SUBSURFACE TRICKLE IRRIGATION SYSTEM EVALUATION AS RELATED TO WATER FLOW IN SOIL AND EMITTER

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ABSTRACT

The purpose of this study was to evaluate subsurface trickle irrigation system as related to water flow in soil and emitter when the discharge of a subsurface emitter becames larger than the soil infiltration intake creating soil back pressure from soil on emitter flow . Field experiments were conducted for 50 m of lateral length φ13.6 inner diameter and 0.5 m spacing was tested under 100 and 150 kPa inlet pressure for 4 and 8 l/h emitter flow rate. Both of them were on soil surface except subsurface emitters that connected to lateral using micro-tube φ 4 mm and set 0.2 m depth from soil surface. Several points were taken into consideration, such as, pressure variation, manufacturing variation, flow rate, hydraulic variation, field emission uniformity ,field uniformity coefficient and wetted distribution area directly after irrigation and soil – water distribution area. They showed that pressure head decreased as lateral length increased. Pressure variation along lateral increased as emitter flow rate increased. pressure head losses increased by the increase of inlet pressure due to increasing emitter flow rate. Furthermore, emitter flow rate decreased in subsurface trickle irrigation compared with surface trickle irrigation, the flow rate decrease has happened because of the increase of soil pressure (H_S) at the emitter outlet, also (H_S) is very sensitive to the formed spherical cavity radius

Keywords: *Surface trickle lateral –Subsurface trickle lateral – Emitter flow rate -Soil back pressure – Uniformity coefficient – Emission uniformity – pressure variation - spherical cavity radius.*

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INTRODUCTION

The most important developments of the drip irrigation system is the subsurface drip irrigation system (SDI). It could also be defined as the application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation **(ASAE, 2005)**. **Lamm (2002) and Payero (2005)** showed some advantages and drawbacks of SDI, the efficiency of water use is high since soil evaporation, surface runoff, and deep per-colation are greatly reduced or eliminated. In addition, the risk of aquifer contamination is decreased since the movement of fertilizers and other chemical Compounds by deep percolation are reduced. The use of degraded water. Drawbacks of SDI are water applications may be largely unseen, and it is more difficult to evaluate system operation and water application uniformity. If emitter discharge exceeds soil infiltration, a soil overpressure develops around emitter outlet .

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 h_s, 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 around the emitter.

Gil M et al. (2008) showed that 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. **Rodriguez-Sinobas et al. (2009b**). Stated that for loamy soils, the inlet flow of laterals with pressure compensating or regular emitters reduces at the beginning of irrigation then it tends to stabilize reaching a steady state in both evaluated models.

The aim of this study was to assess the performace of subsurface trickle irrigation comparing with surface trickle irrigation.

MATERIALS AND METHODS

The experimental designs of laboratory and field experiments were tested for Turbulant flow path emitter type of 4 and 8 l/h emitter flow rate ,their CharacteriSDIc curves were logarithmically found under the foregoing different pressures, q=1.219 $H^{0.531}$,and q=2.3857 $H^{0.5407}$ respectively, where q is emitter emitter discharge in l/h and H is pressure head in m . And find out manufacturer's variation for them in two cases in surface trickle irrigation (SDI) and subsurface trickle emitter (SSDI) system.

Poly Ethylene single laterals of φ13.6 mm inner diameter and φ16mm outer diameter, 50 m length, and 0.5 m emitter spacing were laid on zero-slope soil surface. Laterals were tested under 100kPa and 150 kPa inlet pressures for 4 and 8 l/h emitter flow rate for SDI and SSDI which buried 20 cm under soil surface in cash cans (as shown in fig.1) . Inlet pressures were regulated by measuring them and adjuSDIng the regulator pressure. Pressure and flow rate were measured each 2 m along lateral for lateral size, inlet pressure, and emitter flow rate set. Pressure head was measured using digital pressure transducer. Flow rate was found by measuring water volume in graduated container in recorded time for surface trickle lateral and by weighing the catch cans, where emitter was buried, By using a balance before and after irrigation to measure the total weight of water stored in the soil during irrigation, therefore, the flow rate was determined dividing the recorded weight by the value of the density of water (1000kg/m^3).

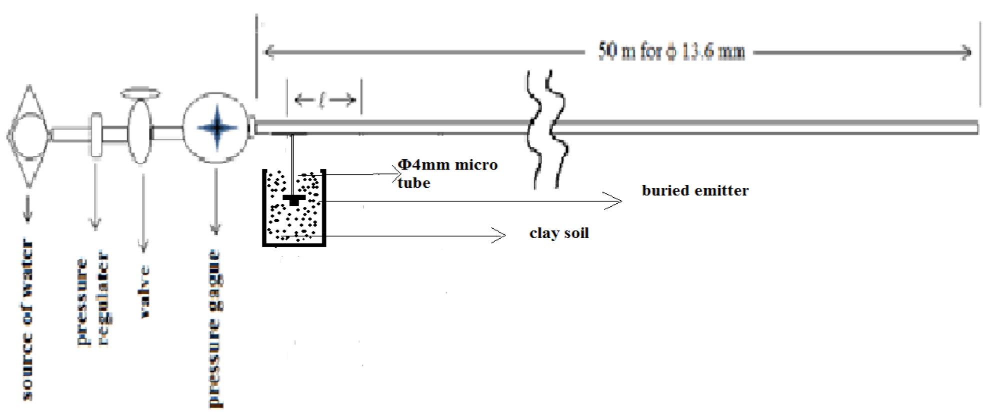

Fig .1: Layout diagram for single lateral with subsurface emitter.

Emitter discharge falls by comparison with free discharge given by eq **(Karmeli and Keller 1975).**

$q_i = k\, H_i^{\,x}$ (1)

Where, q_i is emitter flow rate in l/h, H_i is pressure head in m, k and x are emitter flow rate constant and exponent, respectively.

Where $H_i = H_0 - \Delta H_{\ell i} - \Delta H_t$, (2)

H_0 Is inlet pressure, $\Delta H_{\ell i}$ The friction loss at any section of lateral was determined according to **Amer and Bralts (2005)** as follows:

$$\Delta H_{\ell i} = \frac{K}{2.75}\frac{\alpha Q^{1.75} L}{D^{4.75}}\left(1-\left(1-\frac{\ell}{L}\right)^{2.75}\right) \qquad (3)$$

Where, ΔH_ℓ is friction loss heads in m at a length ℓ measured from inlet, α is an equivalent barb coefficient. Q is inlet flow rate in m^3/s at the beginning of each lateral or submain length L with inside diameter D both are in m.

For the barb of emitter, emitter and lateral connection coefficients were calculated according to **Pitts et al. (1986) and Amer and Gomaa (2003)** as follow:

$$F_e = 1 + \frac{0.01B}{SD^{1.9}} \qquad (4)$$

Where, Fe is an equivalent barb coefficient, B is outer diameter for emitter barb or inlet lateral connector in m, D is the inside pipe diameter in m, S is outlet spacing in m.

Therefore, if there is a soil back pressure $H_s$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,

$q_{iss} = k(H_0 - \Delta H_{li} - \Delta H_t - H_S)$ (5)

The soil over pressure at emitter outlet according to (**Philip (1992)**.

$$H_s = \left(\frac{2-\propto r_0}{8\pi . k_s . r_0}\right). q_i - \frac{1}{\propto} \qquad (6)$$

where q is the emitter flow rate under the permanent flow, $r_0$is the spherical cavity radius around emitter outlet, k_s is the hydraulic conductivity of the saturated soil and $\propto$ is the fitting parameter of **Gardner's (1958)** of the non-saturated hydraulic conductivity expression.

$$r_0 = \frac{2.\alpha.q}{8.\pi.k_s.(q.\mathrm{H_S}.+1) + (\alpha^2.q)} \qquad (7)$$

Where

Table (3.1) Values of soil properties and mean flow and soil pressure.

q(l/h)	4	8
r_0 (m)	0.0189	0.042
$k_s\ (m/s)$	8.08*10^{-6}	8.08*10^{-6}
$\alpha(m^{-1})$	**7.5**	**7.5**
$\mathrm{H_S}$ (m)	0.348	0.194

Average of friction loss ($\Delta\overline{\mathrm{H}}$) in lateral can be expressed by **Amer and Gomaa 2003** as follows:

$$\Delta\overline{H} = 0.73\ \Delta\mathrm{H} \qquad (8)$$

Where, ΔH is total friction loss at lateral downstream end.

The flow variation method was used by **victor et al. (1979)** for design lateral or submain length L. pressure variation was determined as follows:

$$H_{var} = \frac{H_{max-}H_{min}}{H_{max}} \qquad (9)$$

Where, H_{var} is pressure variation the maximum and the minimum pressure along the line are H_{max} and H_{min}, respectively.

Total coefficient of variation CV_t was calculated according to **Bralts et al., (1981**) as follows:

$$CV_t = \sqrt{CV^2{}_{\mathrm{m}} + CV^2{}_h} \qquad (10)$$

Where, CVm is the manufacture's coefficient of variation and CV_h is the hydraulic variation.

Emission uniformity, EU, is a measure of the uniformity for all emitter emissions along drip irrigation lateral line. The basic concept and formulas used for emission uniformity were using the ratio of minimum emission rate to the average emission rate multiplied by the low quarter of emitter flow rates caused by manufacturer's variation. Emission uniformity, EU, was expressed **(Keller and Karmeli, 1974)** as follows:

$$EU = \left(1 - 1.27\frac{CV_m}{\sqrt{e}}\right)\frac{q_{min}}{q_{avg}} \qquad (11)$$

Where, CV_m is manufacturing variation, e is emitter grouping, q_{min} is minimum flow rate, and q_{avg} is average of flow rate. The minimum flow rate was determined by using the following equation which based on the statiSDIcal calculation:

$$q_{min} = k(H_o - \Delta H)^{x} \qquad (12)$$

Where, q_{min} is minimum flow rate, k and x are emitter flow rate constant and exponent respectively, H_0 is the inlet pressure head in m, and ΔH is the calculated friction losses at the end line .

$$q_{avg} = K(H_{avg})^{x} \qquad (13)$$

Where, q_{avg} is average flow rate, H_{avg} is average pressure head along the lateral line.

$$EU_s = 1 - 1.27\sqrt{CV^2{}_m + CV^2{}_h} \qquad (14)$$

Where, EU_S is calculated statiSDIcal emission uniformity.

The total uniformity coefficient based on hydraulic pressure and manufacturing variations, UC_t, was determined according to **(Amer and Gomaa 2003)** as follows:

$$UC_t = 1 - 0.798\sqrt{CV^2{}_m + CV^2{}_h} \qquad (15)$$

Uniformity parameters were found using measured emitter flow rates along lateral using the following equations:

$$UC_f = 1 - 0.798\,CV_f \qquad (16)$$

$$EU_s f = 1 - 1.27CV_f \qquad (17)$$

Where, UC_f is a field uniformity coefficient, EU_sf is a field statiSDIcal emission uniformity, and CV_f is a field coefficient of variation of measured flow rate.

Wetted widths (W) and wetted depth (D) of soil were simulated according to **(Singh et al (2013).**

$$W = 3.39 * (t * Q)^{0.392} \left(\frac{\theta}{Z^3}\right)^{0.059} \qquad (18),$$

$$D = 1.72 * (t * Q)^{0.291} \left(\frac{\theta}{Z^3}\right)^{-0.042} \qquad (19)$$

Whereas, W is the maximum width of the wetted soil volume (L), D is the maximum wetted depth of the soil (L), Z is the depth of placement of lateral (L), Q is the discharge of emitter (L^3/T), t is the duration of water application (T) and $\theta'$is the change in soil moisture content of soil (L^3/L^{-3}).

RESULTS AND DESCUSSION

The results of pressure head along trickle lateral of Φ 16 mm outer diameter and Φ13.6 mm inner diameter was determined and measured along the 50 m lateral length with emitter spacing 0.5 m for 4 and 8 l/h flow rate for both of surface and subsurface trickle lateral. Both of them were on soil surface except subsurface emitters that connected to lateral using micro-tube φ 4 mm and set 0.2 m depth from soil surface. Operating pressure of 100 and 150 kPa were adjusted at inlet lateral. Pressure and flow variations were found along 50 m lateral in each case as explained herein.

1- Pressure head along trickle lateral.

Figs 4.1 and 4.2 show the relationship between the measured and determined pressure head along lateral expressed by meter and lateral length for 4 l/h emitter flow rate at 100 and 150 kPa .It was seemed that pressure head decreased as lateral length increased .Results showed that the higher inlet pressure was, the greater friction loss occurres and pressure head decreased in subsurface emitter compared with surface emitter at the same flow rate and inlet pressure because of the increase of soil back pressure H_S around emitter outlet , also H_S increased by the increase of inlet pressure. It increased from 0.348 m to 0.437 m at the start of lateral by changing inlet pressure from 100 kPa to 150 kPa ,respectively. Also changed from o.322 m to 0.392 m at the end of lateral ,respectively.

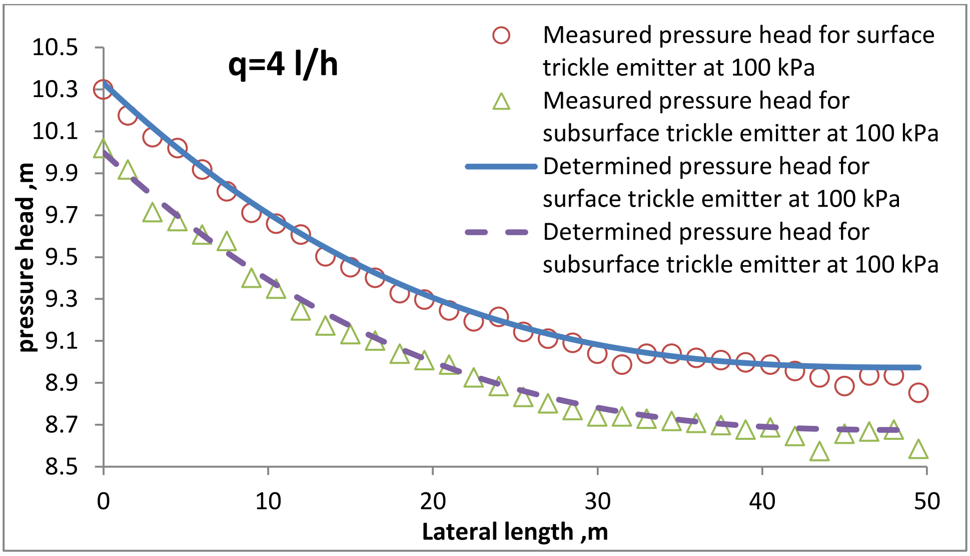

Fig .4.1: the measured and determined pressure head in m vs lateral length, m, at 0.5 m turbulent flow path emitter spacing , at inlet pressure of 100 kPa.

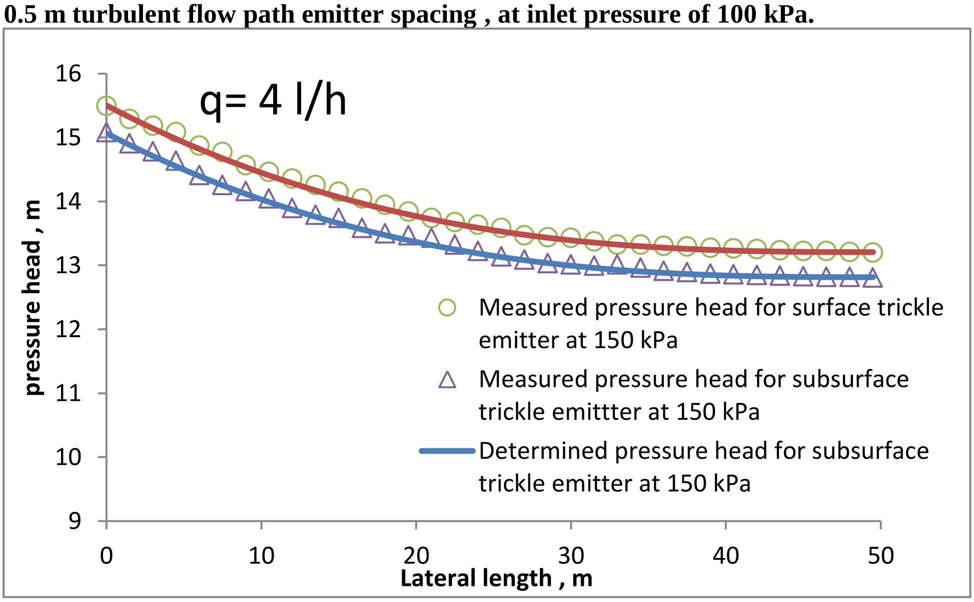

Fig .4.2: the measured and determined pressure head in m vs lateral length, m, at 0.5 m turbulent flow path emitter spacing at inlet pressure 150 kPa.

Figs 4.3 and 4.4 show the relationship between the measured and determined pressure head along lateral expressed by meter and lateral length for 8 l/h emitter flow rate at 100 and 150 kPa .it was seemed that pressure head decreased as lateral length increased**.**

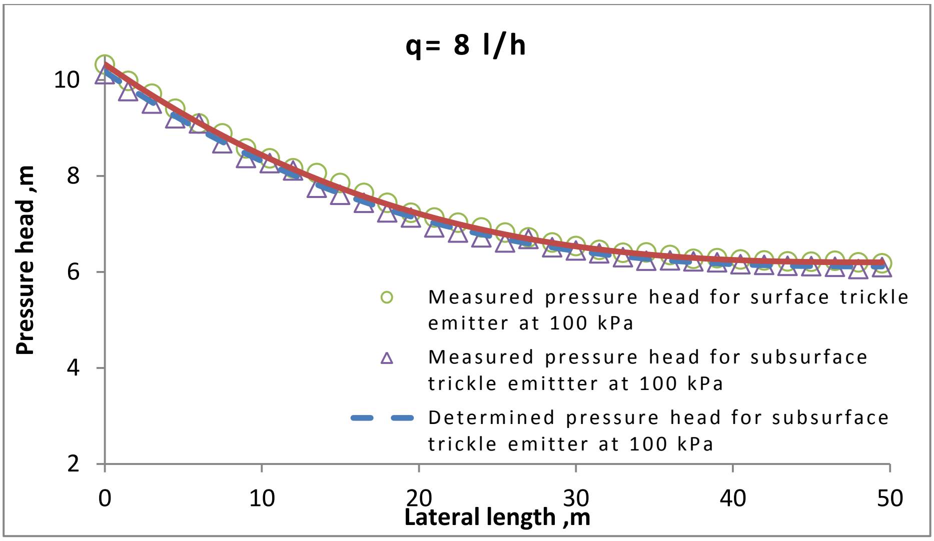

Fig .4.3: the measured and determined pressure head in m for lateral vs lateral length, m, at 0.5 m turbulent flow path emitter spacing

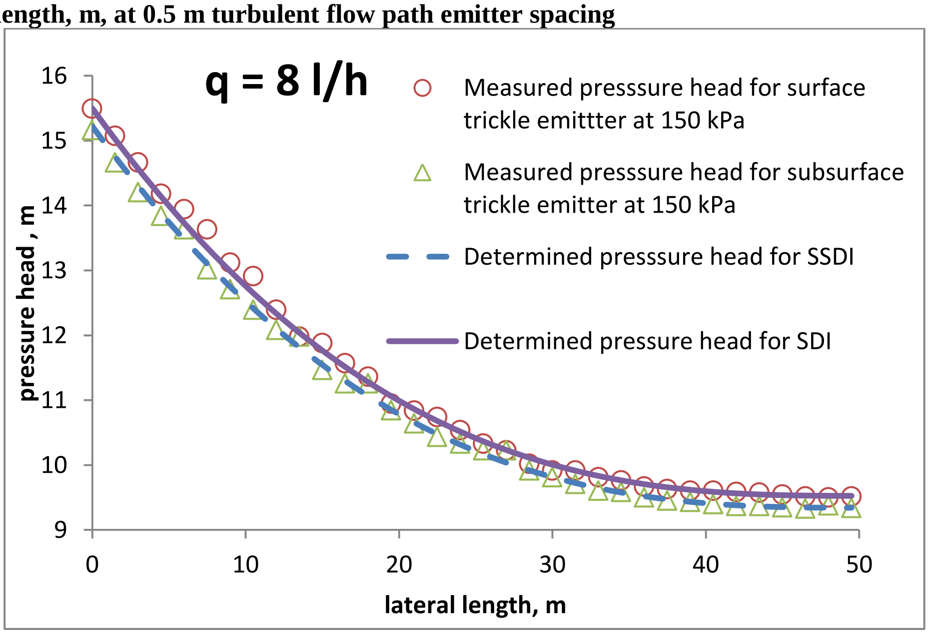

Fig .4.4: the measured and determined pressure head in m vs lateral length, m, at 0.5 m turbulent flow path emitter spacing at inlet pressure of 150 kPa.

Results showed that the higher flow rate was, the lower soil back pressure H_S occurres and larger spherical radius cavity (r_0). Soil back pressure Increased from o.214 to 0.239 m by changing inlet pressure from 100 to 150 kPa .also noticed that $H_S$decreased along lateral , it was 0.13and 0.152 at the end of lateral, respectively.

Flow variation along lateral

Figs 4.6 and 4.7 shows the flow rate versus lateral length for surface and subsurface trickle emitter, at 100 kPa inlet pressure, for 4 and 8 l/h, respectively . The flow rate of emitters was hydraulically determined and smoothly decreased for subsurface trickle emitter than surface trickle emitter at the same experimental conditions of emitter spacing of 0.5m, lateral length of 50 m and inner lateral diameter of 13.6 mm. It is due to high friction losses across the emitter as the increase of soil back pressure around buried emitter outlet. It is also affect on the total coefficient of variation which included the hydraulic and manufacturing variation was lower for subsurface trickle emitter than surface trickle emitter. It was 4.68 % and 4.98 for 4 l/h flow rate emitter ,respectively. And also was 9.12 % and 9.26 % , for 8 l/h flow rate emitter, respectively.

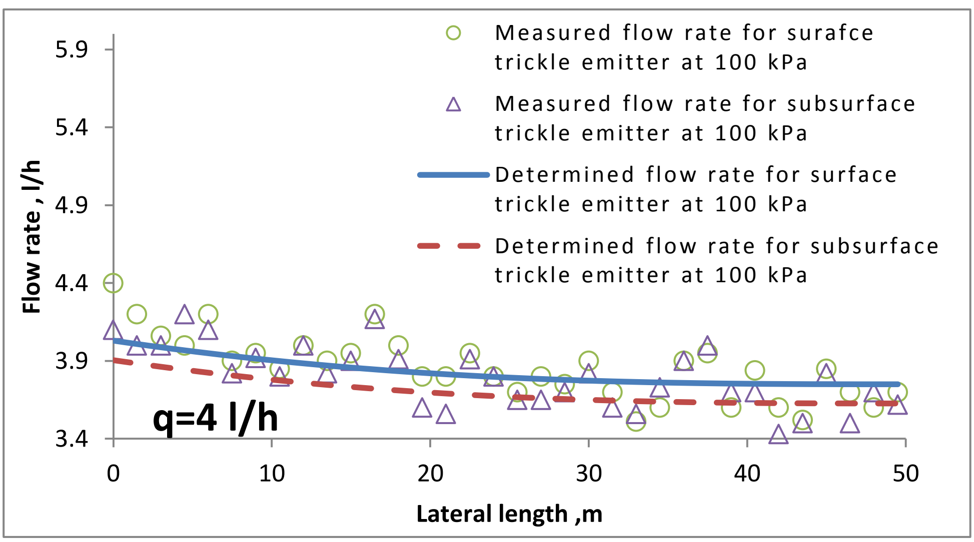

Fig 4.6 :Flow rate versus lateral length at 0.5 m spacing at 100 kPa inlet pressure

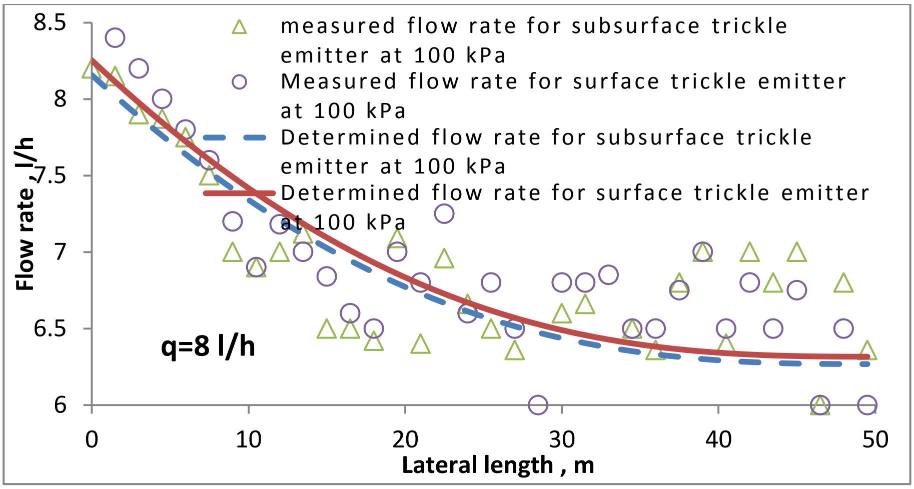

Fig 4.7:Flow rate versus lateral length at 0.5 m spacing at 100kPa inlet pressure.

Field evaluation of trickle irrigation system design:

Data in Tables (1) showed the studied design parameters, such as the friction losses , ΔH ,the average of the friction losses, $\Delta \overline{H}$, coefficient of hydraulic and manufacturing variations , (CV_h and CV_m) ,the minimum flow rate ,q_{min} , emission uniformity (EU) , the calculated statiSDIcal emission uniformity EU_s ,the field statiSDIcal emission uniformity EU_{Sf},the calculated uniformity coefficient ,UC_t , the field uniformity coefficient ,UC_f ,the total coefficient of variation ,CV_t and the field coefficient of variation ,CV_f . The equivalent barb coefficient, Fe was calculated for the lateral about (1.28 m). Meanwhile, the average flow rate, q_{avg} , increased in SDI than SSDI and the minimum flow rate, q_{min} decreased in subsurface emitters than surface emitters, (ΔH)friction head losses increased by increasing emitter flow rate also friction head losses increases for SSDI than SDI because the head pressure at the down steam decreases due to soil back pressure increased.

By comparing surface and subsurface trickle lateral both 50 long and 4 ,and 8 l/h turbulent flow emitters at 100 kPa inlet pressure. The values of emission uniformity (EU) were achieved almost about 94.34 and, 89 %, respectively for SDI and 94.78 and 90.8, respectively for SSDI . And statiSDIcal emission uniformity (EU_S) was 93.7 and 89 %, respectively .for surface trickle lateral and 94.17,and 89.32 %, respectively. For subsurface trickle lateral. Meanwhile, the uniformity coefficient (UC) was about 95.5,and 92.7 % for surface trickle emitters and 95.6 and 92.5 % for subsurface trickle emitters it cleared that the values of irrigation uniformity of subsurface trickle lateral greater than it's values in case of surface trickle lateral.

Table (4.1): Evaluation parameters for φ13.6 mm inner diameter and 0.5m spacing for surface and subsurface trickle lateral at 100kPa.

Evaluation parameter	Surface emitter		Subsurface emitter	
	4 l/h	8 l/h	4 l/h	8 l/h
Δ H(m)	1.291	3.97	1. 42	4.06
$\Delta\bar{H}$ **(m)**	0.981	2.873	1.28	2.981
$\bar{H}$ **(m)**	9. 34	7.45	9.04	7.348
H_{var}%	13.1	39.8	13.3	40
CV_h%	2.23	8.347	2.25	8.32
CV_m%	4.45	4	4.1	3.71
Cv_t%	4.98	9.26	4.68	9.12
q_{avg}**(l/h)**	4.82	6.73	3.76	6.68
q_{min}**(l/h)**	3.748	6.208	3.68	6.162
EU (%)	94.34	94.9	94.78	95.2
EU_S(%)	93.7	89	94.17	89.32
UC_t(%)	96	92.61	96.26	92.72
cv_f(%)	4.98	9.2	4.68	9.1
$EU_s(f)$(%)	94	89.7	94.48	90.2
$UC_F(f)$(%)	96	92.6	96.26	92.72

Also, Table (4.2) shows the evaluation parameters for 4 and 8 l/h emitter flow rates and 0.5 m spacing at 150 kPa inlet pressure in surface and subsurface trickle emitters. In field, emission uniformity, EU_F, achieved values of 93.5 and 89% for 4 and 8 l/h , respectively, using surface trickle emitters and 93.93 and 90 % using 4, and 8 l/h , respectively using subsurface trickle emitters. In addition to the uniformity coefficient values UC_F were 95.9, and 92.5 % for 4, and 8 l/h, respectively using surface trickle emitters and 96.19 and 92.67 for 4, and 8 l/h, respectively using subsurface trickle emitters.

From previous results, it cleared that the uniformity of subsurface trickle lateral greater than surface trickle lateral. Also Tables (4.1) and (4.2) shows hydraulic parameters (ΔH) , ($\Delta \overline{H}$), and ($\overline{H}$) for SDI and SSDI at 100 and 150 kPa, it noticed that friction head losses increased by increasing inlet pressure. Lateral head losses increases for subsurface trickle lateral than surface trickle lateral because the head pressure at the down steam decreases. Total friction losses were highly obtained in subsurface trickle lateral compared with surface trickle lateral with 50 m length and 0.5 m emitter spacing at 100 kPa.

Table (4.2): Evaluation parameters for φ13.6 mm inner diameter and 0.5m spacing for surface and subsurface trickle lateral at 150kPa.

Evaluation parameter	Surface emitter		Subsurface emitter	
	4 l/h	8 l/h	4 l/h	8 l/h
Δ H,(m)	2.293	5.79	2.686	6.092
$\Delta\overline{H}$,(m)	1.95	4.32	2.06	4.46
$\overline{H}$, (m)	13.84	11.17	13.43	11.037
CV_h%	2.255	8.46	2.257	8.462
CV_m%	4.4	4	4.1	3.79
Cv_t%	5.1	9.388	4.81	9.31
$\overline{q}$(l/h)	4.68	8.449	4.59	8.393
q_{min}(l/h)	4.57	7.779	4.488	7.728
EU (%)	94.38	94.84	94.9	95
EU_S(%)	93.4	89.1	93.6	89.8
UC_t(%)	95.7	92.5	95.7	92.65
cv_f(%)	5.1	9.38	4.77	9.3
$EU_s(f)$(%)	93.5	89	93.93	90
$UC_F(f)$(%)	95.9	92.5	96.19	92.67

4. Soil Wetted distribution area:

Fig 4.9 showed that volumetric soil water content under 4 l/h, 1 h operating time of emitter and 0.23 m^3m^{-3} initial soil moisture content were contoured just after irrigation. It was after soil-water redistribution in Fig. 4.18. It noticed that high moisture content at 20 cm from the soil depth at the end of irrigation is 0.53 m^3m^{-3}. It can be seen that downward soil water movement is greater than upward soil water movement. For 4 l/h subsurface trickle source as shown in Fig. 4.9, wetted soil width was 0.347 m and wetted depth was 0.294 m. It reached to 0.435 m^3m^{-3} at 40 cm depth. The volumetric soil moisture content redistribution after 24 h of irrigation for 4 liter/h emitter water flow as shown in Fig. 4.10. It showed that volumetric soil moisture content increased from 0.381 to 0.41 m^3m^{-3} at 50 cm depth from soil surface .

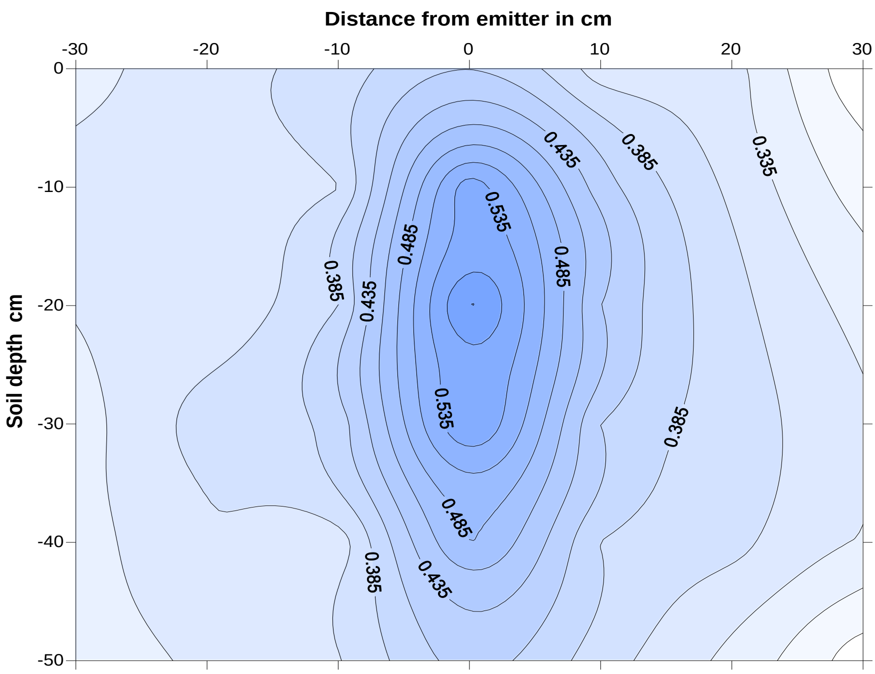

Fig. 4.9 Volumetric soil moisture content just after irrigation for 4 liter/h emitter water flow and 1 h operating time.

Fig 4.11 showed that volumetric soil water content under 8 l/h, 0.5 h operating time of emitter and 0.19 m^3m^{-3} initial soil moisture content was contoured just after irrigation. It was after soil-water redistribution in Fig. 4.20 in clay soil.

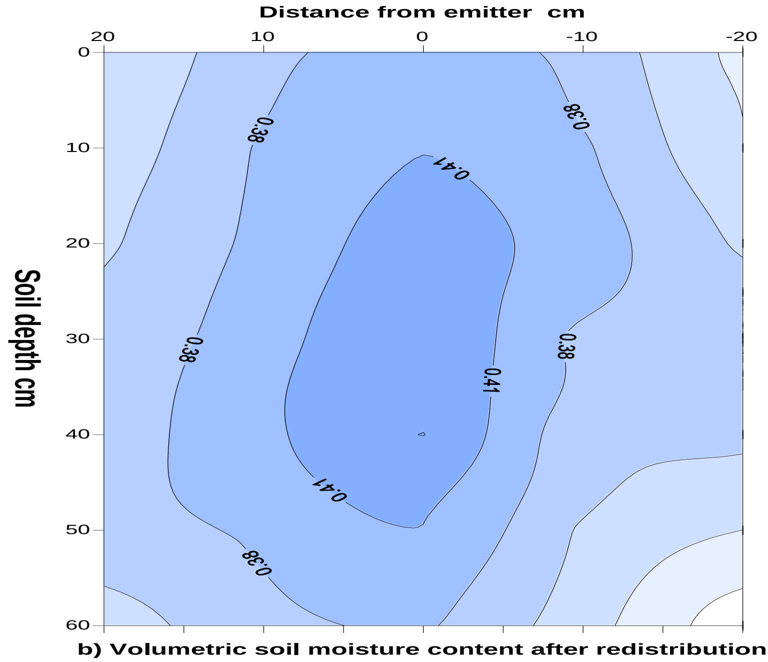

Fig. 4.10 Volumetric soil moisture content redistribution after 24 h of irrigation for 4 liter/h emitter water flow and 1 h operating time.

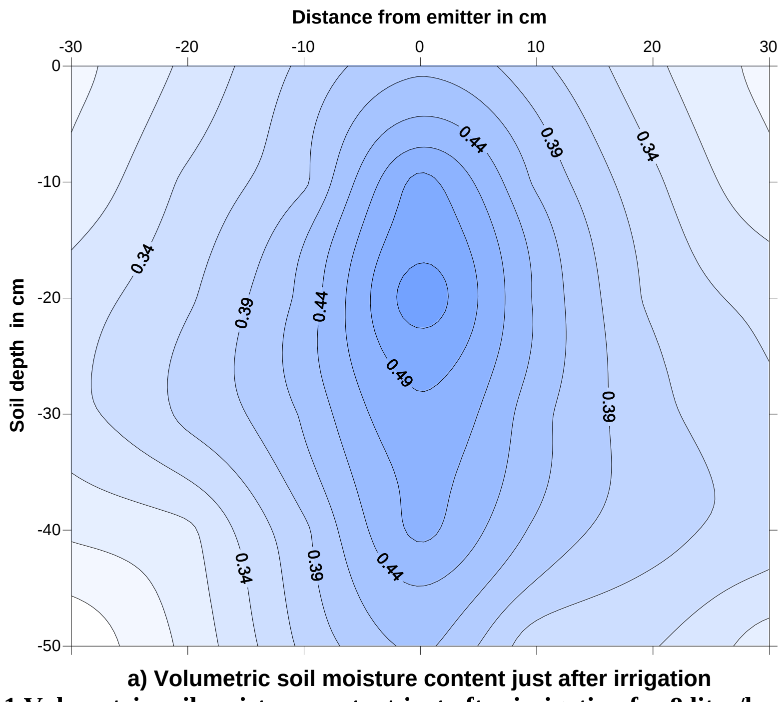

Fig. 4.11 Volumetric soil moisture content just after irrigation for 8 liter/h emitter water flow and 0.5 h operating time.

It noticed that high moisture content at 20 cm from the soil depth at the end of irrigation is 0.54 m^3m^{-3}. It can be seen that horizontal soil water movement is greater than vertical soil water movement. The wetted soil width under 8 l/h subsurface trickle source as shown in Fig. 4.11 was 0.347 m and wetted depth was 0.294 m. Fig. 4.12 showed soil moisture content increased from 0.37 to 0 .40 m^3m^{-3} at 40 cm depth of soil.

CONCLUSION

To evaluate subsurface trickle irrigation system SSDI comparing to surface trickle system SDI based on variable water flow rates of emitter in soil according to soil infiltration rate. Results showed that the friction loss increases as the inlet pressure increases, and the value of the friction head loss for subsurface emitters were higher than that for surface emitters. For buried emitter ,soil back pressure increased by increasing inlet pressure at the same flow rate and decrease for high flow rate emitters due to increase spherical cavity radius.

Moreover, results showed that a highly significant correlation was also achieved between the calculated and measured data.

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الملخص العربي

تقييم نظام الري بالتنقيط التحت سطحي
كعلاقه لمعدل سريان المياه في التربه والنقاط

ا.د/ كمال حسنى عامر[1] ، د/ عبداللطيف عبدالوهاب سمك[1]
و م/ هند ممدوح الجمسي[2]

أجريت هذه الدراسة بمعمل قسم الهندسة الزراعية ومزرعة كلية الزراعة بشبين الكوم جامعه المنوفيه، وتهدف الدراسة الي تقييم نظام الري بالتنقيط التحت سطحي بناءا علي العلاقه بين معدل تصرف النقاط وتسرب التربه للمياه، حيث أن زياده تصرف النقاط عن معدل تسرب المياه بالتربه يؤدي الي ارتجاع في الضغط مما يحدث تغيير في انتظاميه وتوزيع المياه علي طول خط الري بالتنقيط وبناءا علي ذلك لابد الاخذ في الاعتبار مقدار هذه القيمه لدراسه التوزيع الرطوبي بالتربه۰

وقد توصلت الدراسة إلى النتائج التالية :-

١- في حاله الري بالتنقط التحت سطحي يقل تصرف النقاط المدفون تحت عمق ٢٠ سم عن النقاط في حاله الري بالتنقيط السطحي وذلك بسبب تاثير ضغط التربه علي النقاط.

٢- يقل قيمه التصرف والضاغط علي طول خط الري بالتنقيط بزياده كل من التصرف وضاغط التشغيل.

٣-حققت معامل الانتظاميه تحت الظروف الحقليه وتصرفات٤، ٨ لتر لكل ساعه وضغط تشغيل ١٠٠ كيلو باسكال ٩٦% و ٩٢,٥% علي الترتيب في حاله النقاطات فوق سطح التربه وكانت ٩٦,٢٦%و ٩٢,٧٢% في حاله النقاطات المدفونه علي الترتيب.

١- قسم الهندسة الزراعية- كليه الزراعة- جامعه المنوفية.
٢ – طالب دراسات عليا- قسم الهندسة الزراعية- كليه الزراعة- جامعه المنوفيه.