# Quantifying pressure effects on flow rate and water application uniformity of microirrigation emitters

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**Abstract.** *Microirrigation can be an effective method of delivering water to plants from elevated tanks but the head incident to drip emitters may be significantly below that recommended by the emitter manufacturer to provide the specified flow rate (q). The objective of this study was to quantify the effect of variable pressure on q and water application uniformity (WAU) of selected drip emitters. Flow rate was measured at three different heads (3.5 ft., 5.5 ft., and 57.7 ft.) and WAU was calculated as 1 – cv where cv equaled the standard deviation divided by the mean q from eight replicates of each emitter. Mean q ranged from zero to 102% of manufacturer specified q (MSFR) at 5.5 ft. of head and from 95 to 193% of MSFR at 57.7 ft. WAU was greater than 0.90 for more than half the emitters at 5.5 ft. and for 75% of the emitters at 57.7 ft.*

**Keywords.** microirrigation, point source emitters, low pressure, flow rate, water application uniformity

## Introduction

Microirrigation represents an ideal, efficient way of distributing water to plants from elevated vessels such as rainwater catchment barrels or tanks carried in truck beds or trailers. Choosing suitable drip components that function adequately under the low heads provided by the water level in these vessels (commonly less than 10 ft.), however, is problematic since the flow rate (*q*) specified by the manufacturers of drip emitters has been measured under much higher heads (typically greater than 20 ft. or 8 psi). While it's logical to assume that *q* will decrease with decreased pressure (Burt and Styles, 1999; Li, et. al., 2009; Smajstria et. al., 1997) it might also be assumed that water application uniformity (WAU), and hence overall efficiency, of a microirrigation system will decrease when operated at a pressure lower than that specified for the emitters. As in any irrigation system, this would certainly be true if available pressure is insufficient to overcome friction loss caused by excessive lateral lengths and/or total system *q* or elevation changes, it may not be true in systems used to irrigate small gardens or landscapes on fairly level ground at low total *q*.

While reports of studies that measure the effect of ultra-low pressure on *q* and WAU of point source emitters are difficult to find, a few papers reporting measurements from line source systems have been published. In measurements taken from a low-cost line source system in Nepal (Polak, et. al. 1997), for example, *q* variations ranged from 12 to 23% (equivalent to 0.88 and 0.77 WAU) between 25, 0.027 in. diameter holes spaced 30 in. apart in four, 0.54 in. ID laterals at three heads. Average emitter *q* at heads of 6.6 and 9.8 ft. were 59.4 and 80.2%, respectively, of that at 13.1 ft. In a laboratory test of a manufactured drip kit for use by smallholder farmers in Zimbabwe, Chigerwe et al. (2003) reported kit water application uniformities of about 91% (0.91) at heads ranging from 1.6 ft. to 9.8 ft. Li, et al. (2009) compared measured *q* of three different labyrinth flow path emitters to modeled *q* under micro-pressures and observed suitable turbulent flow at pressures as low as 1.5 psi.

This study was implemented to evaluate the effects of substandard pressure on the *q* and WAU of several commercially available point source drip emitters so that objective recommendations on emitter selection could be provided to irrigators using rainwater catchment systems or other low head systems.

## Materials and Methods

Flow rate measurements were taken from twenty different models of point source emitters at two substandard heads (3.5 ft. and 5.5 ft.) in September 2011 at New Mexico State University's Agricultural Science Center at Farmington. These two heads were chosen to simulate potential conditions of rainwater catchment systems and tanks in a pick-up truck bed, respectively. Measurements at these two heads might also provide an indication of *q* change as water level decreases in an elevated drum during irrigation. Water was provided at constant head to drip laterals by an elevated 55-gallon water tank. Water was fed to the tank by a hose attached to a pressurized irrigation pipe and water level in the tank was held constant with a float valve. Outflow from the tank was controlled with a ¾ inch ball valve and filtration was provided by a ¾ inch (150 mesh equivalent) disk filter. Five different emitter models were installed at 24-in. intervals into four separate, 0.6 inch ID, 80 foot long PE laterals in eight, 10-foot long reps: 0-10 feet, 10-20 feet, 20-30 feet, etc. Emitter order was randomized in each rep. A ¾ inch PE line delivered water (through a reducer) to each lateral which was hung level on a wire mesh fence at a height of about 6 inches above ground to facilitate emitter *q* measurements.

In 2012, *q* was measured from the same emitters as in the 2011 evaluation. Lateral and emitter arrangement were identical but incident pressure at the header was maintained at 25 psi by a pressure reducer installed between a high pressure (>50 psi) hose and the lateral.

In all evaluations, after pressurizing the laterals, a glass beaker was used to catch water from emitters for a timed period (1 to 4 minutes) and then the collected water was poured into a graduated cylinder for volumetric quantification in milliliters (ml). Equation 1 was used to convert $q$ from ml/second to gallons per hour (gph) for comparison to the manufacturers specified flow rate (MSFR).

$$q = \text{ml} / \text{sec} \times 3600 / 3785 \qquad \text{[Eq. 1]}$$

Where:

$q$ = flow rate in gallons per hour (gph)
ml = millimeters of water caught in catch cup
sec = seconds cup was held under emitter
3600 = seconds in 1 hour
3785 = ml per gallon

I all evaluations, Equation 2 was used to calculate WAU.

$$\text{WAU} = 1 - cv \qquad \text{[Eq. 2]}$$

Where:

WAU = water application uniformity (decimal; 1.0 indicates perfect uniformity)
$cv$ = standard deviation / mean of all $q$ measurements from given emitter model

Seventeen of the twenty drip emitters used in the evaluations were purchased from ‘The Drip Store’ (http://www.dripirrigation.com/) and the model number shown actually represents their part number. Three emitters were purchased from a local home improvement retailer. Emitter styles were variable (e.g. button, flag, Katif, etc.) and manufacturer specified flow rates (MSFR) ranged from 0.5 to 4.0 gph (Table 1). Most of the emitters utilized a labyrinth path design to create a turbulent flow and silicon diaphragm for self-flushing. The exceptions were the flag emitters which used a screw-like or spiral flow path and a take-apart feature for manual cleaning. The D015 emitter could also be taken apart for cleaning. Manufacturer’s specified operating pressures (MSOP) ranged from 7 psi (16 ft. of head) to 50 psi (115 ft. of head). Twelve of the emitters were pressure compensating (PC) and 8 were not (NC).

## Statistical Regression Analyses

Since replicates were at varying distances (D) away from the water source along each lateral, emitter $q$ was plotted against D and then regression analysis (CoStat 6, 2001) was used to define suspected significant linear or quadratic relationships between $q$ and D for each emitter.

**Table 1.** Drip emitters included in the flow rate and WAU evaluations with manufacturer specified flow rates (MSFR) and recommended operating pressure ranges (MSOP).

| Brand Name | Part Number | Type[a] | MSFR gph | MSOP[b] psi |
|---|---|---|---|---|
| Supertif | D001 | button, PC | 1.0 | 8 - 50 |
| Supertif | D002 | button, PC | 2.0 | 8 - 50 |
| Supertif | D004 | button, PC | 3.3 | 8 - 50 |
| Supertif | D006 | side outlet, PC | 1.0 | 8 - 50 |
| unknown | D012 | button, NC | 1.0 | 10 - 20 |
| unknown | D013 | button, NC | 2.0 | 10 - 20 |
| John Deere | D015 | easy-open, NC | 1.0 | 15 - 20 |
| unknown | D021 | flag, NC | 1.0 | 10 - 25 |
| unknown | D022 | flag, NC | 2.0 | 10 - 25 |
| Katif | D043 | low profile, PC | 3.3 | 10 - 50 |
| Katif | D044 | low profile, PC | 2.0 | 10 - 50 |
| Katif | D045 | low profile, PC | 1.0 | 10 - 50 |
| DIG | D076 | button, PC | 1.0 | 8 - 40 |
| DIG | D077 | button, PC | 2.0 | 8 - 50 |
| DIG | D078 | button, PC | 4.0 | 8 - 50 |
| Netafim | D079 | heavy duty, PC | 0.5 | 7 - 45 |
| Netafim | D080 | heavy duty, PC | 1.0 | 7 - 45 |
| Orbit 1G | unknown | flag, NC | 1.0 | unknown |
| Orbit 2G | unknown | flag, NC | 2.0 | unknown |
| Orbit 4G | unknown | flag, NC | 4.0 | unknown |

[a] PC - pressure compensating; NC - non-pressure compensating
[b] Recommended pressure range may be narrower but within operating range

## Results and Discussion

Measured average *q* at 5.5 ft. of head ranged from 0.075 gph (emitter D021) to 2.15 gph (emitter D078). These rates were 7.5 and 53.8% of MSFR, respectively (Table 2). The average *q* of all emitters at 5.5 ft. of head was 33.6% of MSFR but the measured *q* from one emitter (D045) was about equal (101.8%) to the MSFR at MSOP (Table 2). The average *q* of all emitters at 3.5 ft. of head, at 14.8 % of MSFR, was considerably less than that at 5.5 ft. As with 5.5 ft. of head, the lowest and highest *q* (0.018 and 0.822 gph, respectively) was measured from emitter models D021 and D078 (Table 2). Water application uniformity (WAU) is a more important consideration than *q* in efficient drip irrigation design unless emitter *q* is so low that it would be difficult to satisfy the plant's daily water requirement during peak ET (e. g. emitter D021). Calculated WAU at a head of 5.5 ft. ranged from a high of 0.957 for the Orbit 4G emitter (a high flow, NC, flag emitter) to a low of 0.376 for emitter D077 (a 2 gph, button style, PC emitter). At 3.5 ft. of head, emitter D013 (button style, NC) exhibited the highest WAU of 0.925 while emitter Orbit 1G (low flow, flag) had the lowest WAU of 0.327 (Table 2). Eleven of the twenty emitters exhibited WAU greater than 0.90 at 5.5 ft. of head but only two of the eleven (D043 and D013) maintained a WAU greater than 0.90 at the lower head (3.5 ft.).

**Table 2.** Average measured flow rate (*q*)[a], as gph and as % of manufacturer's specified *q* (MSFR), and water application uniformity (WAU) for 20 different point source emitters at two substandard heads (5.5 feet and 3.5 feet). 2011.

| Emitter[b] (part number) | 5.5 Feet of Head | | | 3.5 Feet of Head | | |
|---|---|---|---|---|---|---|
| | Q (gph) | % MSFR | WAU | Q (gph) | % MSFR | WAU |
| Orbit 4G | 0.791 | 19.8 | 0.957 | 0.310 | 7.7 | 0.794 |
| D043 | 0.475 | 14.4 | 0.956 | 0.378 | 11.5 | 0.923 |
| D015 | 0.210 | 21.0 | 0.954 | 0.092 | 9.2 | 0.845 |
| D006 | 0.442 | 44.2 | 0.948 | 0.235 | 23.5 | 0.773 |
| D001 | 0.447 | 44.7 | 0.946 | 0.200 | 20.0 | 0.842 |
| D012 | 0.172 | 17.2 | 0.941 | 0.123 | 12.3 | 0.880 |
| D013 | 0.354 | 17.7 | 0.936 | 0.251 | 12.6 | 0.925 |
| Orbit 2G | 0.435 | 21.7 | 0.933 | 0.141 | 7.1 | 0.797 |
| D044 | 1.124 | 56.2 | 0.928 | 0.320 | 16.0 | 0.603 |
| D002 | 0.890 | 44.5 | 0.928 | 0.342 | 17.1 | 0.717 |
| D004 | 0.760 | 23.0 | 0.925 | 0.311 | 9.4 | 0.714 |
| D076 | 0.377 | 37.7 | 0.897 | 0.152 | 15.2 | 0.526 |
| D021 | 0.075 | 7.5 | 0.893 | 0.018 | 1.8 | 0.596 |
| D045 | 1.018 | 101.8 | 0.855 | 0.382 | 38.2 | 0.575 |
| D078 | 2.152 | 53.8 | 0.828 | 0.822 | 20.6 | 0.688 |
| D022 | 0.222 | 11.1 | 0.825 | 0.064 | 3.2 | 0.681 |
| Orbit 1G | 0.305 | 30.5 | 0.774 | 0.123 | 12.3 | 0.327 |
| D077 | 0.775 | 38.8 | 0.376 | 0.560 | 28.0 | 0.347 |
| D079 | Insufficient data – some units had zero flow | | | | | |
| D080 | Insufficient data – some units had zero flow | | | | | |

[a] Flow rate (q) values represent the mean of eight replications.
[b] Ordered from highest to lowest WAU at 5.5 ft. of head.

## Regression Analyses

Although WAU was greater than 0.94 at 5.5 ft. of head for emitters D001 and D012, there was a slightly significant linear decrease in *q* with increasing distance from the water source for these emitters at this head (Figure 1). Conversely, *q* of emitters D002 and D045, increased linearly with increased D (Figure 2) but calculated WAU was marginal for emitter D002 at 0.928 and poor but acceptable for D045 at 0.855.

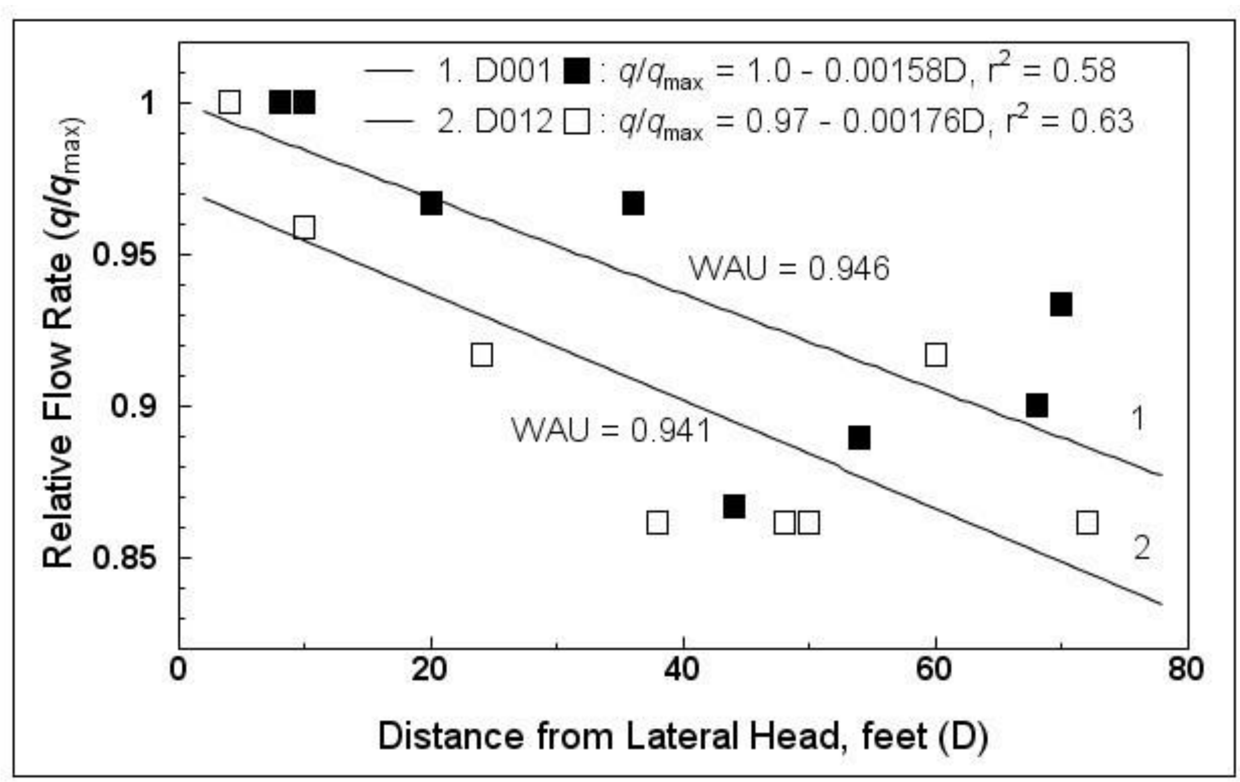


**Figure 1.** **Relative emitter flow rate ($q/q_{max}$) with distance (D) of emitter from the head of a lateral for two emitters that exhibited a slightly significant linear decrease in *q* with increased D.**

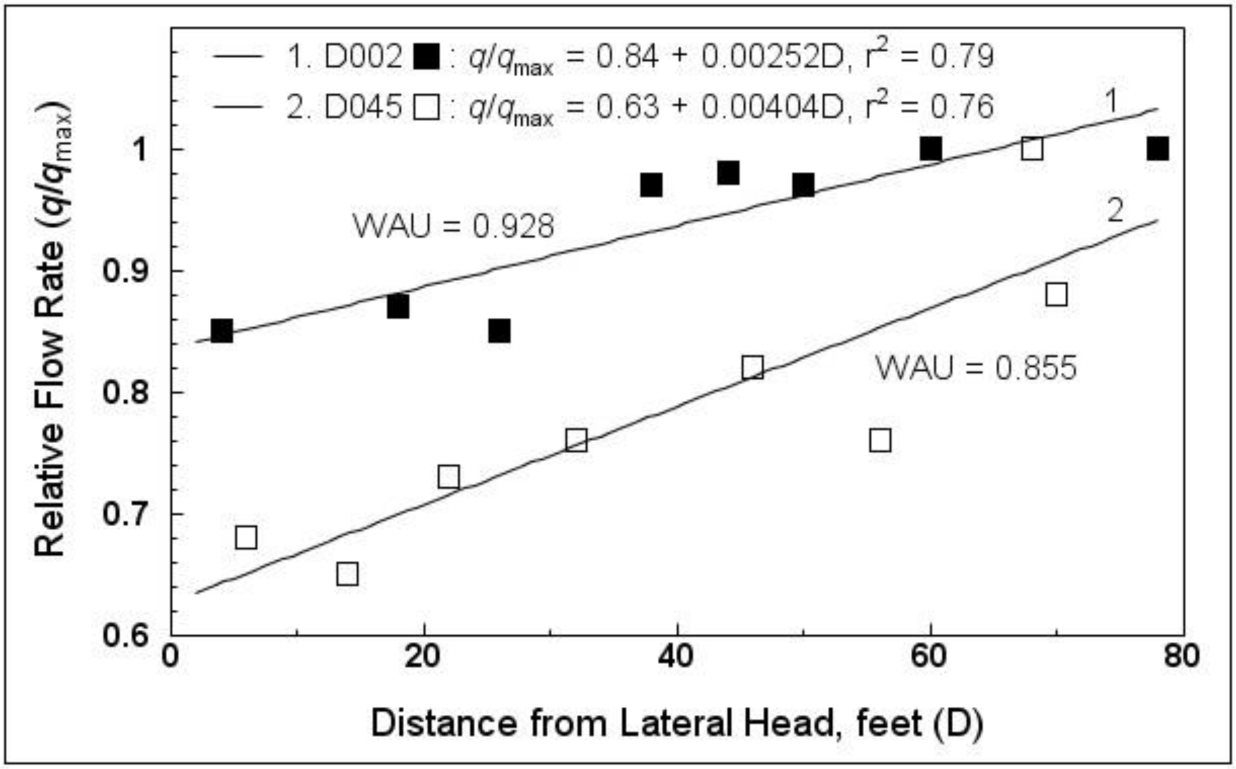


**Figure 1.** **Relative emitter flow rate (q/qmax) with distance (D) of emitter from the head of a lateral for two emitters that exhibited a significant linear increase in q with increased D.**

At 3.5 ft. of head, a statistically significant curvilinear relationship between *q* and D was found in seven of the twenty emitters where lower *q* towards the center of each lateral (i.e. D between 30 and 60 ft.) than at the beginning or end of the lateral occurred (Figure 3). Average WAU for these emitters at this low head ranged from 0.603 (emitter D044) to 0.845 (emitter D015). A similar curvilinear relation between *q* and D was also noted for two emitters (D013 and D043) at 5.5 ft. of head but calculated WAU for these two emitters were 0.936 and 0.956, respectively.

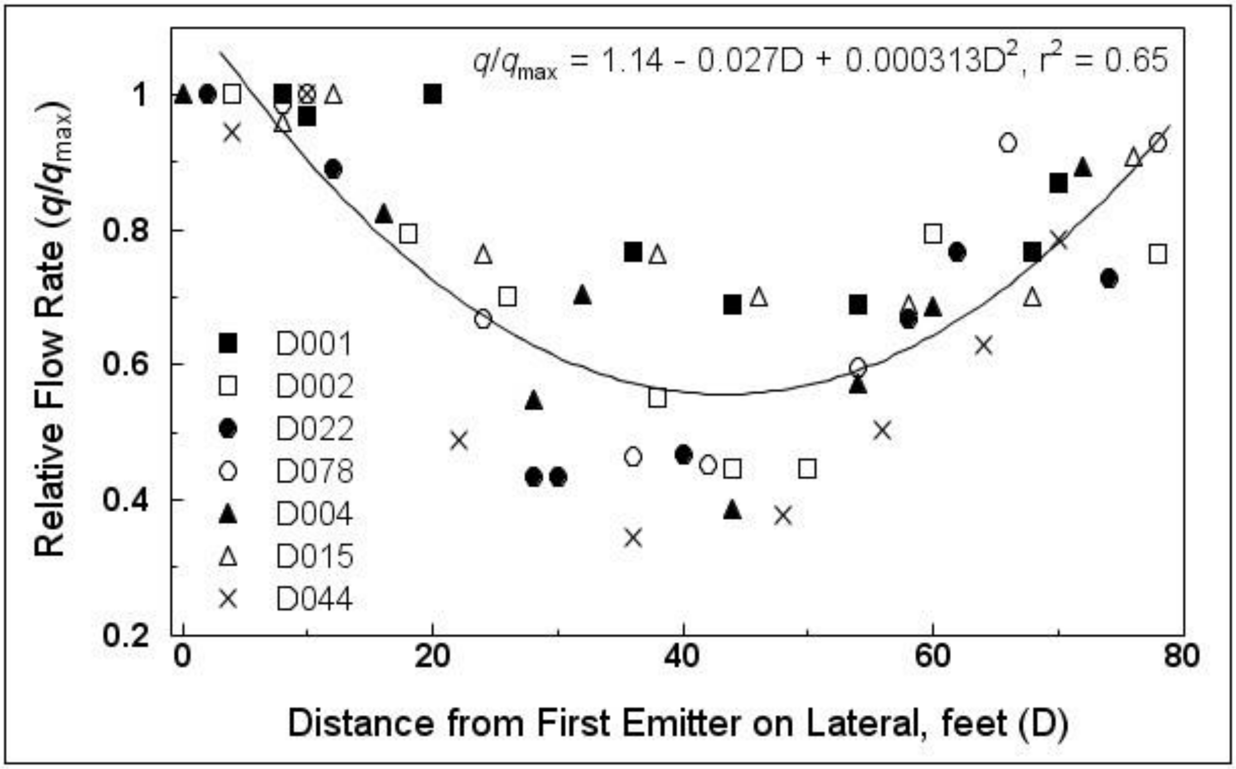


**Figure 2.** **Relative emitter flow rate (q/qmax) with distance (D) of seven emitters exhibiting a significant curvilinear relationship between q and D at a head of 3.5 feet.**

## Emitter Evaluation at 25 psi

Average *q* at 25 psi ranged from 0.56 gph from emitter D079, a 0.5 gph, PC, self-cleaning emitter, to 7.15 gph from the Orbit 4G emitter, a 4.0 gph, NC, flag type (Table 3). These rates were 112.5 and 178.8 % of MSFR, respectively (Table 3). Average *q* from all PC emitters was 112 % of MSFR while that of the NC emitters was 180 % of MSFR. The average measured *q* from only three emitters, two Katif style (D043 and D045) and a 3.3 gph button style (D004) was 5% or less different than the MSFR. WAU was greater than 0.90 for fifteen emitters at 25 psi and for 11 emitters at 5.5 feet of head. Self-cleaning, PC emitters (e.g. D079 and D080) had *q* similar to MSFR and WAU greater than 0.90 at a pressure of 25 psi but did not flow at 5.5 feet of head (Table 3). These self-cleaning types, as well as anti-drip type emitters, apparently have diaphragms that cut off flow at a minimum threshold pressure. The WAU of five emitters (D045, D021, Orbit 1G, D077, and D076) was less than 0.90 at both 5.5 ft. of head and 25 psi (57.7 ft.).

**Table 3.** Average measured flow rate (q)[a], as gph and as % of manufacturer's specified *q* (MSFR), and water application uniformity (WAU) for 20 different point source emitters at 25 psi and 5.5 ft. of head. 2012.

| Emitter[b] (part no.) | 25 psi (57 Feet of Head) | | | 5.5 Feet of Head | | |
|---|---|---|---|---|---|---|
| | Q (gph) | % MSFR | WAU | Q (gph) | % MSFR | WAU |
| D080[c] | 1.10 | 109.6 | 0.979 | - | - | - |
| D015 | 1.98 | 198.0 | 0.974 | 0.210 | 21.0 | 0.954 |
| D012 | 1.69 | 168.6 | 0.963 | 0.172 | 17.2 | 0.941 |
| D004[c] | 3.13 | 95.0 | 0.956 | 0.760 | 23.0 | 0.925 |
| D022 | 3.86 | 192.9 | 0.950 | 0.222 | 11.1 | 0.825 |
| D013 | 3.39 | 169.4 | 0.949 | 0.354 | 17.7 | 0.936 |
| D002[c] | 2.25 | 112.3 | 0.947 | 0.890 | 44.5 | 0.928 |
| D044[c] | 2.33 | 116.4 | 0.943 | 1.124 | 56.2 | 0.928 |
| D078[c] | 5.55 | 138.7 | 0.923 | 2.152 | 53.8 | 0.828 |
| D079[c] | 0.56 | 112.5 | 0.921 | - | - | - |
| Orbit 4G | 7.15 | 178.8 | 0.918 | 0.791 | 19.8 | 0.957 |
| D043[c] | 3.26 | 98.7 | 0.913 | 0.475 | 14.4 | 0.956 |
| D001[c] | 1.07 | 106.5 | 0.909 | 0.447 | 44.7 | 0.946 |
| Orbit 2G | 3.33 | 166.6 | 0.909 | 0.435 | 21.7 | 0.933 |
| D006[c] | 1.07 | 107.4 | 0.909 | 0.442 | 44.2 | 0.948 |
| D045[c] | 0.95 | 94.9 | 0.896 | 1.018 | 101.8 | 0.855 |
| D021 | 1.80 | 180.0 | 0.880 | 0.075 | 7.5 | 0.893 |
| Orbit 1G | 1.87 | 186.8 | 0.835 | 0.305 | 30.5 | 0.774 |
| D077[c] | 2.88 | 143.9 | 0.777 | 0.775 | 38.8 | 0.376 |
| D076[c] | 1.07 | 106.8 | 0.767 | 0.377 | 37.7 | 0.897 |

[a] Flow rate values represent the mean of eight replications.
[b] Ordered from highest to lowest WAU at 25 psi.
[c] Indicates pressure compensating emitter

## Summary and Conclusion

To irrigate efficiently, and provide garden or landscape plants with the volume of water they require for adequate growth or quality, the microirrigator must know the *q* and WAU of the selected emitter. If irrigating with both low pressure (i.e. rainwater catchment) and high pressure (i.e. household water tap) systems, the selected drip emitter should exhibit high WAU at variable pressure, and have a *q* at the low head sufficient to satisfy the peak water requirements of all plants in the management time frame. In this study, more than half of twenty point source emitters evaluated exhibited at least marginal (ASABE Standard, 1988) WAU (> 0.90) along a relatively short lateral (80 feet) at both

25 psi and a low, substandard head of 5.5 ft. As should be expected, *q* of most PC emitters was similar to MSFR at 25 psi and *q* of NC emitters increased or decreased with pressure. At 5.5 ft. of head, *q* of all emitters (PC and NC) except one (D045) fell below MSFR (emitter D045 has a self-flushing mechanism that allows more flow at pressures below 4 psi). When head was decreased to 3.5 feet, average *q* (of all emitters combined) decreased by more than 50 % (from *q* at 5.5 ft.) and only two emitters had an average WAU of greater than 0.90 (D013 and D043).

In conclusion, this preliminary study showed that point source microirrigation can be an effective method of distributing water to plants in small gardens or landscapes at substandard pressures if the correct emitter is chosen. Because of the sensitivity of *q* to even slight changes in head at these low pressures however, actual *q* and WAU of the chosen emitter(s) should be measured on site during initial system operation prior to developing irrigation scheduling programs. Further studies should evaluate *q* and WUE of emitters at different heads, lateral lengths, closed-loop configurations, etc.

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