Turk J Agric For
31 (2007) 275-285


# Water Application Uniformity of a Subsurface Drip Irrigation System at Various Operating Pressures and Tape Lengths

Behrouz SAFI[1*], Mohamad Reza NEYSHABOURI[1], Amir Hossein NAZEMI[1], Sirous MASSIHA[1], Seyed Majid MIRLATIFI[2]

[1]College of Agriculture, Tabriz University, Tabriz - IRAN

[2]College of Agriculture, Tarbiat Modares University, Tehran - IRAN

Received: 19.03.2007

**Abstract:** Subsurface irrigation has been the focus of attention mainly because of its low evaporation rate and deep percolation losses. Uniformity of water applications and its stability, however, are still a matter of controversy and deserve more investigation. An experiment was conducted at the research station of Tabriz University to evaluate discharge variation among emitters and uniformity after 3 years of operation at different pressures, as well as to determine the optimum length for irrigation tapes. Four hydraulic pressures, 50, 90, 150, and 200 kPa, 4 irrigation tapes 34 m long (used tape) installed at a depth of 10 cm, and 5 new irrigation tapes (unused) 34, 50, 80, 100, and 120 m long comprised the experimental treatments. The used tapes were chosen from a subsurface irrigation system that operated for 3 years for onion irrigation. The new tapes (unused) were the same as the used ones and were laid on the soil surface during the experiment. Emitter discharge and pressure were measured every 2 m along both the used and unused tapes at the above mentioned operating pressures, and data were analyzed to compute several uniformity criteria using traditional and ASAE EP458 methods. In both used and unused tapes, emitter performance ($V_{pf}$) at 150 kPa was better than at 50, 90, and 200 kPa. The maximum uniformity coefficient (UC) values of the unused and used tapes 34 m long were 96.9% and 91.8%, respectively. Considering the variation in UC with tape length and an engineering approach toward the performance of the system for used tape, the 80-m length was determined as a suitable length for irrigation tape. The result indicated that both traditional and ASAE methods are suitable for the evaluation of subsurface drip irrigation systems. The ASAE method, however, showed slightly lower uniformity in both unused and used tapes (1.6% and 3.65%, respectively).

**Key Words:** Subsurface drip irrigation, emitter discharge, uniformity coefficient, emitter performance

## Introduction

Subsurface drip irrigation has a higher capability for minimizing the loss of water by evaporation, runoff, and deep percolation in comparison to other irrigation systems that supply water to the soil surface (Camp, 1998; Alizadeh, 2001; ASAE, 2005). In addition, the high cost of traditional drip irrigation systems, due to annual replacement of system components, is substantially reduced when subsurface components are permanently installed below the soil tillage zone (Camp et al., 1997). In contrast, the plugging of emitters by crop roots, soil particles, and iron oxides, plus inadequate upward movement of water in coarse texture soils are the main limitations of subsurface drip systems (Camp, 1998; Ayars et al., 1999; Shaviv et al., 2004).

Camp (1998), in reviewing subsurface drip irrigation, reported comprehensive information about crop types, depth and spacing of tapes, irrigation frequency, and fertilizer injection. According to the report, irrigation tapes, as water distributor pipes, may be buried 0.02 to 0.7 m below the soil surface, with lengths from 50 to 500 m and water application rates from 100 to 500 l/h/100 m. The emitter discharge rate (q) has been described by a power law, $q = kH^x$, where operating pressure (H), emitter coefficient (k), and exponent ($x$) depend on emitter characteristics (Mizyed and Kruse, 1998; Kırnak et al., 2004). Ortega et al. (2002) estimated the emitter exponent using the measured data obtained from a field study and then calculated the localized irrigation system uniformity parameters. They

*Correspondence to: safi_behrooz@yahoo.com

classified localized irrigation systems based on emission uniformity (EU) and the discharge variation coefficient ($VC_q$). Camp et al. (1993) reported that the uniformity of subsurface drip irrigation systems generally would be slightly lower than that of surface drip irrigation systems. If the water and fertilizer are to be applied together, it is crucial to evaluate emitter discharge uniformity and system performance (Camp et al., 1997). Nakayama and Bucks (1986) evaluated and compared sprinkler and drip irrigation systems based on the parameters of uniformity coefficient (UC), distribution uniformity (DU), emitter flow variation ($q_{var}$), and coefficient of variation of emitter flow (CV). Phene et al. (1992) found that when emitters are not plugged revised energy gradient line (REGL) or step-by-step (SBS) models would be useful to design and evaluate drip irrigation systems. Camp et al. (1997), applying both traditional and ASAE methods, evaluated surface and subsurface irrigation systems after 8 years of operation. This evaluation compared statistical parameters; UC, $q_{var}$, CV, and DU were computed by the traditional method and discharge statistical uniformity ($U_{qs}$), emitter discharge coefficient of variation ($V_{qs}$), emitter discharge coefficient of variation due to hydraulics ($V_{qh}$), and emitter performance coefficient of variation ($V_{pf}$) were computed by the ASAE method. They reported $U_{qs}$ = 92.8% and UC = 96.4% for surface, and $U_{qs}$ = 63.3% and UC = 73.7% for subsurface irrigation systems. Plugged emitters were the main reason for the low uniformity of the subsurface system. Ortega et al. (2002) calculated emission uniformity (EU), pressure variation coefficient ($VC_p$), and flow variation coefficient per plant ($VC_q$) at localized systems and reported that they were 84.3%, 0.12, and 0.19, respectively. They classified the systems unacceptable for $VC_q > 0.4$ and excellent for $VC_q < 0.1$. In addition to pressure variation along irrigation tape, variation in emitter structure or emitter geometry has been known to cause poor uniformity of emitter discharge (Wu and Gitlin, 1979; Alizadeh, 2001; Kırnak et al., 2004). Differences in emitter geometry may be caused by variation in injection pressure and heat instability during their manufacture, as well as by a heterogeneous mixture of materials used for the production (Kırnak et al., 2004).

Qualitative classification standards for the production of emitters, according to the manufacturer's coefficient of emitter variation ($CV_m$), have been developed by ASAE. $CV_m$ values below 10% are suitable and > 20% are unacceptable (ASAE, 2005). The emitter discharge variation rate ($q_{var}$) should be evaluated as a design criterion in drip irrigation systems; $q_{var}$ < 10% may be regarded as good and $q_{var}$ > 20% as unacceptable (Wu and Gitlin, 1979; Camp et al., 1997). The acceptability of micro-irrigation systems has also been classified according to the statistical parameters, $U_{qs}$ and EU; namely, EU = 94%-100% and $U_{qs}$ = 95%-100% are excellent, and EU < 50% and $U_{qs}$ < 60% are unacceptable (ASAE, 1996). The third factor affecting uniformity is soil limiting flow. It is created by a decrease in soil capillary conductivity around irrigation tapes due to soil compaction during tape installation. Soil particle movement caused by water flow from an emitter outlet may also decrease conductivity (Warrick and Shani, 1996; Shaviv and Sinai, 2004). Phene et al. (1983) related the subsurface emitter plugging and decrease of water distribution uniformity to micro particles, growth of bacteria, and root intrusion. Hills et al. (1989) reported a number of hydraulic parameters that may deform irrigation tapes. They evaluated 4 different irrigation tapes, normal circular tape, and varying degrees of compressed tapes. They indicated that deformation of the cross section of irrigation tape due to soil compression around the tape considerably increased head loss and retarded the emitter flow rate. The objectives of the present research were:

1. To investigate emitter discharge application uniformity and its dependence on operation pressure and tape length.

2. To compare emitter discharge uniformity between tapes buried in soil that had been used for onion irrigation for 3 years and new (unused) tapes.

## Materials and Methods

### System design

This experiment was conducted at the research farm of Tabriz University, Iran, on a 0.50 ha site with sandy loam soil, in 3 replicates. The experimental design was randomized complete block. Four irrigation tapes 34 m long that were installed at a depth of 10 cm and operated for 3 years in an onion producing area (Safi et al., 2007), 5 new (unused) tapes 34, 50, 80, 100, and 120 m long laid on the soil surface, and 4 hydraulic pressures, 50, 90, 150, and 200 kPa, comprised the experimental treatments. Irrigation tapes were 250 µm thick with emitter spacing of 20 cm. The manufacturer's recommended operating pressure and discharge for the tapes are shown in Table 1.

Table 1. Operating pressure and discharge rates.

| | | | | |
|---|---|---|---|---|
| Operating pressure (kPa) | 50 | 90 | 150 | 200 |
| Discharge (l $h^{-1}$) | 1.0 | 1.6 | 2.1 | 2.5 |

Installation design for the experiment, and discharge and pressure measurement locations are shown in Figures 1 and 2. Details of the pressure and water supply control have been described by Safi et al. (2007).

### Emitter Discharge and Pressure Measurement

a) New (unused) tapes

Emitter discharge every 2 m along the tapes was measured by collecting emitter discharge for 6 min in plastic containers (Figure 2). Measurements were made at 50, 90, 150, and 200 kPa, with 3 replications. Thus, depending on tape length (34 and 120 m), measurements were performed at 17-60 emitters.

During measurement, pressure heads were kept constant and water temperature was about 19 °C. For pressure measurement a 16 mm tee was installed on the tapes every 2 m. For evaluation of the manufacturer's coefficient of variation ($CV_m$) 3 new (unused) irrigation tapes 5 m in length were selected and connected to a manifold and pressure regulating system. The discharges of 70 emitters were then measured for 6 min at pressures of 50, 90, 150, and 200 kPa, in 3 replications. During the experiment pressure along the tapes remained constant.

b) Used tapes

Four used irrigation tapes 34 m long were selected randomly and then flow rate and pressure at specified emitters 2 m apart (total of 17 emitters) were measured with 3 replications. For this purpose the soil beneath each emitter was carefully excavated and then a plastic container was placed in the excavated hole directly below the emitters and outflow water was collected for 6 min. Emitter pressure was measured similarly at 17 locations along the 34-m tape. Water temperature during the test was about 19 °C. Measurements of discharge and pressure as just described, however, raised the question of whether or not excavating soil below the emitter and exposing it to the atmosphere may alter discharge. To investigate this problem 3 of the buried tapes were carefully brought out of the soil and then each was passed through a single row of soil gallons with 10 cm of soil laid on the tapes. The diameter of the gallons was 20 cm and this allowed one emitter to be located in each gallon at a depth of 10 cm, similar to the field condition where tapes were previously installed. Water was then allowed to enter the tapes and irrigation was accomplished at the specified pressure. The discharge from each emitter under real conditions (emitters buried in soil) was measured by the increase in the weight of every soil gallon.

### Uniformity Parameter Calculations

The evaluations of water application uniformity were calculated with 2 methods using discharge and pressure measurement data.

Traditional method

The following equations reported by Camp et al. (1997) and Nakayama and Bucks (1986) were employed to compute statistical parameters and analyze uniformity of the subsurface drip system. The method is simple and straightforward and is still widely used:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \qquad [1]$$

$$CV = \frac{S}{\bar{q}} \qquad [2]$$

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

where $q_{max}$ and $q_{min}$ are maximum and minimum emitter discharge, respectively, $\bar{q}$ and $S$ are the mean and standard deviation, respectively, of discharge (q), and n is the number of emitters.

Emission uniformity was calculated using the equation (Ortega et al., 2002)

$$EU\ (\%) = \frac{\bar{q}_{25\%}}{\bar{q}}\ 100 \qquad [4]$$

where $\bar{q}_{25\%}$ is the mean of the lowest 0.25 of emitter discharge.

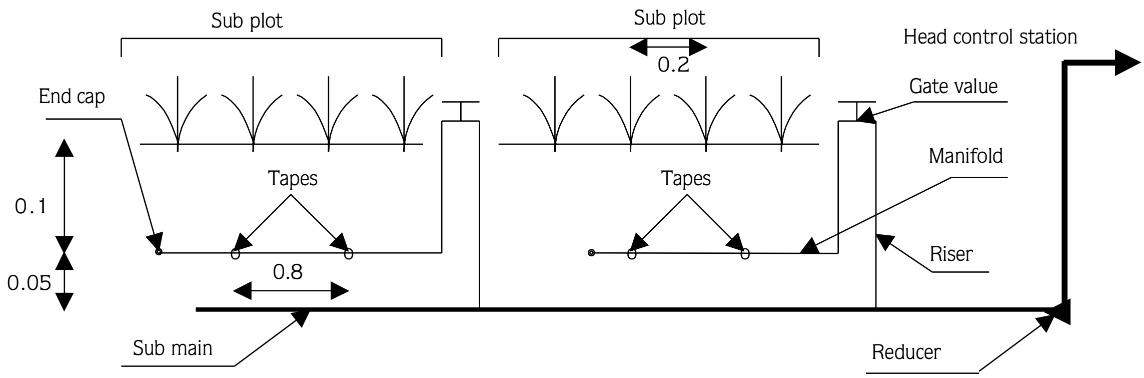


Figure 1. Depth and spacing of irrigation tapes (used) and row spacing between onion rows (units are in meters).

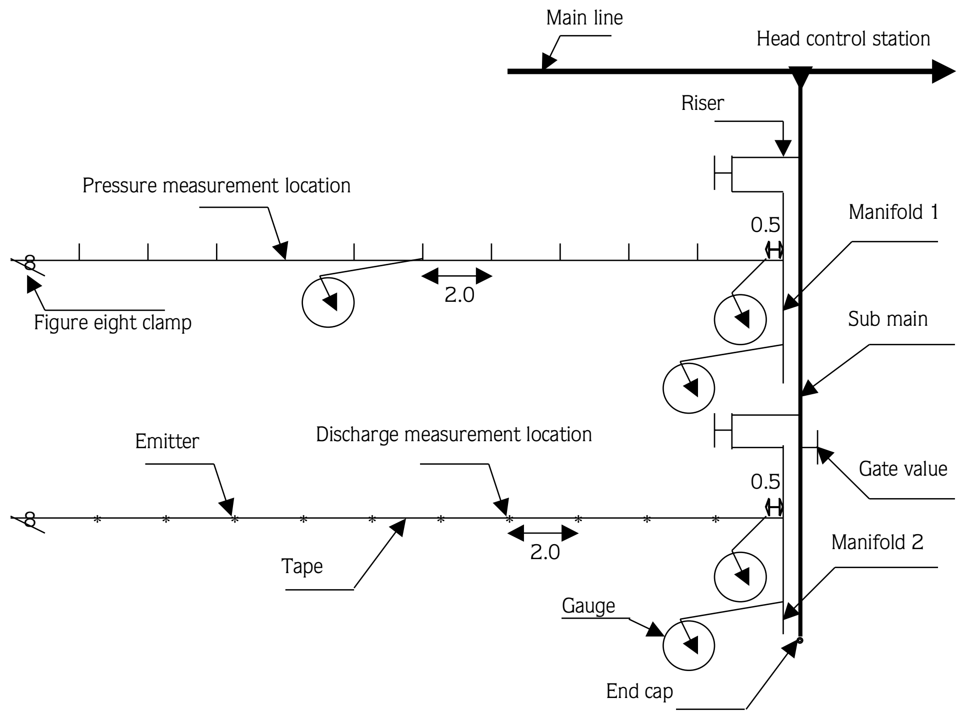


Figure 2. Installation design of new (unused) irrigation tapes laid down on the soil surface, and the emitter discharge and pressure measurement locations (units are in meters).

### ASAE EP458 method

The following equations, as adopted by ASAE (Camp et al., 1977; Ortega et al., 2002), were applied to analyze emitter performance. $\bar{q}$ and standard deviation $S_q$ were calculated using the equations:

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \quad [5]$$

$$S_q = \sqrt{\frac{\sum_{i=1}^{n} q_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} q_i\right)^2}{n-1}} \quad [6]$$

$$V_{qs} = \frac{S_q}{\bar{q}} \quad [7]$$

$$U_{qs} = 100\,(1 - V_{qs}) \quad [8]$$

where $V_{qs}$ and $U_{qs}$ represent the discharge coefficient of variation and the statistical uniformity coefficient, respectively.

The mean hydraulic head ($\bar{h}$) and hydraulic coefficient of variation ($V_{hs}$) were computed using Eqs. 5, 6, and 7, respectively, substituting $h_i$ for $q_i$.

For normally distributed discharge data, adjusted uniformity coefficient ($UC_a$) values were calculated using the following equation:

$$UC_a = 20.2 + 0.798\ U_{qs} \quad [9]$$

The emitter discharge coefficient of variation due to hydraulics ($V_{qh}$) was calculated using the equation

$$V_{gh} = xV_{hs} \quad [10]$$

where $x$ is the emitter discharge exponent and $q = kH^x$. Likewise, the statistical uniformity of the emitter discharge rate due to hydraulics ($U_{sh}$) was calculated using the equation

$$U_{sh} = 100\ (1-V_{qh}) \quad [11]$$

In this research $x$ values for new and used irrigation tape were calculated as 0.53 and 0.59, respectively. Hills et al. (1989) reported that the $x$ value varied between 0.49 and 0.93. The overall performance of an emitter ($V_{pf}$) depends on the discharge variation that originates from several sources, such as variations in temperature and pressure within the pipeline network, emitter geometrical configuration and plugging, and wear. $V_{pf}$ was computed from the equation

$$V_{pf} = \sqrt{V_{qs}^2 - V_{qh}^2} \quad [12]$$

According to the findings from previous research, if $V_{pf} > 0.2$, then emitter geometry and wear, and soil limiting flow would account for low distribution uniformity. For $V_{pf} < 0.2$, hydraulics of the system (bad pressure regulation, inadequate hydraulic design, inadmissible pressure oscillations during irrigation period) would lead to a decrease in distribution uniformity (Warrick et al., 1996; Ortega et al., 2002).

## Results and Discussion

Uniformity parameters for used irrigation tapes (Table 2) were quite similar for tapes 1, 2, and 3. In tape 4, the values decreased due to emitter plugging. The highest mean value of uniformity occurred at 150 kPa (UC = 91.8, EU = 84.8, and $UC_a$ = 89.4) and the corresponding lowest values (89.8, 80.4, and 86.9, respectively) were obtained at 200 kPa. Camp et al. (1997) reported UC = 73.7% and $UC_a$ = 70.9% for used tapes. Comparing $\bar{q}$ at 150 kPa of the 2 measurement methods (soil excavation and soil gallons) showed that excavation led to about a 7% increase or over-prediction in emitter discharge. Sadler et al. (1995) also reported that excavating increased the flow rate between 2.8% and 4%. Maximum and minimum $q_{var}$ were obtained from tapes 4 and 3, respectively. The value of $q_{var}$ = 1.000 indicated that in tape 4 at least one emitter was completely plugged and its out flow rate was zero. The manufacturer's coefficient of variation ($CV_m$) for the emitters at 50, 90, 150, and 200 kPa were to 0.060, 0.052, 0.036, and 0.067 (not tabulated), respectively, which is in accordance with the ASAE classification. Distribution uniformity parameters based on ASAE are shown in Table 3. $S_q$, $V_{qs}$, and $U_{qs}$ for tapes 1, 2, and 3 were almost equal, but for tape 4, due to the complete plugging of one emitter, $S_q$ and $V_{qs}$ were higher and $U_{qs}$ was lower (Table 3). The highest values for $U_{qs}$ and $U_{sh}$, 93.8 and 99.0, respectively, were obtained at 150 kPa in tapes 1 and 2. The lowest $U_{qs}$ and $U_{sh}$ values obtained at 50 kPa for tape 4 were 72.2 and 95.1, respectively. Emitter performance ($V_{pf}$) was > 0.2 for tape 4 and < 0.2 for the other tapes, at all operating pressures. $V_{qh}$ values for all irrigation tapes were almost equal. Camp et al. (1997) reported that the emitter performance for subsurface drip irrigation and surface drip irrigation were 0.186 and 0.029, respectively.

Uniformity evaluation parameters for unused irrigation tapes according to the traditional method are indicated in Table 4. The mean value for emitter discharge and pressure in unused irrigation tapes at 50, 90, 150, and 200 kPa were 0.91, 1.29, 1.66, and 1.98 $l\ h^{-1}$, respectively. The measured discharge at 150 kPa was 6.5% lower than the value recommended by the manufacturer, implying that adopting the factory discharge rates in the system design may create problems in irrigation. It is appropriate to measure discharge at a specified pressure instead of adopting factory supplied rates.

Uniformity parameter values in 3 new irrigation tapes (Table 4) were similar. The highest mean values, UC =

Table 2. Emitter discharge uniformity parameters for 5 used tapes computed with the traditional method. Discharge was measured either by soil excavation (tapes 1 to 4) or by soil gallons (tape 2**) (n = 17).

| Tape | Operating pressure (kPa) | $\bar{q}$(l h$^{-1}$) | CV | $q_{var}$ | UC (%) | EU (%) | $UC_a^*$(%) |
|---|---|---|---|---|---|---|---|
| Tape 1 | 50 | 0.87 | 0.109 | 0.432 | 93.2 | 87.0 | 91.3 |
| | 90 | 1.23 | 0.121 | 0.503 | 93.5 | 89.0 | 90.3 |
| | 150 | 1.49 | 0.107 | 0.392 | 93.7 | 89.9 | 95.1 |
| | 200 | 1.83 | 0.126 | 0.495 | 92.8 | 85.1 | 89.9 |
| Tape 2 | 50 | 0.78 | 0.140 | 0.430 | 89.2 | 83.3 | 88.8 |
| | 90 | 1.12 | 0.103 | 0.342 | 93.1 | 85.9 | 91.7 |
| | 150 | 1.43 | 0.099 | 0.316 | 93.7 | 86.9 | 91.9 |
| | 200 | 1.73 | 0.137 | 0.435 | 90.2 | 82.4 | 88.9 |
| Tape 3 | 50 | 0.87 | 0.122 | 0.407 | 91.8 | 84.5 | 90.0 |
| | 90 | 1.24 | 0.112 | 0.343 | 92.3 | 86.9 | 91.0 |
| | 150 | 1.57 | 0.099 | 0.296 | 94.2 | 92.2 | 92.1 |
| | 200 | 1.84 | 0.117 | 0.381 | 91.1 | 85.9 | 90.7 |
| Tape 4 | 50 | 0.85 | 0.278 | 1.000 | 85.5 | 70.3 | 77.8 |
| | 90 | 1.17 | 0.266 | 1.000 | 86.0 | 70.5 | 78.9 |
| | 150 | 1.40 | 0.268 | 1.000 | 85.7 | 70.2 | 78.5 |
| | 200 | 1.72 | 0.276 | 1.000 | 85.1 | 68.3 | 78.0 |
| Mean Tape | 50 | 0.84 | 0.162 | 0.567 | 89.9 | 81.3 | 87.0 |
| | 90 | 1.19 | 0.151 | 0.547 | 91.2 | 83.1 | 88.0 |
| | 150 | 1.47 | 0.143 | 0.501 | 91.8 | 84.8 | 89.4 |
| | 200 | 1.78 | 0.164 | 0.578 | 89.8 | 80.4 | 86.9 |
| Tape 2** | 90 | 1.06 | 0.102 | 0.302 | 91.8 | 84.6 | 91.5 |
| | 150 | 1.34 | 0.103 | 0.350 | 93.0 | 86.6 | 91.7 |

*Calculated from Eq. 9.

96.9, EU = 95.3, and $UC_a$ = 96.3, were obtained at 150 kPa. Uniformity parameters for new tapes calculated with the ASAE method are reported in Table 5. The parameters were similar in all new tapes; the highest $U_{qs}$ and $U_{sh}$ occurred in tape 1 at 150 kPa, 95.4 and 99.1, respectively. Emitter performance for each of the 3 new irrigation tapes was < 0.2, implying that there was no uniformity problem originating from hydraulics (Ortega et al., 2002).

### Uniformity comparison of used and unused tapes

According to Tables 2-5 the mean uniformity parameter values of used tapes were lower than those of new tapes. In both types of tape insufficient hydraulic pressure (50 and 90 kPa) along the tape probably created an elliptical cross section and led to lower discharge. At 200 kPa, probably the internal spiral layer of the tapes stretched, which led to decreased discharge. The emitter performance coefficient of variation ($V_{pf}$) at 150 kPa in

Table 3. Emitter discharge uniformity parameters for 5 used tapes computed with the ASAE EP458 method. Discharge was measured either by soil excavation (tapes 1 to 4) or by soil gallons (tape 2* ) (n = 17).

| Tape | Operating pressure(kPa) | $\bar{q}$(l h$^{-1}$) | $S_q$ | $V_{qs}$ | $U_{qs}$ (%) | $\bar{h}_{(kPa)}$ | $S_h$ | $V_{hs}$ | $V_{qh}$ | $U_{sh}$ (%) | $V_{pf}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tape 1 | 50 | 0.87 | 0.094 | 0.109 | 89.1 | 45 | 0.035 | 0.078 | 0.046 | 95.4 | 0.099 |
| | 90 | 1.23 | 0.149 | 0.121 | 87.9 | 84 | 0.035 | 0.042 | 0.025 | 97.5 | 0.118 |
| | 150 | 1.49 | 0.092 | 0.062 | 93.8 | 144 | 0.027 | 0.019 | 0.011 | 98.9 | 0.061 |
| | 200 | 1.83 | 0.230 | 0.126 | 87.4 | 198 | 0.061 | 0.031 | 0.018 | 98.2 | 0.125 |
| Tape 2 | 50 | 0.78 | 0.109 | 0.140 | 86.0 | 46 | 0.035 | 0.077 | 0.045 | 95.5 | 0.133 |
| | 90 | 1.12 | 0.117 | 0.104 | 89.6 | 85 | 0.043 | 0.051 | 0.030 | 97.0 | 0.100 |
| | 150 | 1.43 | 0.144 | 0.101 | 89.9 | 146 | 0.023 | 0.017 | 0.010 | 99.0 | 0.101 |
| | 200 | 1.73 | 0.241 | 0.139 | 86.1 | 195 | 0.050 | 0.026 | 0.015 | 98.5 | 0.138 |
| Tape 3 | 50 | 0.87 | 0.109 | 0.125 | 87.5 | 44 | 0.035 | 0.080 | 0.047 | 95.3 | 0.116 |
| | 90 | 1.24 | 0.139 | 0.112 | 88.8 | 85 | 0.035 | 0.041 | 0.024 | 97.6 | 0.104 |
| | 150 | 1.57 | 0.156 | 0.099 | 90.1 | 146 | 0.035 | 0.024 | 0.014 | 98.6 | 0.098 |
| | 200 | 1.84 | 0.215 | 0.117 | 88.3 | 195 | 0.048 | 0.025 | 0.015 | 98.5 | 0.116 |
| Tape 4 | 50 | 0.85 | 0.236 | 0.278 | 72.2 | 45 | 0.035 | 0.080 | 0.047 | 95.1 | 0.274 |
| | 90 | 1.17 | 0.310 | 0.265 | 73.5 | 86 | 0.025 | 0.029 | 0.017 | 98.3 | 0.264 |
| | 150 | 1.40 | 0.376 | 0.269 | 73.1 | 147 | 0.035 | 0.024 | 0.014 | 98.6 | 0.268 |
| | 200 | 1.72 | 0.474 | 0.276 | 72.4 | 197 | 0.055 | 0.028 | 0.017 | 98.3 | 0.275 |
| Mean Tape | 50 | 0.84 | 0.137 | 0.163 | 83.7 | 45 | 1.350 | 0.079 | 0.047 | 95.3 | 0.156 |
| | 90 | 1.19 | 0.179 | 0.151 | 84.9 | 85 | 1.350 | 0.041 | 0.024 | 97.6 | 0.147 |
| | 150 | 1.47 | 0.192 | 0.132 | 86.7 | 146 | 0.037 | 0.021 | 0.012 | 98.9 | 0.131 |
| | 200 | 1.78 | 0.290 | 0.165 | 83.6 | 194 | 0.054 | 0.028 | 0.016 | 98.4 | 0.164 |
| Tape2* | 90 | 1.06 | 0.112 | 0.106 | 89.4 | 84 | 0.042 | 0.05 | 0.030 | 97.0 | 0.102 |
| | 150 | 1.34 | 0.140 | 0.104 | 89.6 | 140 | 0.026 | 0.019 | 0.011 | 98.9 | 0.103 |

used and new tapes was 0.131 and 0.044, respectively, implying that 150 kPa was more suitable than the other 3 tested pressures. The mean value in used tape at 150 kPa resulted in UC, EU, and $UC_a$ values that were 5.56%, 12.38%, and 7.72%, respectively, lower compared to new tapes. $V_{qs}$, $V_{qh}$, and $V_{pf}$ in used tapes increased 287.0%, 9.0%, and 298.0%, respectively, in comparison to new tapes in which $U_{qs}$ decreased 10.03%. Based on ASAE classification, at 150 kPa the uniformity parameters $U_{qs}$ = 95.4, $V_{qs}$ = 4.6%, and EU = 95.3 for new tapes would be classified as excellent and $U_{qs}$ = 86.7, $V_{qs}$ = 13.2%, and EU = 84.8 in used tapes would be classified as moderately good.

Application uniformity parameters in new tapes 50, 80, 100, and 120 m long are shown in Table 6. By increasing the length of irrigation tape, CV and $q_{var}$ increased. In the 120-m long tape, 3 of the emitters had discharge problems and 2 were completely plugged. The variation in the uniformity coefficient of new tapes of various lengths is presented in Table 6. Uniformity coefficients of $UC_a$, UC, and EU varied according to tape length, all having the lowest values for 120-m long tape.

In contrast, $V_{pf}$ increased with tape length and reached its highest value (0.248) at the 120-m length; at the 80-m length it was 0.064. In consideration of the variation in uniformity coefficient value with tape length and

Table 4. Emitter discharge uniformity parameters for new tapes (n = 17) computed with the traditional method.

| Tape | Operating pressure (kPa | $\bar{q}$ (l h$^{-1}$) | CV | $q_{var}$ | UC (%) | EU (%) | $UC_a^*$(%) |
|---|---|---|---|---|---|---|---|
| Tape 1 | 50 | 0.95 | 0.067 | 0.216 | 94.6 | 87.5 | 94.9 |
| | 90 | 1.36 | 0.049 | 0.136 | 95.7 | 94.7 | 95.3 |
| | 150 | 1.66 | 0.026 | 0.059 | 97.8 | 96.4 | 96.3 |
| | 200 | 2.07 | 0.088 | 0.244 | 93.3 | 91.5 | 93.0 |
| Tape 2 | 50 | 0.88 | 0.081 | 0.252 | 93.7 | 92.6 | 93.5 |
| | 90 | 1.24 | 0.081 | 0.172 | 95.2 | 92.9 | 95.0 |
| | 150 | 1.64 | 0.041 | 0.188 | 97.4 | 94.4 | 96.8 |
| | 200 | 1.89 | 0.064 | 0.201 | 94.5 | 92.6 | 95.0 |
| Tape 3 | 50 | 0.91 | 0.099 | 0.307 | 93.1 | 89.8 | 92.3 |
| | 90 | 1.27 | 0.077 | 0.267 | 95.0 | 91.5 | 93.7 |
| | 150 | 1.67 | 0.068 | 0.229 | 95.4 | 95.1 | 94.3 |
| | 200 | 1.97 | 0.083 | 0.295 | 93.6 | 89.8 | 93.4 |
| Mean Tape | 50 | 0.91 | 0.082 | 0.258 | 93.8 | 90.0 | 93.6 |
| | 90 | 1.29 | 0.069 | 0.192 | 95.3 | 93.0 | 94.7 |
| | 150 | 1.66 | 0.045 | 0.159 | 96.9 | 95.3 | 96.3 |
| | 200 | 1.98 | 0.078 | 0.247 | 93.8 | 91.3 | 93.6 |

Table 5. Emitter discharge uniformity parameters for new tapes (n = 17) computed with the ASAE EP458 method.

| Tape | Operating pressure (kPa) | $\bar{q}$(l h$^{-1}$) | $S_q$ | $V_{qs}$ | $U_{qs}$ (%) | $\bar{h}$(kPa) | $S_h$ | $V_{hs}$ | $V_{qh}$ | $U_{sh}$ (%) | $V_{pf}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tape 1 | 50 | 0.95 | 0.061 | 0.064 | 93.6 | 46 | 0.025 | 0.054 | 0.029 | 97.1 | 0.057 |
| | 90 | 1.36 | 0.079 | 0.058 | 94.2 | 87 | 0.025 | 0.029 | 0.015 | 98.5 | 0.056 |
| | 150 | 1.66 | 0.076 | 0.046 | 95.4 | 148 | 0.025 | 0.017 | 0.009 | 99.1 | 0.024 |
| | 200 | 2.07 | 0.182 | 0.088 | 91.2 | 198 | 0.035 | 0.018 | 0.010 | 99.0 | 0.087 |
| Tape 2 | 50 | 0.88 | 0.071 | 0.081 | 91.9 | 148 | 0.025 | 0.053 | 0.028 | 97.2 | 0.076 |
| | 90 | 1.24 | 0.079 | 0.064 | 93.6 | 86 | 0.035 | 0.041 | 0.022 | 97.8 | 0.060 |
| | 150 | 1.64 | 0.066 | 0.040 | 96.0 | 146 | 0.035 | 0.024 | 0.013 | 98.7 | 0.038 |
| | 200 | 1.89 | 0.120 | 0.063 | 93.7 | 197 | 0.043 | 0.022 | 0.014 | 98.8 | 0.062 |
| Tape 3 | 50 | 0.91 | 0.087 | 0.096 | 90.4 | 47 | 0.025 | 0.053 | 0.028 | 97.2 | 0.092 |
| | 90 | 1.27 | 0.100 | 0.079 | 92.1 | 86 | 0.026 | 0.030 | 0.016 | 98.4 | 0.077 |
| | 150 | 1.67 | 0.120 | 0.072 | 92.8 | 147 | 0.025 | 0.022 | 0.012 | 98.8 | 0.071 |
| | 200 | 1.97 | 0.164 | 0.083 | 91.7 | 198 | 0.035 | 0.018 | 0.017 | 99.0 | 0.082 |
| Mean Tape | 50 | 0.91 | 0.073 | 0.080 | 92.0 | 47 | 0.025 | 0.053 | 0.028 | 97.2 | 0.075 |
| | 90 | 1.29 | 0.082 | 0.067 | 93.3 | 86 | 0.029 | 0.033 | 0.018 | 98.2 | 0.064 |
| | 150 | 1.66 | 0.400 | 0.046 | 95.4 | 147 | 0.028 | 0.021 | 0.011 | 98.9 | 0.044 |
| | 200 | 1.98 | 0.155 | 0.078 | 92.2 | 198 | 0.032 | 0.019 | 0.014 | 98.9 | 0.077 |

Table 6. Emitter discharge uniformity parameters for new tapes (n = 17) of various lengths computed with the traditional method.

| Tape length (m) | Operating pressure (kPa) | $\bar{q}$ (l h$^{-1}$) | CV | $q_{var}$ | UC (%) | EU (%) | $UC_a$ (%) |
|---|---|---|---|---|---|---|---|
| 50 | 50 | 0.94 | 0.087 | 0.304 | 93.3 | 88.3 | 93.3 |
| 50 | 90 | 1.35 | 0.068 | 0.228 | 94.2 | 91.4 | 94.3 |
| 50 | 150 | 1.76 | 0.063 | 0.207 | 95.8 | 91.8 | 94.8 |
| 50 | 200 | 1.94 | 0.091 | 0.282 | 93.3 | 91.1 | 92.7 |
| 80 | 50 | 0.96 | 0.095 | 0.336 | 92.9 | 88.9 | 92.4 |
| 80 | 90 | 1.32 | 0.080 | 0.285 | 93.0 | 89.5 | 93.5 |
| 80 | 150 | 1.68 | 0.067 | 0.260 | 94.9 | 92.9 | 94.6 |
| 80 | 200 | 1.99 | 0.093 | 0.346 | 92.6 | 88.2 | 92.6 |
| 100 | 50 | 0.88 | 0.140 | 0.672 | 91.2 | 91.8 | 88.8 |
| 100 | 90 | 1.26 | 0.132 | 0.617 | 92.5 | 88.1 | 89.4 |
| 100 | 150 | 1.54 | 0.132 | 0.635 | 93.1 | 87.8 | 91.1 |
| 100 | 200 | 1.77 | 0.143 | 0.655 | 91.3 | 85.9 | 88.6 |
| 120 | 50 | 0.81 | 0.264 | 1.000 | 84.7 | 70.3 | 79.1 |
| 120 | 90 | 1.12 | 0.258 | 1.000 | 85.4 | 73.3 | 80.1 |
| 120 | 150 | 1.43 | 0.245 | 1.000 | 86.6 | 79.4 | 80.5 |
| 120 | 200 | 1.61 | 0.255 | 1.000 | 85.9 | 71.4 | 79.9 |

engineering approach towards the performance of the system for used tape, an 80-m length was specified as suitable for used irrigation tape. In new tapes plugging and emitter wear due to 3 years of operation evidently did not affect their discharge, and the higher $V_{pf}$ apparently was related to their geometry or manufacturing. The variation in statistical uniformity coefficient values, statistical uniformity due to hydraulics, and adjusted uniformity coefficient values for new irrigation tapes are shown in Figure 3. Apparently, increases in tape length led to decreases in all uniformity parameters; decreases in $U_{qs}$ and $UC_a$ were more pronounced than those in $U_{sh}$. Emitter plugging accounted for greater decreases in $U_{qs}$ and $UC_a$ as compared to $U_{sh}$. Comparison of the 2 methods is possible using $UC_a$ (traditional) and $U_{qs}$ (EP458). Results show that the $UC_a$ value in used and new tapes is closer to UC than it is to $U_{qs}$, and $UC_a$ was greater than $U_{qs}$. Based on these results it appears that both traditional and ASAE EP458 methods can be used to evaluate subsurface drip irrigation systems. The EP458 method showed lower uniformity parameters in used and new tapes 34 m long of 3.65% and 1.60%, respectively. Emitter discharge dependence on operating pressure in new tapes 80 m long is illustrated in Figure 4. It shows that the pressure decrease along the length of the tape is linear and that

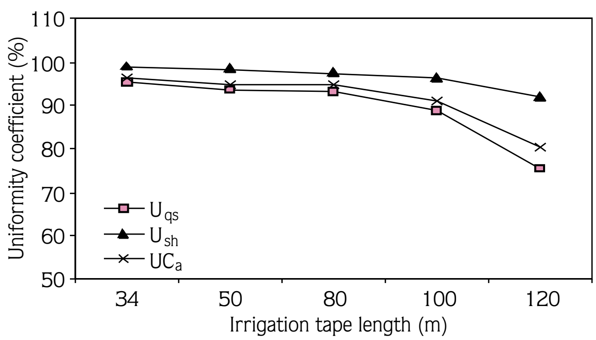


Figure 3. Variation in coefficients UCa, Uqs, and Ush according to tape length (ASAE method).

scattering of the points around the curve is related to emitter manufacturing non-uniformity. The relationship between discharge and pressure for both the subsurface drip irrigation system (used tape) and new tape is show in Figures 5 and 6. Variation in emitter discharge with pressure in the subsurface system (Figure 5) indicates that emitter discharge increases with pressure, but in some emitters this was not true, which led to scattering of points around the fitted curve, especially in used tapes. The pressure-discharge relationship in new emitters is illustrated in Figure 6; emitter discharge steadily increased with increased operating pressure.

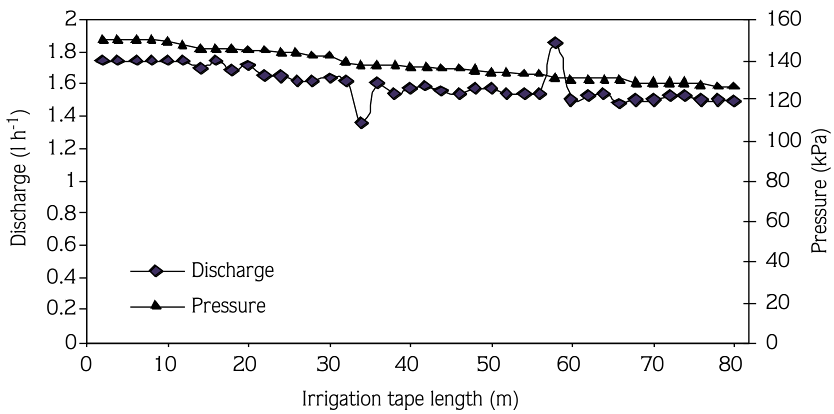


Figure 4. Variation in pressure and emitter discharge of new irrigation tape 80 m long.

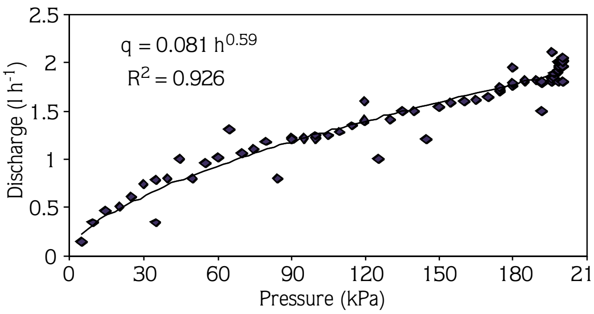


Figure 5. The emitter discharge-pressure relationship in the subsurface drip irrigation system after 3 years of operation (used tape).

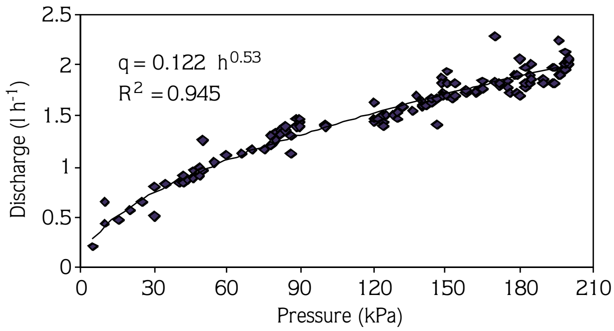


Figure 6. The emitter discharge-pressure relationship in the subsurface drip irrigation system (new tape).

## References

Alizadeh, A. 2001. Principles and Practices of Trickle Irrigation. Ferdowsi University, Mashad,Iran.

ASAE STANDARDS, 43rd ed. 1996. EP458. Field Evaluation of Microirrigation Systems. St. Joseph, Mich. ASAE: 756-761.

ASAE STANDARDS. 2005. EP405.1 FEB03. Design and Installation of Microirrigation Systems. ASAE, St. Joseph, Mich.

Ascough, G.W. and G.A. Kiker. 2002. The effect of irrigation uniformity on irrigation water requirements. Water SA, 28: 235-241.

Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail and R.M. Mead. 1999. Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. Agr. Water Manage. 42: 1-27.

Camp, C.R., J.T. Garrett, E.J. Sadler and W.J. Busscher. 1993. Microirrgation management for double-cropped vegetables in a humid area. Transactions of the ASAE, 36: 1639-1644.

Camp, C.R., E.J. Sadler and W.J. Busscher. 1997. A comparison of uniformity measure for drip irrigation systems. Transactions of the ASAE, 40: 1013-1020.

Camp, C.R. 1998. Subsurface drip irrigation: A review. Transactions of the ASAE, 41: 1353-1367.

Hills, D.J., M.A.M. Tajrishy and Y. Gu. 1989. Hydraulic consideration for compressed subsurface drip-tape. Transactions of the ASAE, 32: 1197-1200.

Kırnak, H., E. Doğan, S. Demir and S. Yalçın. 2004. Determination of hydraulic performance of trickle irrigation emitters used in irrigation system in the Harran Plain. Turk. J. Agric. For. 28: 223-230.

Mizyed, N. and E.G. Kruse. 1989. Emitter discharge evaluation of subsurface trickle irrigation system. Transactions of the ASAE, 32: 1223-1228.

Nakayama, F.S. and D.A. Bucks. 1986. Trickle irrigation for crop production- Design, Operation, and Management, Developments in Agricultural Engineering 9. Elsevier, New York.

Ortega, J.F., J.M. Tarjuelo and J.A. de Juan. 2002. Evaluation of irrigation performance in localized irrigation system of semiarid regions (Castilla-La Mancha, Spain): Agricultural Engineering International: CIGR Journal of Scientific Research and Development. 4: 1-17.

Phene, C.J., M.F. Blume, M.M.S. Hile, D.W. Meek and J.V. Re. 1983. Management of subsurface trickle irrigation systems. ASAE Paper No. 83-2598, ASAE, St. Joseph, Mich.

Phene, C.J., R. Yue, I. Wu, J.E. Ayars, R.A. Schoneman and B. Meso. 1992. Distribution uniformity of subsurface drip irrigation systems. ASAE, Paper No. 92-2569, ASAE, St. Joseph, Mich.

Sadler, E.J., C.R. Camp and W.J. Busscher. 1995. Emitter flow rate changes caused by excavating subsurface microirrigation tubing. In: Proceedings of the 5th International Microirrigation Congress. (Ed. F.R. Lamm) ASAE, St. Joseph, Mich. pp. 763-768.

Safi, B., M.R. Neyshabouri, A.H. Nazemi, S. Masiha and S.M. Mirlatifi. 2007. Subsurface irrigation capability and effective parameters on onion yield and water use efficiency. Journal of Scientific Agricultural. 1: 41-53.

Shaviv, A. and G. Sinai. 2004. Application of conditioner solution by subsurface emitters for stabilizing the surrounding soil. J. Irrig. Drain. Eng. 130: 485-490.

Warrick, A.W. and U. Shani. 1996. Soil-limiting flow from subsurface emitters. II: Effect on uniformity. J. Irrig. Drain. Eng. 122: 296-300.

Wu, I-Pai. and H.M. Gitlin. 1979. The Manufacturer's coefficient of variation of emitter flow for drip irrigation. University of Hawaii at Manoa U.S.D.A. Cooperating: 1-3.