ISSN 1023-1072

Pak. J. Agri., Agril. Engg., Vet. Sci., 2010, 26 (1): 1-15

WATER DISTRIBUTION PATTERN, DISCHARGE UNIFORMITY AND APPLICATION EFFICIENCY OF LOCALLY MADE EMITTERS USED IN ATRICKLE SUBUNIT

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ABSTRACT

The experiments were conducted at the experimental site near the Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam. A trickle irrigation system was installed in a 25 m long and 14.5 m wide plot. The hydraulic performance of emitters was based on water flow, uniformity coefficient, application efficiency, and water losses through deep percolation.

The flow volumes along the lateral length were fairly consistent and the variation was diminutive under both types suggesting uniform distribution of water. The system achieved rationally high D_U, C_U, E_a. The C_U values for randomly selected laterals with smooth emitters averaged to 81.7% and spiral emitters averaged to 87.4%. The D_U values averaged to 75.4% for smooth and averaged to 81% for spiral emitters. The overall $E_a$achieved were 82.7% and 89.4% for smooth and spiral emitters, respectively. The higher values of C_U, D_U, and E_a with spiral emitters as compared to smooth emitters suggest that they performed better and could be preferred to achieve uniform water distribution.

Water movement below the emission point was more pronounced in the vertical. In most cases, the wetting front followed an axially symmetric pattern. The water laterally moved to about 0.35 m while it moved to a 0.56 m depth. The root zone for many short rooted crops is located in this range hence the percolation losses would practically be negligible under such situations.

Keywords: Design parameters, emitters, percolation, trickle irrigation, uniformity coefficient.

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INTRODUCTION

In the developed countries like USA, UK, Australia, Turkey etc., several modern irrigation methods such as sprinkler, trickle, bubbler, pitcher, and sub irrigation are now in practice, which have high irrigation application efficiencies thus save water and produce high yields. Among them, trickle irrigation provides prescribed amount of water to a plant, lowers soil moisture tension, improves fertilization efficiency, reduces weed growth, insures uniform water distribution, and increases water application efficiency. Trickle irrigation, also known as drip irrigation, is among the latest micro irrigation methods and is quite popular in areas with water scarcity and coarse textured soils having high infiltration rate. But due to high installation cost it has yet to find its way in the countries like Pakistan. However, this method stands a bright future in the water scare areas such as Thar Desert, Kohistan, and tail reaches of the irrigation network of the country. The method consists of water source pumping unit, mixing chamber, mainline, sub-main, laterals and emitters. The main line delivers water to the sub-mains and they carry water into the laterals. Irrigation is accomplished by emitters or drippers made up of small diameter polyethylene tubes installed in the lateral lines at selected spacing near the plants. The emitters deliver water at a desired rate near the plants. Though the system slowly and partially wets the soil near the plant root zone, but, it is practically difficult to apply the equal amount of water to all plants within a field unit. Therefore, in most cases, even a well designed system gives poor uniformity as a consequence the yields are pretentious (Bhatnagar and Srivastava, 2003). Since, frequent application near the plants is ensured (Youngs *et al.*, 1999) hence; the conveyance and the other conventional losses such as deep percolation, runoff and soil water evaporation are minimal as water is conveyed through a network of pipes.

A best and desirable feature of trickle irrigation is that the uniform distribution of water is possible, which is one of the most important parameters in design, management, and adoption of this system. Ideally, a well designed system applies nearly equal amount of water to each plant, meets its water requirements, and is economically feasible. But, due to manufacturing variations, pressure differences, emitter plugging, aging, frictional head losses, irrigation water temperature changes, and emitter sensitivity results in flow rate variations even between two identical emitters (Mizyed and Kruse, 2008). Uniform distribution of water application means that all the plants receive an equal amount of water. In a poorly designed system, one cannot get uniform distribution of water, thus he would either under irrigate or over irrigate his field. Under both cases, plants will either suffer the dry or the wet stresses. Through a properly designed trickle system, uniform distribution of water is ensured which results in better yields. The uniform distribution is reflected by the values of uniformity coefficient (C_U) which in turn suggests the variability in the amount of water received by a plant in a subunit system. A system with uniformity co-efficient of at least 85% is considered appropriate for standard design requirements. Such a high uniformity coefficient is only possible through properly designed emitters (Al-Amound, 1995) that provide steady discharge to all emission points. However, the distribution uniformity (D_U) and the uniformity coefficient are function of hydraulic head and slope of lateral and sub-main lines. The coefficient of uniformity generally follows a linear relationship either with head or slope. The C_U and D_U decrease substantially at sub-main slopes steeper than 30 % (Ella et al., 2009).

Water application efficiency (E_a) is another important parameter for system selection, design, and irrigation management. The ability of an irrigation system to apply water equally and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the farming enterprise. With a well designed trickle system, it is possible to attain an efficiency >90% (Solomon, 1983). The system efficiency is associated with application uniformity and water losses that can be evaluated by direct measurements of emitter flow rates. If, the water losses are high or distribution uniformity is poor, it would result in low application efficiency. However, the distribution of water as measured in the field does not really represent the distribution of moisture in the soil. As a matter of fact, the true soil moisture distribution is the result of some side movement of water in the soil away from the emission point. Therefore, it is possible to irrigate with a much lower uniformity coefficient under many conditions without suffering from yield reductions. The uniformity co-efficient might be affected by the length of lateral itself. Longer laterals result pressure drop in the line and cause poor uniformity towards the tail ends. Distribution of moisture under trickle irrigation depends upon the uniformity of application, one of the critical factors for the designer and the purchaser. The initial cost of the system, operating cost, and crop yield response to irrigation, all are related to the uniformity of water application. However, proper design guidelines are prerequisite for a better system performance. As soon as a system has been installed in the field, the evaluation must be carried and periodically repeated with time if the best performance is desired (Keller and Blisner, 1990). This study was aimed to evaluate the performance of locally made emitters used in a trickle subunit. The water flow, distribution pattern, uniformity coefficient, field application efficiency, and percolation losses have been set as the performance indicators.

MATERIALS AND METHODS

The experiments were conducted at the experimental site near the Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam. The site is located at an altitude of about 26 m above sea level with a latitude of 25^0 25' 28" N, 68^0 32' 25" E. The soil at the experimental site is characterized as a sandy loam. A 25 m long and 14.5 m wide plot was utilized to install a trickle irrigation system. The experimental layout is shown in Figure-1. The plot was equally divided into three subunits and 18 laterals each with 8 m length were laid on the ground. The laterals were made from 12-mm diameter polyethylene rubber tubes. They were connected to sub-main lines having 2.54 cm internal diameter using aluminum nipples. The sub-main was connected to a 45 m long mainline with 5 cm internal diameter. At the head of each sub-main, a control valve was installed to regulate the flow. Two water meters were also installed on the sub mains to measure the gross volume of water applied to subunits served by 54 laterals. The water supply was taken from a low pressure overhead tank (2 m x 2 m x 2 m) placed at a 200 cm height above the ground level. The orifices were made in the lateral pipes at 30 cm spacing and emitter tubes with 3.2 mm diameter were inserted in them. Two emitter types, one with smooth tube and the other locally made spiral type were used in this study. The smooth emitters were made by just cutting a 3.2 mm diameter tube to desired lengths. While, the spiral pipes were locally fabricated from the same 3.2 mm diameter polyethylene tubes. The tubes were wrapped around an iron bar and dipped into a bucket of boiling water. They were left for few minutes and taken out to cool down and finally cut into small spiral emitter. The emitters were fixed in the lateral lines and checked in the laboratory throughout the lateral length. For measurement purposes, the water was allowed to run through them for 10 minutes and collected in small catch canes placed under each emitter. Both emitter types were tested for different flow rates under different pressure heads. The discharge of these emitters varied from 1.3 to 3 L/hour.

Hydraulic evaluation of trickle system was based on a method defined by the ASAE (1999). Three emitters on a lateral were selected at the head, mid-point and tail-end and discharges were measured on them. The discharges were taken at selected emitters in two ways. In the first case, 12 laterals, for each emitter type, were randomly identified. Along each lateral, flow volumes were collected at three points, corresponding approximately to the head, mid-point and tail-end of each lateral (36 emitters in all). The pressure flow measurements along a lateral line are shown in Figure 2. For each measurement, a small area in the bed was excavated, anda catch-can placed under the trickling emitter (Figure. 2).

The irrigation system was then pressurized and the volume from each of the 36 emitters was measured over a period of two hours. In order to collect a minimal volume of 100 ml, a 10 minutes collection time was fixed. The collected volume in a given time was then measured using a graduated cylinder. In the second case, three laterals for each type were randomly selected in a sub-unit and flow volumes were taken on all 162 emitters. The procedure was repeated using different flow rates.

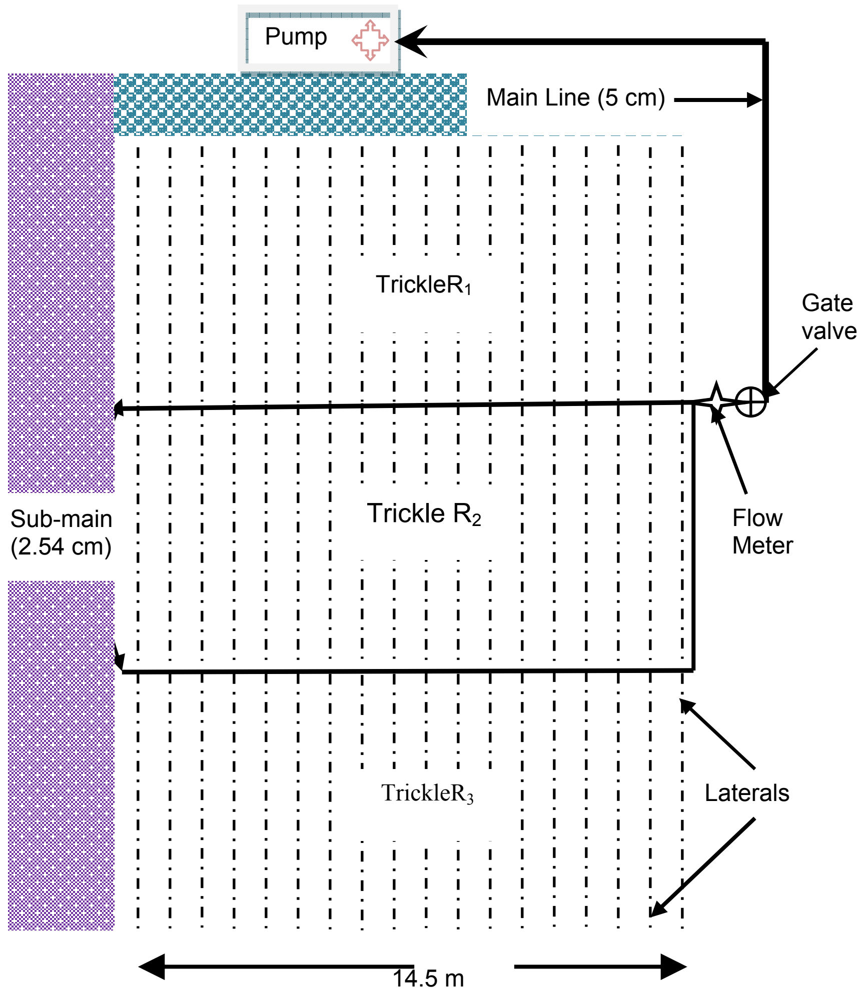

Figure 1. Layout of the experimental plot

Uniformity coefficient and distribution uniformity

Trickle irrigation system is designed to apply precise amount of water near the plant with a certain degree of uniformity. The uniformity describes how evenly an irrigation system distributes water over a field. It is regarded as one of the important features for selection, design, and management of the irrigation system. Uniformity also plays a similar role in decisions in other types of irrigation systems like sprinkler, subsurface and Pitcher etc. In surface irrigation design, the factors like flow rate and furrow length are set so that non-uniformity in the water application will not be excessive. There are many measures of irrigation uniformity in use. Also numerous design formulas are used to calculate uniformity of a system. One of the widely used is Christiansen uniformity coefficient (Mosh, 2006):

$$C_u = 100 - \left(80 \, x \, \frac{S_d}{V_{avg}} \right) \quad (1)$$

where,

C_u=Uniformity coefficient (%),
S_d=Standard deviation of observations,
V_{avg} = Average volume collected.

Figure2. Water pressure and emitter discharge along a lateral line

The other measure is distribution uniformity (D_U) proposed in one form or another by various researchers. The D_U measures the consistency of water application across a field during irrigation, expressed as a %age. D_U of less than 70% is considered poor, between 70 - 90% is good, whereas D_U greater than 90% is excellent. In short, poor D_U means that either too much water is applied, costing unnecessary expense, or too little water is applied, causing stress to crops. Its most common measure is related to lower quarter D_U, which is measure of the ratio of the average low quarter volume of water caught to the average volume of total samples. It can be calculated using the following relationship (Mosh, 2006):

$$D_U = 100 \left(\frac{V_{LQ}}{V_{avg}} \right) \quad (2)$$

where,

D_U= Distribution uniformity (%),

V_{LQ}= Average of the lowest ¼ volume of water collected,
V_{avg} = Average volume collected.

Both these uniformity measures are (approximately) related by the equations:

$$U_C = (0.63)(D_U) + 37 \quad (3)$$

$$D_U = (1.59)(U_C) - 59 \quad (4)$$

Soil water distribution pattern

The water movement and distribution pattern differs under trickle source than from the conventional irrigation methods. Under trickle irrigation, besides higher frequency of application, water is applied at discrete points on the surface of the soil rather than over the entire area, thus soil is wetted in a bulb like axially symmetric pattern rather than in one dimensional fashion. However, the wetting front and moisture distribution depends upon the discharge rate and application time. With low flow rate, water moves in vertical direction thatresults in higher moisture adjacent to the emission point. The moisture distribution pattern in the soil profile was determined by taking soil samples at different depths on the both sides of the emission pointsbefore and after 24 hours of application. The wetting front in horizontal (x) and vertical (y) directions was measured to determine the moisture distribution pattern in the soil profile. Samples were collected at 0-15, 15-30 and 30-45 cm depths for 0, 15, 30, and 45cm distances on both sides of the emission point. The undisturbed soil samples were collected using a core sampler and placed in an oven for 24 hours at 104 ^{0}C. The oven dried samples were weighed and their volumes determined, finally the moisture content and average bulk density of soil samples was determined.

The irrigation application efficiency (E_a) and deep percolation (D_p) were evaluated using methodology described by Anyoji and Wu (1994) and subsequently followed by Soccol *et al.* (2002) using following equations:

$$E_a = \left[\frac{V_s}{V_d}\right]100 \quad (5)$$

$$D_p = \left[\frac{V_p}{V_d}\right]100 \quad (6)$$

where,

V_s = volume of water stored in the root zone after irrigation,
V_d =volume of water delivered to the subunit,
V_p= volume of water percolated below the root zone.

RESULTS AND DISCUSSION

The flow pattern through smooth emitters along a lateral line is illustrated in Figure 3a which portrays that the volume along the lateral length ranged between 0.11L and 0.24 L and yielded an average value of 0.17 L and the standard deviation turns to be 0.038 L. The emitters located at the middle section of a lateral showed slightly higher volumes as compared to those located at the tail-end. This is anticipated because the pressure reduces towards the end of lateral due to head loss. Figure 3b shows flow volumes through locally made spiral emitters. The flow volumes along the lateral length are fairly consistent and the variation is smallas compared to smooth emitters. Volumes fluctuated between 0.11 Land 0.22 L and turned an average value of 0.16 L and the standard deviation was 0.034 L. The flow variation along a lateral pipe might be due to head losses as well as the length and orientation of emitter in the inner side of polyethylene pipe. A slight elongation of emitter tube inside the lateral pipe causes resistance to flow hence fluctuations along the line could be anticipated.

The flow through emitters was used to calculate C_U and results are given in Table1. The smooth emitters showed lower C_U than the spiral ones. The C_U of randomly selected laterals with smooth emitters ranged between 79.1% and 84.4% with an average value of 81.7%. However, it ranged between 85.9 and 89% with average value of 87.4% with spiral emitters. Similarly, the distribution uniformity ranged between 71.2% and 81.2% and averaged to 75.4% for the smooth emitters, while it ranged between 76.9% and 85% and averaged to 81% for the spiral emitters.The findings of this study were quite close to those reported by Bağdatlı and Acar (2009), the uniformity coefficient varied between 79.2% and 94.5% in their study.

The system achieved an overall field application efficiency of 82.7% with smooth emitters compared to 89.4% with spiral emitters (Table1). Almost similar results were reported in previous studies by Solomon (1983) and Mirjat *et al.* (1999). In a study,Soccol et al. (2002) suggested that the application efficiency could even be increased over 90% by adopting new management procedures. In a study Safi *et al.*, (2007) observed 96.9% and 91.8% uniformity coefficient values of the unused and used tapes, respectively. The results on uniformity coefficient, distribution uniformity and application efficiency all suggest that the spiral emitters were performing well thus could be preferred over smooth emitters. However, the variation through smooth emitters could also be reduced by adjusting the length of an individual emitter. Care should be taken during fixing the emitters in the lateral line otherwise it might resist the flow inside it.

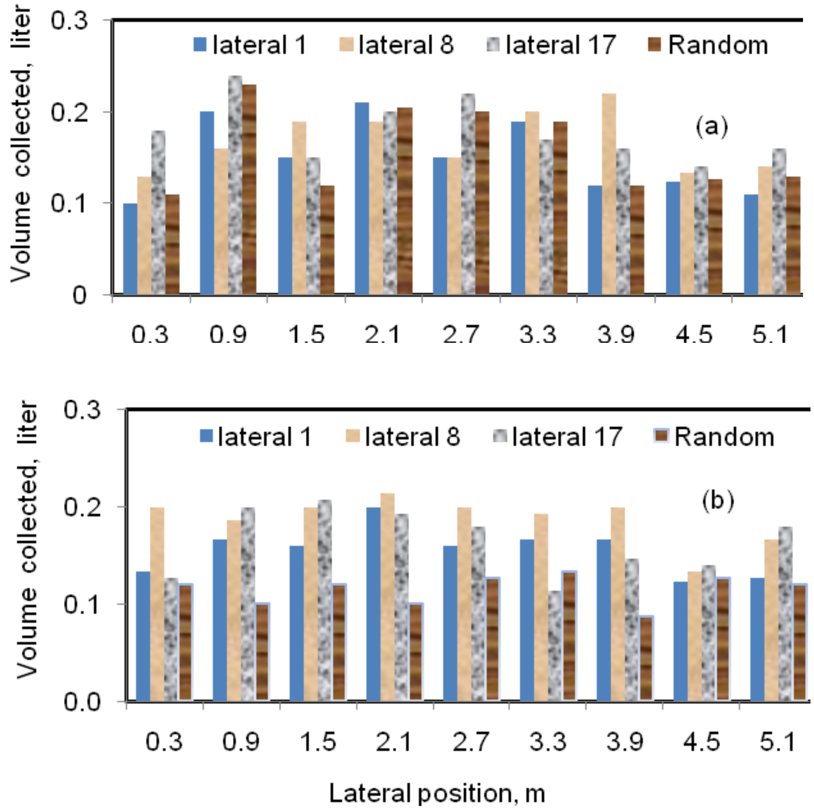

Figure 3. Volumes collected under (a) smooth (b)spiral emitters from randomly selected laterals.

The wetting periphery and moisture distribution pattern at various locations from trickling points was determined by removing the wetted soil beneath the emitters and the actual shape and the diameter of wetted perimeter with depth was measured. Water movement below the emission point was more pronounced in vertical direction rather than in horizontal direction (Figure 4).

As expected, the wetted perimeter followed an axially symmetric bulb like pattern. It was observed that the water front moved by about 0.38 m in the horizontal direction while, it covered a maximum depth of about 0.56 m in the vertical direction. The deeper water movement suggests more water available to the roots, which is necessary for plant growth. A horizontal movement of water will generally result in evaporation losses. Almost similar results have been reported in a numerical analysis of the different experiments by Elmaloglou and Diamantopoulos (2009). They concluded that for a similar irrigation depth and identical dripper spacing, the vertical component of the wetted zone is greater for a smaller discharge than for a higher discharge. They also noticed that there was a faster overlapping of the wetted bulbs in the fine-grained soil and that deep percolation seems to be lower in the fine-grained soil than in the coarse-grained. Deep percolation increased as the applied irrigation depth was increased. The percolation depends upon soil physical properties (soil texture, permeability and porosity), irrigation operational time, and flow rate through the emitter.

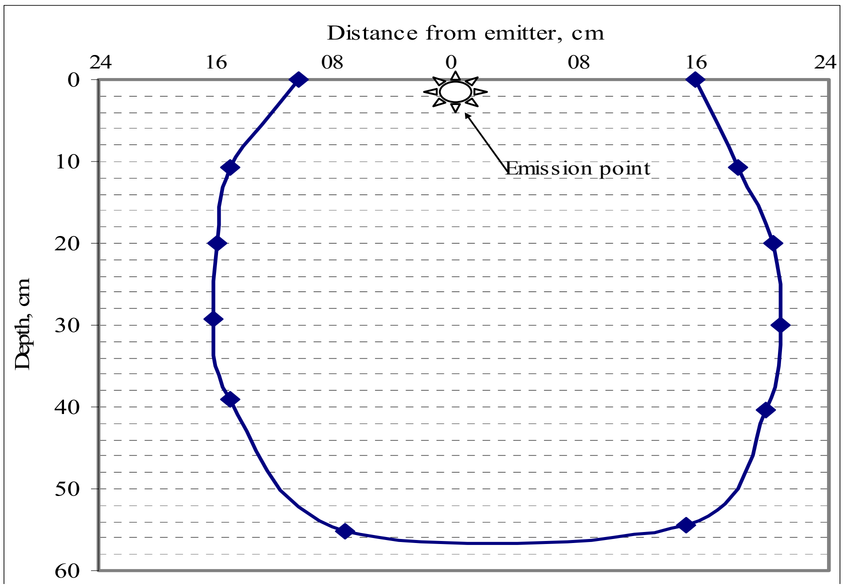

Figure 4. Water distribution pattern beneath an emitter

Hydrus Simulations

Version 1.1 of the HYDRUS 2D/3D software package (Šimůnek et al., 2007) was used to simulate soil moisture distribution pattern under a trickling emitter. Model simulates variably saturated water flow solving the mixed form of the Richards equation. The details on the governing equations and their applications are given in the literature (Rassam et al., 2003; Šimůnek et al., 1999, and Šimůnek et al., 2006). Figure 5 depicts simulation results for the flow rates of 2, 4, 6, and 8 L/h through an emitter. Using a kriging interpolation algorithm, the contour plots were drawn.

The wetting front for different moisture contents are shown by the contour plots. With higher emitter flow rates, the distribution is wider and deeper in the soil profile. The simulation results matched the field observed data; a good agreement between the experimentaland simulated results suggested that model could also be used for different soil textures and flow rates.

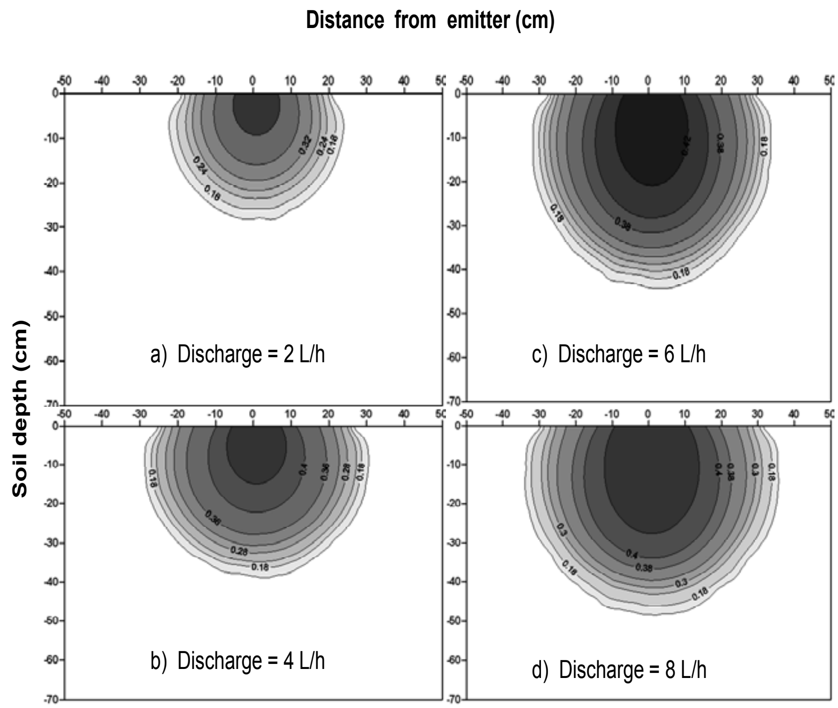

Figure 5. Model simulated moisture pattern under a trickle emitter for different flow rates

Percolation losses

The deep percolation is defined as the downward movement of water below the root zone. In this study, the vertical movement of water up to 0.56 m was recorded. Most of the crops grown in Pakistan have roots within 0.3 and 0.5 m depths hence deep percolation losses would practically benegligible for such crops. However, deep percolation could also be controlled through proper management and application rates of emitters.

Table 1. Coefficient of uniformity, distribution uniformity, and application efficiency for smooth and spiral emitters.

Lateral position	Uniformity coefficient (%)		Distribution uniformity %		Application efficiency %	
	Smooth	Spiral	Smooth	Spiral	Smooth	Spiral
Top-end	80.9	89.0	71.2	81.5	86.2	90.5
Mid-point	82.2	85.9	71.3	76.9	83.4	91.4
Tail-end	84.4	88.3	81.2	80.5	79.8	86.3
Random	79.1	86.5	77.9	85.0	81.4	89.4
Average	81.7	87.4	75.4	81.0	82.7	89.4
ST Dev.	0.038	0.034	--	--	--	--

This study focused only on trickle design parameters such as water distribution uniformity and application efficiency hence crops were not grown thus root depth of a particular crop could not be used to determine thepercolation losses here.

Under trickle irrigation method, only 25% to 30% of the total surface was wetted while about 70% to 75% remained dry as compared to any other conventional flooding method. Based on the measured pattern of wetted surface, over 70% to 75% of the water could be saved through this method as compared to traditional flooding. In a study previously conducted by Mirjat et al. (1999) trickle irrigation saved over 63% of water as compared to furrow irrigation. In another study Memon et al. (1996) observed about 49% saving in water under trickle irrigated mango orchard as compared to traditional basin irrigation methods.

DISCUSSION

The trickle irrigation seems to have better future in the area with water scarcity. Since water is applied directly to individual plants instead of irrigating the entire area thus saves water which is otherwise lost by the use of traditional surface irrigation methods. The method is more suitable for production of orchards and high value vegetables. Results of this and previous studies suggest that over 50-75% water could be saved. Water can be provided to a plant with low pressure and at a high frequency. A major economic factor of this system is yield increase per unit water; fertilizer and pesticide application are other added benefits. The system is cost intensive hence the farmers are reluctant to use it. However, progressive farmers have adopted this system in some water scare areas and it has potential to be adopted in following areas of the country:

- Most of the arid zone areas including Kohistan, Nangar Parker, Thar, Kharan, Quetta Valley, Thal, Cholistan, deserts.

- Fringe areas where water is either saline or extremely scarce including inland basins having very thin layer of fresh groundwater in Sindh and Southern Punjab.
- Areas within Indus basin with high elevations that require huge investments for surface irrigation.
- Undulated riverbanks with steep slopes in NWFP and Barani lands on steep slopes with very coarse textures in the Northern Areas.
- Urban agricultural areas where high values vegetable, fruits, cut-flowers and nursery plants could be grown with premium water.

CONCLUSION

An experiment was conducted near the Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam to determine the performance of trickle subunit in terms of distribution uniformity, water application efficiency, and deep percolation through a trickling emitter.

Results of the study revealed that the trickle irrigation achieved high uniformity coefficient and distribution uniformity. The C_U of randomly selected laterals with smooth emitters ranged between 79.1 and 84.4% with an average value of 81.7%. However, it ranged between 85.9 and 89% with average value of 87.4% with spiral emitters. Similarly, the distribution uniformity ranged between 71.2 and 81.2% and averaged to 75.4% for the smooth emitters, while it ranged between 76.9 and 85% and averaged to 81% for the spiral emitters.The system achieved an overall field application efficiency of 82.7% with smooth emitters compared to 89.4% with spiral emitters. Further, the spiral emitters showed higher uniformity coefficient, and application efficiency as compared to smooth ones hence could be preferred with great degree of confidence to achieve uniform water distribution.

Water distribution pattern under trickle emitter is different than other traditional methods and modern methods. Soil is wetted in a bulb like axially symmetric pattern rather than in one dimensional fashion in this method. The wetted perimeter and moisture distribution is a function of emitter discharge and application time. Water movement below the emission point was more pronounced in vertical direction rather than in horizontal direction. The water front moved by about 0.38 m in the horizontal direction while, it covered a maximum depth of about 0.56 m in the vertical direction. Under this situation, deep percolation losses would be practically negligible for the crops having roots within this range. The operational time under this system is at the liberty of farmer hence it can be decreased or increased if water movement at any stage departs beyond root zone to avoid deep percolationFurther, about 30% of the total surface area was wetted while 70% area remained dry suggesting a huge saving of water otherwise required under traditional flooding methods.

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(Received 20 January 2010; Revised 22 June, 2010)