Emitter discharge variability of subsurface drip irrigation in uniform soils: effect on water-application uniformity

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Abstract Emitter discharge of subsurface drip irrigation (SDI) decreases as a result of the overpressure in the soil water at the discharge orifice. In this paper, the variation in dripper discharge in SDI laterals is studied. First, the emitter coefficient of flow variation $CV_?$ was measured in laboratory experiments with drippers of 2 and 4 L/h that were laid both on the soil and beneath it. Additionally, the soil pressure coefficient of variation CV_{te} was measured in buried emitters. Then, the irrigation uniformity was simulated in SDI and surface irrigation laterals under the same operating conditions and uniform soils; sandy and loamy. CV_q was similar for the compensating models of both the surface and subsurface emitters. However, $CV_?$ decreased for the 2-L/h non-compensating model in the loamy soil. This shows a possible self-regulation of non-compensating emitter discharge in SDI, due to the interaction between effects of emitter discharge and soil pressure. This resulted in the irrigation uniformity of SDI non-compensating emitters to be greater than surface drip irrigation. The uniformity with pressure-compensating emitters would be similar in both cases, provided the overpressures in SDI are less than or equal to the compensation range lower limit.

Introduction: objectives

Poor irrigation-water-application uniformity can be a cause of low crop-yields. Drip irrigation has a high potential in reducing energy use, water and soluble nutrient losses and enhancing efficiency (Dasberg and Or 1999). Subsurface drip irrigation (SDI) also has a higher capability for minimizing the loss of water by evaporation, runoff, and deep percolation in comparison to other irrigation methods (Camp 1998). Uniformity will depend on emitter manufacturing variation, land slope-induced hydraulic variability of the irrigation unit and head losses in pipes, emitter sensitivity to pressure and temperature variations, and emitter clogging (Mizyed and Kruse 1989; Rodriguez-Sinobas et al. 1999). Any study of water distribution within an irrigation unit usually takes into account the first two of the above factors. Consequently, the final water-application variability will depend on both the manufacturing variability and the hydraulic variability.

The potential relationship between pressure head and free discharge in orifices can be applied to dripper discharge (Karmeli and Keller 1975):

$$q = k \text{ x } ff, \qquad (1)$$

where q is the dripper flow rate, h is the working pressure head, and k and x are the emitter coefficient and exponent, respectively.

Values of k, h and x throughout an irrigation system are affected by variables commented above, as will be the final flow-rate distribution in any irrigation unit. This has been considered a normal distribution (Solomon 1977; Anyoji and Wu 1994). This hypothesis is better suited when the emitter manufacturing variation is the main cause of the final variation. Normal flow distribution in the unit will then be characterized by two parameters: the mean (the mean flow rate of the evaluated sample) and the standard deviation (or the coefficient of variation, $CV_?$ of the measured flow rates). If the temperature is constant and dripper clogging is negligible, the emitter discharge variability, $CV_?$, will depend on the hydraulic variation and the manufacturing variation, CV_m. Adding these two variations to Eq. (1), results in:

$$q = kx\ h^x\ x\ (l+uxCV_m), \tag{2}$$

where u is a normal random variable of mean 0 and standard deviation 1.

The coefficient of manufacturing variation CV_m is a measure of the variability of flow of a random sample of emitters of the same brand, model and size, as produced by the manufacturer and before any field operation or ageing has taken place (ASAE, 1996).

One of the key differences between subsurface (SDI) and surface drip irrigation is that the emitter flow rate could be affected by soil properties. Philip (1992) studied the movement of water at a buried point source and concluded that, in most soils, a spherical-shaped saturated region of positive pressure is formed around the source. Philip developed an analytical expression to determine the pressure at the discharge point in a permanent-flow regime. Shani et al. (1996) tested the applicability of this expression under the variable conditions of subsurface irrigation. They used Philip's solution to relate soil cavity pressure (h_s) to the soil hydrophysical properties and the emitter flow rate q from

$$h_s = \sim \left/ \frac{2 - a\ x\ r_0}{d,n\ x\ K_s\ x\ r_0 J} \right\backslash * q \;\_\; \frac{1}{a'} \qquad (\ '$$

where q is the emitter flow rate under the permanent flow regime, r_0 is the formed spherical cavity radius, K_s is the hydraulic conductivity of the saturated soil and a is the adjustment parameter of Gardner's (1958) subsaturated hydraulic conductivity expression.

For moderate flows, the pressure at the discharge point is linear, and the emitter flow rate is a straight line whose slope depends on r_0, K_s and a.

Shani et al. (1996) measured the water pressure at separate emitter discharge points under field conditions (and recorded values of up to 8 m) on different emitter models with various discharges. They found that the water pressure increased in soils that had lower infiltration than the emitter flow rate. In this case, a smaller pressure difference across the emitter appears and, consequently, emitter discharge falls by comparison with free discharge given by (Eq. 1). Discharge reduction is greater in fine-pore soils and proportional to the nominal emitter flow rate.

Therefore, if there is an overpressure h_s at the discharge point of a buried emitter, the hydraulic gradient between the emitter interior and the soil would decrease, and the emitter flow rate would have to slow down following Eq. (4):

$$q = k\ x\ (h_0 - h_s)^x \tag{4}$$

Lazarovitch et al. (2005) measured, also under field conditions, the overpressures in the soil generated by the application of water through two isolated emitters, although the maximum values they observed, up to 3 m, were lower than Shani et al.'s for the same emitter flow rate and similar soils.

Gil et al. (2007) also examined the influence of soil properties in laboratory tests on pots containing uniform soil with the same bulk density. However, the observed overpressures, for the same flow rate and similar soils, were lower than what the other authors obtained in field evaluations, because, under these conditions, the soil structure increases the soil mechanical resistance to water pressure.

Warrick and Shani (1996) and Lazarovitch et al. (2006) simulated the variability of the flow rate along a SDI lateral taking into consideration the spatial variability of the soil properties. They used variograms to estimate the spatial variability for their simulations. The hydraulic variability of the lateral was ignored in the study by Warrick and Shani (1996), however, it was considered by Lazarovitch et al. (2005, 2006). Their results show that SDI would be less uniform than surface drip irrigation.

Recent experimental works show an interest in project variables (lateral spacing and length) and the management of SDI on crop production (Camp et al. 1997b; Ayars et al. 1999; Bordovsky and Porter 2006; Grabow et al. 2006). However, few papers show experimental data on measuring water-application uniformity in field SDI laterals, and no evaluation method has yet been reported to measure, in the field, the flow of buried emitters (Phene et al. 1992; Sadler et al. 1995; Camp et al. 1997a; San et al. 2007). Sadler et al. (1995) have reported an increase of emitter discharge between 2.8 and 3%, in 12-m-long laterals, due to the effect of excavating the emitters for lateral evaluation. They concluded that this effect would not cause significant errors in the uniformity calculation. Most of these works compare SDI uniformity with other irrigation methods.

Earlier research has been concerned with studying the effect of soil properties on the emitter discharge in SDI and on simulating the flow-rate variability considering soil variability. However, no laboratory experiments have been run to examine the flow-rate variability across more than one buried emitter and supplement the field work on separate emitters. The main goal of this article is to study and compare, under controlled conditions, the variation on emitter flow in surface drip irrigation and in SDI. The variation of soil pressure at the emitter-discharge point will also be measured and compared. The causes of flow-rate variability in buried emitters will be analyzed and quantified. Likewise, irrigation uniformity of drip laterals will be compared with SDI ones in homogeneous soils and with emitters of different manufacture variation.

Materials and methods

Flow-rate variability of a buried emitter

If, instead of considering a single buried emitter, a sample of emitters is considered, Eq. (4) can be substituted in Eq. (2), and results in

$$q = kx \ (h_0 \text{-} \ h_s f \ \mathrm{x} (\mathrm{l} + \mathrm{w} \ \mathrm{x} \ \mathrm{CV_m}). \tag{5}$$

where u is a standard Gaussian variable.

The variance of q, Vq, was calculated using the delta method for estimating the variance of a function of two random variables u and h_s in Eq. (5) (Oehlert 1992):

$$\begin{aligned} Vq = {} & Vh_s \ \mathrm{x} \ [x \ \mathrm{x} \ k \ \mathrm{x} \ (ho \text{ - } h_s)^{x \sim l}] \\ & + \ [kx \ (h_0 \text{ - } h\sim_s)^x \ \mathrm{x} \ \mathrm{CV_m}]^2 \text{-} 2 \ \mathrm{x} \ cov(h_s, u) \\ & \mathrm{x} \ [xxkx \ (ho\text{-} \ h_s)^{x \sim l}] \ x \ [k \ x \ (ho \text{ - } h_s)^x \ x \ \mathrm{CV_m}], \end{aligned} \tag{6}$$

where: Vh_s = pressure variance at the discharge point and h_s = mean overpressure.

The above equation can be expressed as a coefficient of variation, CV^:

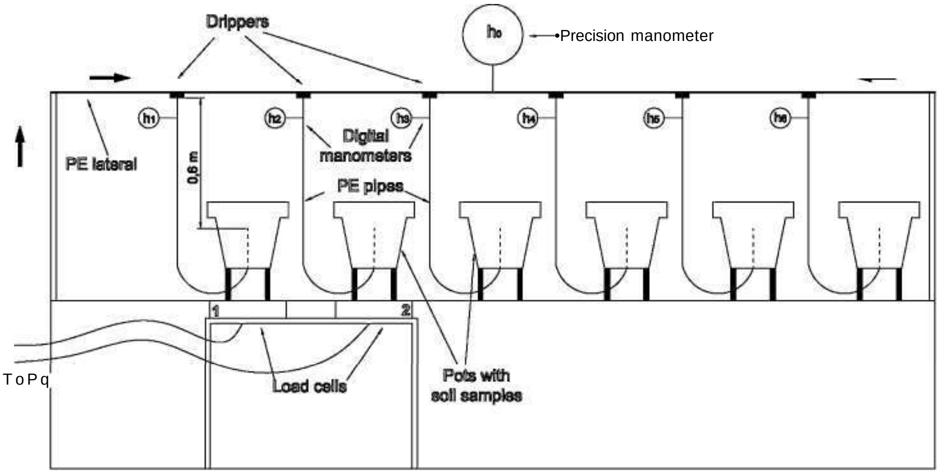
In this paper, the interaction on emitter discharge and soil properties is evaluated by the determination of $cow(h_{SI}\ u)$ from the values obtained for the other variables in Eq. (7) calculated with experimental data. For cases with no interaction, the effect of soil properties will be independent of the emitter discharge, and Eq. (7) transforms to:

$$\mathrm{CV}_q = \frac{1}{\bar{q}}\left[Vh_s \times \left[x \times k \times (h_0 - \overline{h_s})^{x-1}\right]^2 + \left[k \times (h_0 - \overline{h_s})^x \times \mathrm{CV}_m\right]^2\right]^{0.5}$$

The experimental procedure used buried plastic pipes, each with an inside diameter of 6 mm, in six 5.5-L-capacity pots (see Fig. 1). They were each connected to six emitters inserted into two 1.5-m laterals placed in an emitter-testing bench and fed from both ends to assure a constant pressure along the entire length. Pressure, h_0, measured at the centre of the lateral, was kept constant throughout the trial. The nominal emitter flow rates were 2 and 4 L/h.

In each trial, the time evolution of the flow rate was measured on two of the pots. Each pot was weighed on a load cell with a nominal load of 20 kg. A data acquisition card recorded its weight onto a computer every second. The other four pots were weighed before and after irrigation to measure the total weight of the water stored in the soil during irrigation.

The flow rate was determined dividing the recorded weight by the value of the density of water at 20°C. The application time was set, previously, at 1,800 s for the emitters with a nominal flow rate of 2 L/h and 900 s for the 4-L/h emitters. Additionally, the time at which the water was observed to reach the surface of the pot (if applicable) was also recorded. The pressure, /IQ, of the lateral was measured by a manometer with a precision of



±0.25% MPa and the dripper outlet pressures h_t (i — 1...6) were monitored by six digital manometers with a precision of ±0.01 m. The pressure at the discharge point of the plastic tube, h_{si}, was determined by adding the differences of elevation (approximately 60 cm) between the manometer measurement point and the end of the buried tube to the h_t pressures.

To observe the effect of the soil properties on emitter discharge, two soils with different textures were selected (as per the USDA soil taxonomy), sandy soil and loamy soil. The soils were screened using a mesh-sieve with 1-mm openings. The Bouyoucos method of densimetry (Day 1965) was used to determine the texture of the soil samples in the laboratory; Table 1 shows the soil texture. The soils were dried at room temperature for at least a week.

The bulk density was set at 1.5 g/cm^3 for sandy soil and 1.4 g/cm^3 for loamy soil. The procedure for filling the pots was first to feed the plastic tube through the bottom and then add a constant weight of soil to each pot. This was then compacted down to a previously calculated height equivalent to a volume of half a liter.

Four models of punched emitters were studied; two were pressure-compensating models and the other two were non-compensating. For each model, six drippers sample were selected and ran trials at h_0 x 10 m were conducted. In the first trial, the dripper discharged on to the soil surface and, in the second, the top-end of the tube was connected to the dripper and it discharged below the soil surface. The discharge equation of each dripper model, taking the six trial drippers as a sample, was also determined.

Variation in the water-application uniformity in a drip subsurface lateral

A MATLAB program was used to simulate the uniformity of water application along a SDI lateral in homogeneous soil with the same values of a and K_s than the trials. The behavior of a lateral with 100 non-compensating emitters, all working at the same pressure h_0, was simulated. This would be equivalent under field conditions to laterals with negligible hydraulic variability. The working pressure-head range was from 5 to 15 m, which are standard values for drip irrigation units. The effect of the emitter coefficient of manufacturing variation was also considered, and the simulations included the CV_m value range obtained in the trials and the effect of the spherical cavity radius r_0 for values from 0.001 to 0.006 m. These values were calculated from the experimental measurements using (Eq. 3). Additionally, r_0 was kept constant at all discharge points in each simulation. Likewise, the same simulation was repeated with compensating emitters.

Table 1 Percentage of sand, silt, and clay of soils determined by Bouyoucos method of densimetry

	Sandy soil	Loamy soil
Sand (%)	91.2	50.3
Silt (%)	7.5	31.9
Clay (%)	1.3	17.8

The values of a and K_s were determined using the HYDRUS-2D/3D program (Simunek et al. 2006) by means of the Genuchten-Mualem model (van Genuchten 1980). This program uses pedotransfer functions based on ROSETTA-model neural networks (Schaap et al. 2001) to calculate the water-retention-curve parameters; the saturated soil hydraulic conductivity from soil texture class: sand, silt and clay percentages, and bulk density.

First, the simulation program calculates a random Gaussian standard variable u, for the 100 emitters. Then, an iterative calculation that equates the soil pressure values to (Eqs. 3) and (5) is used to calculate the flow rates for buried emitters. This iterative process starts with flow-rate values calculated for surface emitters with Eq. (2). Then soil pressure is calculated with Eqs. (3) and (5), and both values are compared; if the value of h_s obtained with Eq. (3) is greater than the one obtained with Eq. (5), the initial flow rate is decreased, and conversely. The iterative process stops when soil pressures calculated with both equations match. Finally, the coefficient of variation $\mathrm{CV}_?$ is determined for surface and subsurface emitters; its value for surface emitters is CV„.

Results and discussion

Flow-rate variability in surface and subsurface drip irrigation

Table 2 shows the mean flow and soil pressure values in the trials. As earlier works found (Shani et al. 1996 ; Gil et al. 2007), the non-compensating emitter flow rate decreases to a value determined using Eq. (4). This reduction is greater in loamy than in sandy soil, since the overpressure at the discharge point is higher in the first, which also has lower infiltration. For the same soil, the observed reduction is proportional to the nominal emitter flow rate.

The value of h_s in pressure-compensating and non-compensating emitters was similar, but no flow-rate variation was observed in pressure-compensating emitters, as h_s was less than the lower limit of the emitter compensation range. The small variations observed could be considered within the range of experimental error.

Table 3 shows the emitter hydraulic characteristics: parameters x and k of Eq. (1) and the coefficient of

Table 2 Mean flow and mean soil pressure in the trials with h_0 = 10.19 mwc

	Non-compensating		Compelnsating	
	2 L/h	4 L/h	2 L/h	4 L/h
q at surface (L/h)	2.27	4.11	2.03	3.94
Sandy soil				
q (L/h)	2.25	4.07	2.03	3.94
K (m)	0.14	0.29	0.20	0.27
<j relative variation (%)	0.69	0.95	0.11	0.04
Loamy soil				
q (L/h)	2.20	3.97	2.03	3.94
h_s (m)	0.92	0.98	1.38	1.26
^relative variation (%)	3.05	3.47	0.11	0.00

Table 3 Discharge and soil pressure variability in the trials

	Non-compensating		Compensating	
	2 L/h	4 L/h	2 L/h	4 L/h
K (L/h/m^x)	0.795	1.492	1.868	3.629
x	0.453	0.435	0.035	0.035
CV_m	0.054	0.010	0.023	0.019
h_Q (m)	10.19	10.19	10.19	10.19
Sandy soil				
CV,	0.055	0.011	0.023	0.020
Var_{hs}	0.002	0.004	0.005	0.014
CV_{to}	0.311	0.231	0.362	0.446
cov(h_s, u)	-0.021	-0.012	-0.011	-0.062
Correlation coefficient	-0.476	-0.185	-0.153	-0.515
Loamy soil				
CV,	0.041	0.011	0.023	0.019
Var_{to}	0.095	0.978	0.036	0.036
CV_{to}	0.335	0.025	0.138	0.151
cov(h_s, u)	0.270	0.035	0.048	-0.046
Correlation coefficient	0.877	0.222	0.251	-0.241

manufacturing variation CV_m. It also displays the variability of the flow rate—expressed as a coefficient of variation, CV^ and overpressure—expressed as a variance, Var_{fa} and as a coefficient of variationCV^-, for the two soils analyzed in the trials. It also shows the covariance between the mean soil pressure and the random variability due to the emitter manufacture, cov(/z_s, *u)* calculated from Eq. (7) for each soil type. Finally, the value for Pearson's correlation coefficient is shown as well.

In the sandy soil, the covariance between h_s and *u* is fairly close to zero and the value of $CV_?$ is very similar to CV_m. On the other hand, in the loamy soil, soil properties do have an effect, and h_s values are greater than for sandy soil (see Table 3). Note that the value of *Jcov(h_s,u)* in trials with 2-L/h non-compensating emitters in loamy soil is higher than the other, and $CV_?$ is smaller than CV_m. In all the cases, Pearson's correlation coefficient, in absolute value, is lower than 0.7, except for the 2-L/h non-compensating emitters, with a value of 0.877. This could be explained taking into account a possible stronger interaction, between the emitter discharge and soil pressure, than in the sandy soil. Likewise, the positive value showed for the correlation coefficient in most of the experiments in the loamy soil support that possibility. In this case, the interaction between soil properties and discharge would mean the reduction of $CV_?$. Thus, the uniformity of water application of SDI systems in homogenous soils, with non-compensated emitters, would increase.

In non-compensating surface emitters at the same working pressure, the flow-rate variability $CV_?$ is due to the emitter manufacturing variability CV_m. The chosen models have a $CV_m < 0.054$. Therefore, they would be classified as excellent, according to the ASAE classification (1996), and the irrigation uniformity would also be very good in an irrigation system with negligible hydraulic variation. The flow-rate variability of buried emitters would not only depend on the manufacturing variability, but also on soil overpressure. When the effect of the soil on emitter discharge is negligible, i.e., sandy soil, the overpressure at the discharge point is also negligible, and its variability would have little impact on the final observed variability. In loamy soils, the variability of the observed flow will depend not only on the manufacturing variability and the soil effect, but also on the possible interaction between them. If both effects were independent, Eq. (8) would hold, and the resulting value would be greater than the CV_m. On the contrary, the results shows that $CV_q < CV_m$. The drop in the buried emitters $CV_?$ suggests that they self-regulate the flow rate. Along with this theory, in subsurface irrigation, the reduction in the flow rate of emitters discharging at a greater flow rate in surface irrigation would be steeper than for emitters with a smaller flow rate. The greater the surface emitter flow rate is, the higher the overpressure in the soil will be, and, consequently, the flow rate will fall proportionally in buried emitters according to Eq. (4). They would act to some extent like compensating emitters. Figure 2 shows that the flow-rate variability within the six drippers sample is higher in drip surface irrigation than SDI.

The above interaction is not observed in compensating emitters, even for the same or greater soil pressure variability, because their elastomers keep the flow rate constant within a compensation range, and it was never below the lower limit of this range during the trial.

It should be kept in mind that the trials were run in a controlled environment, where careful attention was paid to assure that soil samples were as homogeneous as possible,

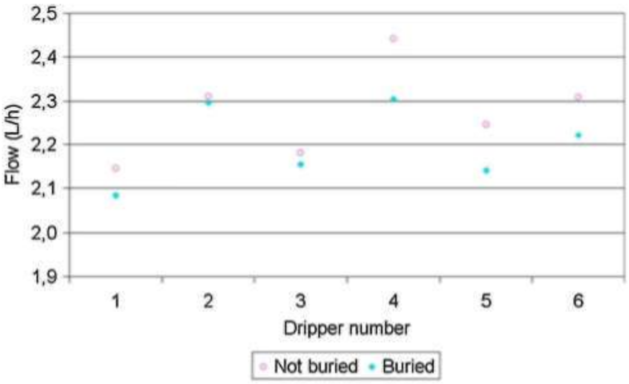


Fig. 2 Flows for each of the six non-compensating 2-L/h drippers

something not to be expected under field conditions. Even so, variability was significantly affected in one of the trials, corresponding to the emitter with the greatest CV_m

Table 4 shows the values of a and K_s of each soil, together with the mean flow rate and overpressure values, as well as the mean value of r_0. This was estimated from Eq. (3).

The mean values of h_s were lower than expected from our earlier work on larger pots (Gil et al. 2007) and other field evaluations (Shani et al. 1996). Therefore, they have greater r_0 values than had been previously calculated for similar soils. This difference may be due to the soil homogenization procedure as the screening may have deprived the soil of its natural structure, and, even though it was later compacted, it would be less resistant to pressure than in its natural state.

Uniformity of irrigation in a drip lateral

Figure 3 shows the uniformity of irrigation in a lateral, expressed as a coefficient of flow-rate variation, $CV_?$, calculated for non-compensating emitters in the homogeneous soils used in the experimental study and considering a constant r_0. Simulated results confirm that SDI would be more uniform than surface irrigation.

Table 4 Values of soil properties and mean flow and soil pressure

	Non-compensating		Compensating	
	2L/h	4L/h	2L/h	4L/h
Sandy soil				
K_s (m/s)	6.84E-05			
a (m~)	3.83			
$q(L/h)$	2.25	4.07	2.03	3.94
$\boldsymbol{h_s(m)}$	0.14	0.29	0.20	0.27
r_0 (m)	0.002	0.002	0.001	0.002
Loamy soil				
K_s (m/s)	9.00E-06			
a (m^{-1})	1.40			
$q(L/h)$	2.20	3.97	2.03	3.94
$\boldsymbol{h_s(m)}$	0.92	0.98	1.38	1.26
r_0 (m)	0.003	0.006	0.002	0.005

The drop in flow variability and the resulting improvement in irrigation uniformity is greater, the smaller the spherical cavity radius r_0 and the lesser the inlet pressure, h_0, are. It is also observed (results are not shown) that, for the same values of r_0 and h_0, the flow rate self-regulation due to soil properties is greater in loamy than in sandy soil. On the other hand, results in compensating emitters show that, as expected, self-regulation is negligible.

The results of the simulations for the 2-L/h non-compensating emitter in loamy soil indicate that, for a calculated cavity radius r^ of 0.003 m (see Table 5) and a head pressure of 10 m, the $CV_?$ would drop from 0.054 to 0.049. These values are close to the variability observed in the experimental trials, where the variability decreased from 0.054 to 0.041. Values simulated for mean soil pressure shows good agreement with measured value but its coefficient of variation was smaller than the experiments. Coefficients of variation for other pressure heads are shown in Table 6.

The results of these simulations reflect the variability of soil pressures, h_s, due to the flow-rate variability of emitters, but they do not include the spatial variability of agricultural soil, which can be large, and the hydraulic variability of the lateral, which, generally, tends to be small. Under such conditions, the self-regulating effect of soil is unlikely to be noticeable, and water application of subsurface irrigation would probably be less uniform than surface irrigation. Nevertheless, it is shown here that the uniformity of SDI would be greater than surface irrigation for scenarios with uniform soils.

Conclusions

Under the experimental conditions of this study, the flow-rate variability of non-compensating emitters in SDI of homogeneous soils with high infiltration is more or less the same as for surface drip irrigation. In these cases, the variability of the soil overpressure is low. On the other hand, the variability of overpressures is greater in soils with low infiltration and this could lead to obtain smaller discharge variability than in surface drip irrigation.

Using compensating emitters, the flow-rate variability in SDI is similar to the surface drip irrigation in both soils. Thus, under the experimental conditions, the head pressure gradient across the emitter and the soil was above the lower limit of the emitter compensation range and the variability of soil overpressure was offset by the elastomer regulation.

Fig. 3 Uniformity of water application on an irrigation lateral, expressed as CV_g, for the loamy soil and the non-compensating 2-L/h, as a function of the inlet head and the spherical cavity radius

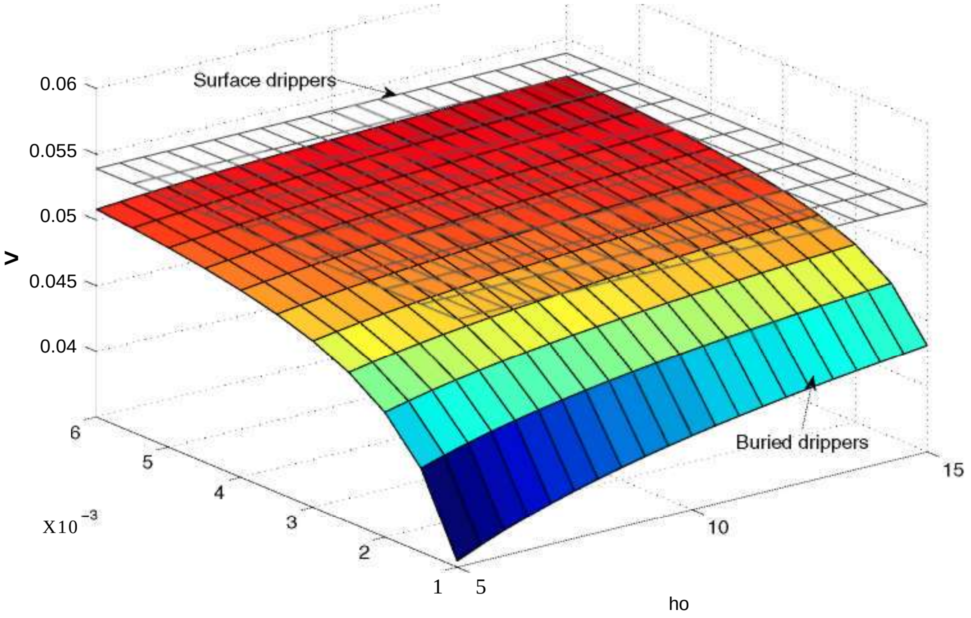


Table 5 Simulation results in loamy soil for an SDI lateral of 100 emitters for different r_0 and h_0 = 10 m for the non-compensating 2-L/h emitter

r_0 (m)	Qsurface (L/h)	qbimed (L/h)	*q* relative variation (%)	h_s (mwc)	CV„	CV„	CV_{fe}
0.0010	2.25	1.82	19.20	3.75	0.054	0.041	0.048
0.0015	2.25	1.98	12.32	2.52	0.054	0.045	0.058
0.0020	2.25	2.06	8.65	1.81	0.054	0.047	0.066
0.0025	2.25	2.11	6.39	1.35	0.054	0.049	0.074
0.0030	2.25	2.15	4.85	1.04	0.054	0.049	0.084
0.0035	2.25	2.17	3.73	0.80	0.054	0.050	0.095
0.0040	2.25	2.19	2.89	0.63	0.054	0.051	0.108
0.0045	2.25	2.20	2.23	0.48	0.054	0.051	0.126
0.0050	2.25	2.22	1.70	0.37	0.054	0.051	0.150
0.0055	2.25	2.23	1.26	0.28	0.054	0.052	0.185
0.0060	2.25	2.23	0.90	0.20	0.054	0.052	0.240

Table 6 Simulation results in loamy soil for an SDI lateral of 100 emitters for different h_Q and r_0 = 0.003 m for the non-compensating 2-L/h emitter

ho (mew)	qsurface (L/h)	qburied (L/h)	{relative variation (%)	h_s (mwc)	CV„	CV_{ff}	CV,
5	1.65	1.56	5.25	0.56	0.054	0.048	0.108
6	1.79	1.7	5.23	0.67	0.054	0.048	0.100
7	1.92	1.82	5.16	0.77	0.054	0.049	0.094
8	2.04	1.93	5.06	0.87	0.054	0.049	0.089
9	2.15	2.04	4.95	0.95	0.054	0.049	0.086
10	2.25	2.15	4.85	1.04	0.054	0.049	0.084
11	2.35	2.24	4.74	1.12	0.054	0.050	0.081
12	2.45	2.34	4.64	1.19	0.054	0.050	0.080
13	2.54	2.42	4.54	1.27	0.054	0.050	0.078
14	2.63	2.51	4.44	1.34	0.054	0.050	0.077
15	2.71	2.59	4.35	1.40	0.054	0.050	0.076

The interaction between the effect of emitter discharge and soil properties could be appreciated in soils with low infiltration. In this case, it was acting as a self-regulated mechanism. Consequently, the flow emitter variability would be smaller in buried emitters than in surface ones.

In homogeneous soil, the uniformity of water application in a subsurface emitter drip irrigation lateral would be greater than the uniformity of surface drip irrigation. The soil overpressure would act as a regulator, and the emitters with a greater flow rate in surface irrigation would generate a higher overpressure in the soil, which would reduce the subsurface irrigation flow rate to a greater extent than in emitters with a lower flow rate.

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