lateral fine and manifold are affected by elevation changes, pipe length and pipe diameter. Individual emitter flow non-uniformity is caused primarily by manufacturing variation and emitter plugging and wear. System water application uniformity is the combination of flow variations of all emitters in the system.

System pressure uniformity is established by proper design and installation of the system. Pressures at submains and laterals should be checked carefully after installation of a new system (or on an existing system when known to be operating properly) and the readings recorded to provide a baseline for future monitoring. Changes in system pressures then signal problems such as defective pressure regulators, leaking or broken lines, or plugged emitters.

Emitter flow uniformity is established in the manufacturing process, and each manufacturer publishes the range of variability (departure from perfect uniformity) in water output to be expected for each type of emitter at constant pressure. The manufacturing variability of the chosen emitter is fixed and taken into consideration in design of the individual micro-irrigation system. After proper design and installation of the system, unless the system is damaged in some way the only factors left to affect system water application uniformity are emitter clogging and wear. Over time, particularly with poor maintenance, some emitters may become partially or completely clogged. The system then can drop below an acceptable level of water distribution uniformity.

System uniformity should be checked immediately after installation. This check provides baseline data to be used for comparison with periodic checks over time to track system performance.

Uniformity Guidelines

For systems designed to supply all of the crop's water needs, Table 1 presents guidelines for system uniformity considered acceptable by the American Society of Agricultural and Biological Engineers for various emitter types and field situations. Although slightly lower uniformity ranges may be acceptable in humid areas like Alabama, 80% is the minimum acceptable uniformity when fertilizers are applied through the system.

Emitter Type	**Soil Slopes**	**Uniformity Range (%)**
Point source on widely spaced (>13 ft.) crops	Flat (< 2%) Steep (>2%)	90 to 95 85 to 90
Point source on closely spaced (<13 ft.) crops	Flat (< 2%) Steep (>2%)	85 to 90 85 to 90
Line source on annual or Perennial crops	Flat (< 2%) Steep (>2%)	80 to 90 70 to 85

Table 1. Acceptable Uniformities for Micro-Irrigation Systems
NOTE: If system is used for applying fertilizer, uniformity must be at least 80%.

Estimating Distribution Uniformity

Uniformity is usually determined for each zone of the irrigation system (a zone being a portion of the field that is operated at one time). The water distribution can be actually measured for each zone, but catching and recording water flow from each of hundreds of emitters is usually impractical. A much simpler way is to use a sampling and estimation procedure based on statistical analysis (see box, below). The statistical treatment includes in the final estimate all of the factors affecting uniformity mentioned above. **The advantage of this procedure is that while field measurements are simple, we can have confidence that the uniformity estimate will be accurate within a set range of values.**

Field determination of system uniformity can then be based on the measured flow rates of a small number of emitters. *This method assumes the distribution of emitter flows is normal and uses the* *highest one-sixth and the lowest one-sixth of the measurements to graphically estimate the statistical uniformity using the **Field Uniformity Estimator** shown on the back page of this publication.*

Definition and Measurement of Uniformity

Uniformity of water application is defined using statistical terms:

U (%) = 100 x (1 - [Sd/Qav]),

where U = uniformity of application,

Sd = standard deviation of flow measurements, and

Qav = average of flow measurements.

When a certain number of flow measurements are taken and evaluated according to the formula, the result is an estimate that will be accurate within a certain range, and the value U represents the midpoint of this range. Confidence limits represent the high and low values of the range the estimate falls within, at a given probability level. The 95% confidence level, for example, means that if the sampling procedure is repeated the uniformity estimate would be within the indicated range 95 out of 100 times.

The uniformity estimate read from the Estimator actually represents the midpoint of a range, called the *95% confidence limits*, shown in Table 2, page 3. For example, if we have taken 18 field measurements and the uniformity estimate read from the Estimator is 90%, the range is ±2.9%. That is, we don't know that the actual field uniformity is exactly 90%, but there is very high probability (95 times out of 100) that it falls somewhere between 87.1% and 92.9%. If the Estimator estimate is 80%, the range is ±5.8%, and we can be confident only that actual field uniformity falls somewhere between 74.2% and 85.8%.

As the system uniformity gets lower, the estimate confidence range gets wider because in a system with low uniformity our chances of getting a representative sample are smaller. To compensate for this, we can increase the sample size. As Table 2 shows, taking 36 or 72 field measurements can narrow the estimate range (confidence limits) significantly.

In general, uniformity estimates read from the Field Uniformity Estimator can be interpreted as follows: 90% or greater, excellent; 80 to 90%, very good; 70 to 80%, fair; 65 to 70%, poor. Anything below 65% is definitely unacceptable. Values of 80% or below may be questionable, depending on the individual field (compare with Table 1 guidelines).

Table 2. Field Uniformity Value Ranges (95% Confidence Limits)

Uniformity Estimate	With 18 Field Measurements	With 36 Field Measurements	With 72 Field Measurements
95%	93.5-96.5% (+-1.5%)	94.0-96.0% (±1%)	94.3-95.7% (±0.7%)
90%	87.1-92.9% (+-2.9%)	88.0-92.0% (±2%)	88.6-91.4% (±1.4%)
85%	80.6-89.4% (±4.4%)	82.0-88.0% (±3%)	82.9-87.1% (±2.1%)
80%	74.2-85.8% (±5.8%)	76.0-84.0% (±4%)	77.2-82.8% (±2.8%)
75%	67.4-82.6% (±7.6%)	69.7-80.3% (±5.3%)	71.3-78.7% (±3.7%)
70%	60.6-79.4% (±9.4%)	63.5-76.5% (±6.5%)	65.5-74.5% (±4.5%)
65%	53.6-76.4% (±11.4%)	57.1-72.9% (±7.9%)	59.5-70.5% (±5.5%)
60%	46.7-73.3% (±13.3%)	50.8-69.2% (±9.2%)	53.6-66.4% (±6.4%)

To be very sure that actual field uniformity is within acceptable guidelines, use the lower range limit from Table 2. For instance, at least 80% uniformity is essential for successful fertigation. Using 18 field measurements, an Estimator reading of 80% would seem to be acceptable for fertilizer application, but the confidence range lower limit is 74.2%, definitely too low. An Estimator reading of 85%, with a lower confidence limit of 80.6%, would be just barely acceptable.

Taking Field Samples

Using the Field Uniformity Estimator, as few as 18 flow measurements per zone can provide a reasonable estimate of actual water flow uniformity in a good micro-irrigation system. Whether more samples than this have to be taken will depend on how far the system departs from an acceptable value as discussed above. Measurements must be taken only after the system has reached its normal operating pressure and flow rate. These measurements should be scattered uniformly over the zone to be tested to accurately represent conditions throughout the entire zone.

A suggested measurement pattern is to take measurements near the beginning, middle, and end of six laterals equally spaced along the manifold at the inlet end, 1/5 way, 2/5 way, 3/5 way, 4/5 way, and far end of the manifold. Use the Field Uniformity Worksheet below to record measurements.

FIELD UNIFORMITY WORKSHEET						
IRRIGATION ZONE _______			**MANIFOLD # _____**		**DATE __________**	
	Emitter Flow Readings (millimeters/minute)					
Location on **lateral**	Lateral location on **manifold**					
	inlet end	1/5 way	2/5 way	3/5 way	4/5 way	far end
inlet end						
half way						
far end						
Pressure readings (PSI)						
inlet end						
far end						
3 highest/3 lowest flow readings (ml/min)					F_{max}/F_{min} Calculation	
	1	2	3	Totals	÷ 63.06 = gal/hr	
high					÷ 63.06 =	Fmax
low					÷ 63.06 =	Fmin
Uniformity Value from Field Estimator ____% **RATING**: __Excellent, ___Very Good, ___Fair, ___Poor						
Note: Worksheet is set up for 18 field measurements. Use worksheet as a guide for 36 or 72 measurements. For 36 measurements, select 6 highest/6 lowest readings to calculate F_{max}/F_{min}; for 72 use 12 highest and lowest.						

Take 18 samples for the initial estimation. Individual emitters should be randomly selected. Catch each emitter flow over 1 minute, disturbing emitter and lateral as little as possible. A wrist watch with a second's indicator can do the timing. For accuracy, the water caught should be measured in milliliters. A human medication oral dosage syringe calibrated in milliliters can be found in almost any drug store and is one way to measure milliliters that will work well. (A graduated cylinder marked in milliliters may be faster.) Emitter flow can be caught in any clean container and the syringe/cylinder used to measure volume caught.

The milliliters per minute value can be changed into gallons per hour by dividing by 63.08.

It is also a good idea to measure the lateral pressure at the inlet and far end of each lateral used for flow rate measurements. This will help isolate any problems that may be discovered. Record the measured flow rates and pressure readings on the worksheet (a filled-in example is also included below).

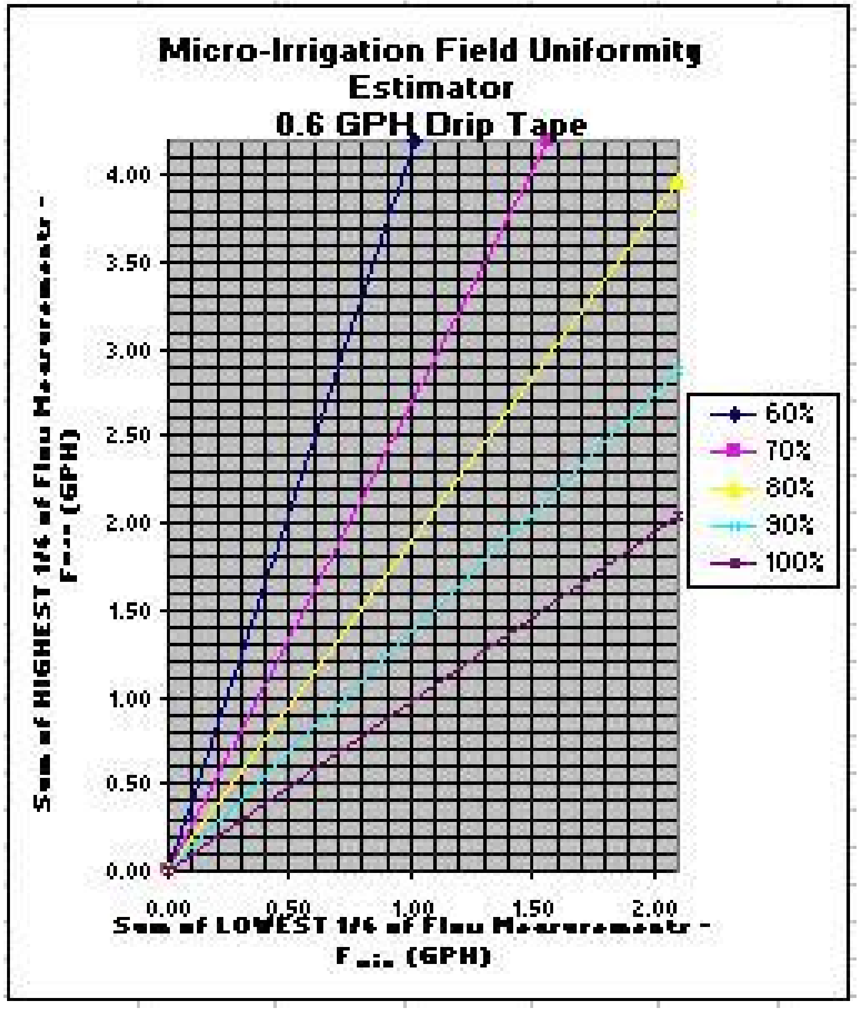
FIELD UNIFORMITY WORKSHEET (filled in as an EXAMPLE)						
IRRIGATION ZONE __2A_____			**MANIFOLD # __2___**		**DATE _3/27/09__**	
	(EXAMPLE) Emitter Flow Readings (millimeters/minute)					
Location on **lateral**	Lateral location on **manifold**					
	inlet end	1/5 way	2/5 way	3/5 way	4/5 way	far end
inlet end	**41**	**41**	**40**	38	37	37
half way	39	38	38	35	35	34
far end	37	37	35	**34**	**32**	**29**
(EXAMPLE) Pressure readings (PSI) (EXAMPLE)						
inlet end	22	22	20	20	20	19
far end	19	20	19	18	18	18
3 highest/3 lowest flow readings (ml/min)					F_{max}/F_{min} Calculation	
	1	2	3	Totals	÷ 63.06 = gal/hr	
high	41	41	40	122	÷ 63.06 =	**1.94 Fmax**
low	34	32	29	95	÷ 63.06 =	**1.51 Fmin**
Uniformity Value from Field Estimator _92_% **RATING**: _X_ Excellent, ___Very Good, ___Fair, ___Poor						
Note: Worksheet is set up for 18 field measurements. Use worksheet as a guide for 36 or 72 measurements. For 36 measurements, select 6 highest/6 lowest readings to calculate F_{max}/F_{min}; for 72 use 12 highest and lowest.						

Using the Field Estimator

After recording, inspect the 18 readings for the three highest and three lowest readings. The value of F_{max} to be used with the Field Estimator is the sum of these three highest readings. F_{min} is the sum of the three lowest readings. For the example set of readings (see worksheet, above), taken from a zone of 0.6-GPH drip tape irrigated blueberries, F_{max} = 1.94 and F_{min} = 1.51.

Entering the Field Estimator on the vertical (F_{max}) axis, we draw a horizontal line across the figure at F_{max} = 1.94. On the horizontal (F_{min}) axis, we draw a vertical line up the figure at F_{min} = 1.51. The intersection of these lines occurs at about 92% emission uniformity. This is within the EXCELLENT category. We cannot, of course, be absolutely sure that our sample measurements are truly representative of the field. But we can conclude with very high probability that the system design and installation were done well.

For 18 measurements and a field uniformity of 92%, our confidence limits (interpolating) are 92 ± 2.3%, or 89.7% to 94.3%. This means we can be confident that 95 out of 100 times when estimating the uniformity with this method; the result would fall within the range of 89.7% to 94.3% uniformity.



If our field uniformity estimate and lower confidence limit fell below our expectations, we could increase our number of field measurements to 36. Doubling our measurements increases our chance of getting a representative sampling and narrows the range of the estimate. Thus we should get a more precise idea of what the field uniformity is likely to be, in order to evaluate and plan maintenance procedures. Practically though, results from 18 measurements should in most cases indicate whether the system is performing adequately and if maintenance procedures should be stepped up or modified to address falling system uniformity.

IMPORTANT: If 36 or 72 measurements are necessary, remember to use the highest and lowest one-sixth of the measurements to calculate F_{max} and F_{min}, in order to use the Field Estimator. For 36 measurements, this means taking the six highest and lowest; and for 72, the twelve highest and lowest.

Summary of Field Procedures

1. **Start the irrigation system and allow time to reach normal operating pressure and purge air from lines.**

2. **Disturbing emitters as little as possible, measure water flow per minute from each of at least 18 emitters uniformly spaced over the zone. Suggested locations are near the beginning, middle, and end of six laterals coming off the manifold at the inlet, 1/5 way, 2/5 way, 3/5 way, 4/5 way and far end of the manifold serving the zone. Measure pressure at the entrance and far end of the six flow measurement laterals. Record all readings on worksheet.**

3. **Add the three highest flow rates (or 1/6 of the number of emitters measured) to compute Fmax. Record on worksheet.**

4. **Add the three lowest flow rates (or 1/6 of the number of emitters measured) to compute Fmin. Record on worksheet.**

5. **From Field Uniformity Estimator, identify field uniformity value at the intersection of a vertical line drawn from Fmin and a horizontal line drawn from Fmax.**

6. **If field uniformity is too low (or the confidence interval too wide), increase the number of emitters for flow measurements to obtain a more precise estimate of uniformity.**

The advantages of this method are that field measurements are simple and that only 18 measurements can confirm the high uniformity of a good system with reasonable confidence. More measurements may need to be taken with lower uniformity systems. Using this procedure can give an ongoing record of micro-irrigation system performance and assist greatly in scheduling appropriate maintenance procedures to maintain acceptable performance.

When System Uniformity of Water Application Is Not Acceptable

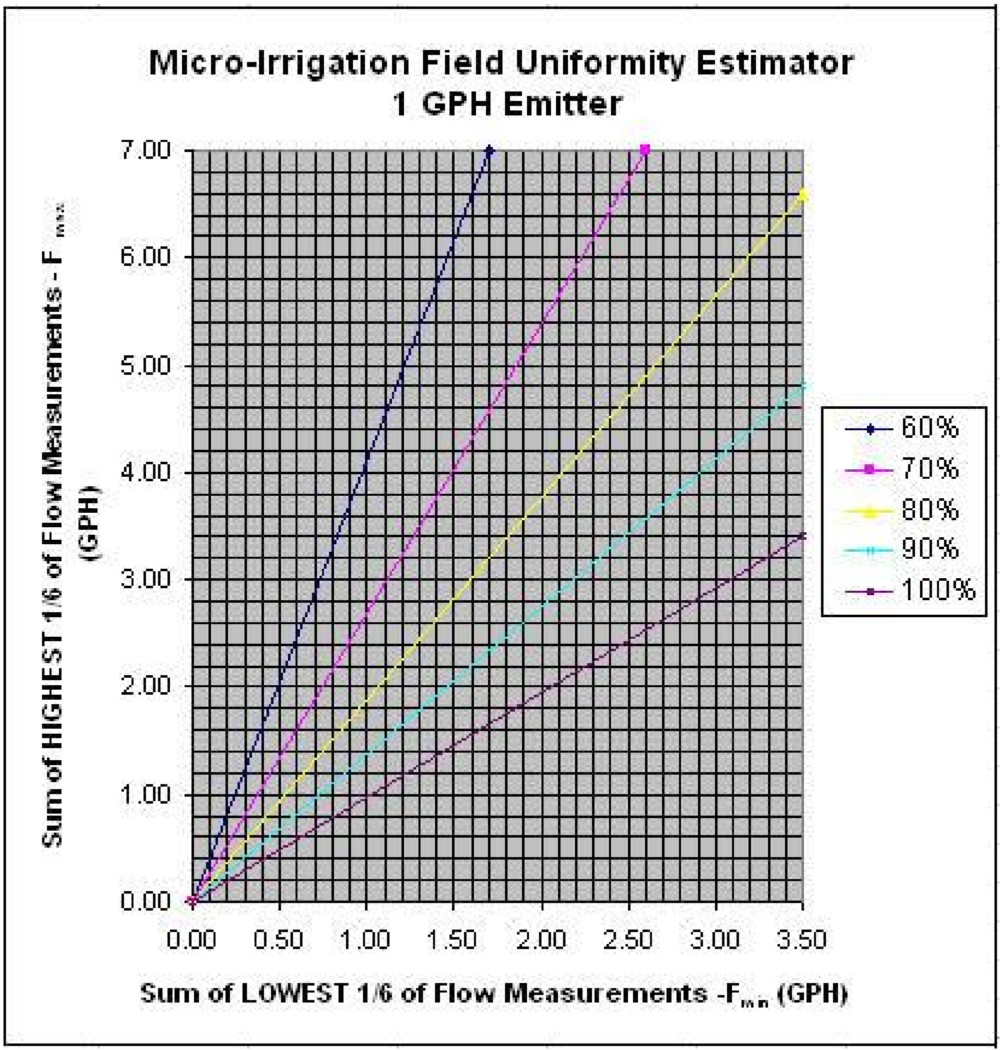
If, after estimating the system uniformity with this procedure, you get an unacceptable value, the next step is to determine if system pressure variation or emitter clogging or a combination of these is at fault.

System pressure variation can usually be identified by comparing measured system pressures with initial system pressures. If actual initial system pressures were not recorded, then compare with initial design pressures. Generally, any reduction in pressure over time should be suspect. These are usually the result of pipeline breaks, malfunctioning pressure regulators, or poor filter maintenance. Locate and correct any such deficiencies present.

Emitter plugging is mainly a function of water quality and water treatment measures. If no water treatment procedures have been performed, the first maintenance step should be super-chlorination and a water quality test. Based on results of a second uniformity check, an acid treatment may be required for system clean-up or as a pH control measure to increase effectiveness of chlorination. After initial clean-up, periodic chlorine treatments and uniformity checks should be scheduled.

If periodic chlorination has been part of the maintenance procedure, the time between treatments should be shortened. A water test should be obtained to determine if an acid treatment is needed. Periodic uniformity checks should be scheduled.

The Estimator is set up for 1 GPH emitters, but can be used for emitters of any nominal flow rate as long as the numbers on both the horizontal and vertical scales are multiplied by the new emitter nominal flow rate. In our blueberry drip tape example with 0.6 GPH emitters, both scales were multiplied by 0.6 to get 2.1 and 4.2, respectively.



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