Net Journal of Agricultural Science
Vol. 3(1), pp. 14-22, January 2015
ISSN: 2315-9766
Full Length Research Paper

Analysis of application uniformity and pressure variation of microtube emitter of trickle irrigation system

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Accepted 27 October, 2014

ABSTRACT

Micro-irrigation systems can apply irrigation water quite efficiently, but only if they are operated and maintained properly. Irrigation using drippers is often considered the most efficient method in terms of both water use and labour, but, because it is more complex in design and management, a drip system must be designed, installed, managed and maintained correctly. Keeping in view this fact trickle irrigation system using locally produced materials was designed and installed on an area of 1.2 acres for citrus orchard at the field station of water resources research institute, NARC Islamabad, Pakistan. The cost of this indigenized trickle irrigation system was Rs.125880 for the area which is about Rs. 104900/acre for orchards. The drip system installed on citrus orchards was evaluated for its hydraulic performance. Results of the study revealed that the discharge of the micro tube-emitter varied from 15.67 to 8.67 L/h under the pressure head of 10.56 to 7 m when the drip irrigation system was operated at 10.54 m pressure head. The water application uniformity was found to be above 80% which describes that the drip irrigation was designed on the basis of proper scaling and dimensions.

Keywords*:* Water scarcity, discharge, pressure head, uniformity, trickle irrigation, performance.

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INTRODUCTION

Shortage of canal water is one of the major limitations in the Indus Basin Irrigation System (IBIS) for increasing agricultural productivity. There is an ever-increasing competition for water among agriculture, industry and domestic users. According to the 1999 report (PWP, 1999) by Pakistan Water Partnership (PWP), domestic and industrial water uses will increase in 2025 by 15% of the available water resources as against the present use of 3%. Rising population and industry will create dual burden on agriculture. First, a large population will need more food and fiber. Second, agriculture will have a less reliable supply of irrigation water to meet these rising demands. One of the options for future water needs is to use available water resources more efficiently and effectively. Trickle irrigation systems are generally permanent and have low labour requirements. The low rate of water application reduces deep percolation losses. The systems generally have lower energy requirements than sprinkler systems because of reduced water use and lower operating pressure requirement (James, 1993). Mass et al. (1982) found considerable bums on tomatoes and potatoes, especially on older leaves with sprinkler irrigation when using low quality (saline) waters.

The problem of leaf damage with sprinkler irrigation may be completely avoided by the use of trickle irrigation system. Meiri et al. (1982) presented that the threshold salinity was slightly lower with sprinklers but the rate of yield decline was greater (8% per dSm^{-1}) than with the trickle irrigation (4% per dSm^{-1}). Another advantage of trickle irrigation lies in the pattern of salt distribution under the emitters and maintenance of constantly high matric potentials. Bernstein and Francois (1973) found a yield difference of 59% for bell pepper between trickle and sprinkler irrigation when the salinity of irrigation water was 4.4 dSm^{-1} but no difference when good water was used.

Trickle irrigation system provides the best possible conditions of total soil water potential for low quality of irrigation water. It is the best method for supplying saline water to crops. It avoids leaf injury and at the same time provides optimum soil water conditions (Shalhevet, 1984). However, there are several problems associated with trickle irrigation. The most severe problem is the clogging of emitters by particulate and biological materials and this can cause poor application uniformity (James, 1993). Flushing the system after each cropping season can solve this problem. A salt accumulation problem can occur when only a portion of the root zone is wet and saline waters are being used without proper management. High water application uniformity is one of the significant advantages that a properly designed trickle irrigation system has over other methods of irrigation. Variation in application uniformity of trickle irrigation system may be due to several factors. One of these factors is the manufacturing variation in emitters or variation in emitter construction due to tolerances of parts, assemblies, etc. Another factor of variation in pressure within a system is due to pipe friction or elevation changes (Pitts et al., 1986).

Trickle irrigation system offers considerable potential for saving irrigation water while maintaining or even increasing yield in drought conditions. Now the appropriate technology, skills and services are available which will be used in future for large-scale adoption of trickle irrigation in the country. Trickle irrigation systems are high in initial investment but at the same time these are labour, water and fertilizer efficient while no investment is involved in land levelling (WRRI, 2001). Although trickle irrigation systems have reached a level that farmers are adopting them yet their performances under field condition has to be tested and standardized.

In view of all the above facts, the study was thus designed to evaluate the performance of the indigenized trickle irrigation system in the available agro-ecological zone of NARC Islamabad, Pakistan.

Objective

The objective of this research work is to determining the variations in discharge, pressure of emitters and application uniformity of the trickle irrigation system.

MATERIALS AND METHODS

Location of the study area

The study was undertaken at CAEWRI field station NARC Islamabad, Pakistan. Mean monthly maximum temperature varies from 20.2 to 41.7°C and the mean monthly minimum from 3.6 to 15°C. Mean annual rainfall in the area is about 1150 mm.

Layout design and cost of the system

The trickle irrigation was designed and installed on a ½ ha (1.2 acre) farm of citrus orchard (Figure 1). The system consists of two manifolds with 6 laterals for each manifold. The diameter of the main, manifold and laterals are 50 and 14 mm, respectively. Micro-tube was used as an emitter of 2 mm diameter and single emitter per plant was installed with a discharge capacity of 20 lph. Length of the manifold and lateral was 58 and 75 m, respectively. The row to row and plant to plant distance of the orchards was 6 m each. There are 144 citrus trees, and on each trees a single micro-tube is installed with a discharge of 20 lph. The discharge and pressure of the system were 0.8 lps and 10 m, respectively. An electric motor of 2 hp had been used as a prime mover. The detail of the design of the trickle system is presented in Table 1.

Trickle irrigation system cost

The cost of this indigenized trickle irrigation system was Rs.125,880 for the area which includes material cost of Rs.115,880 and the installation cost of Rs. 10000 (Table 2). The cost of pumping system and prime mover was 17% of the total cost. The cost of manifold was 35% of the total cost. The cost of laterals and emitter in both blocks was similar. The cost per acre of the system was Rs. 115,880 that is affordable by the farmers. The running cost of the system is Rs 500/month for three hour daily operation. The annual maintenance cost of the electric prime mover varies from 1.5 to 2.5% of the initial cost for trickle emitters (James, 1993). As reported by Akbar et al. (2001) the capital and operating costs are more for sprinkler irrigation system than surface irrigation but more financial benefits could be obtained from sprinkler irrigation system in term of water saving and increased yield, the same may be true for trickle irrigation systems.

Measurement of pressure, discharge and application uniformity

Hydraulic estimation of drip irrigation system was based on a method defined by the ASAE (1999). Emitters at the head, mid-point and tail-end on each lateral were selected and pressures and discharges were measured on them accordingly. The discharges were taken at selected emitters. Along each lateral, flow volumes were collected at selected points, corresponding approximately to the head, mid-point and tail-end of each lateral. The irrigation system was then pressurized and water bottles for each selected emitter were placed in such a way that the water drops from emitters could be collected in these bottles simultaneously and the filling time of these bottles was recorded accordingly with the help of stop watch. Three times the experiment was repeated in order to have accuracy and avoid any human error. Finally, on the basis of results obtained AutoCAD used to generate drip layout and statistical analysis was done accordingly. The discharge and pressure of emitters can be described by the following equation (Keller and Karrneli, 1975):

$$Q = kHx \quad (1)$$

Where;
Q = Emitter flowrate (discharge), L/h
K = Discharge coefficient, which is a constant of proportionality that characterizes each emitter
H = Working pressure head at the emitter, and
X = emitter discharge exponent that characterizes the flow regime.

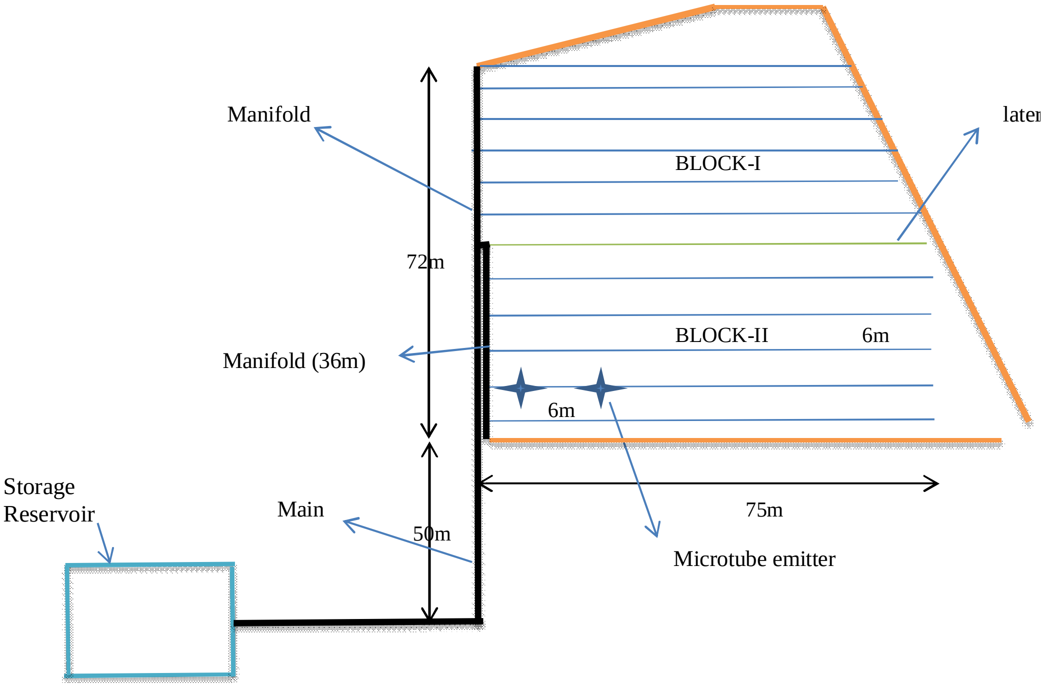

Figure 1. Layout of the newly designed drip/trickle irrigation system.

Table 1. Detail of design parameters of trickle irrigation system.

General information	
Area (acres)	1.2
Plant spacing (m*m)	6
Number of plants	144
Design Peak water requirements (liters/day/plant)	72
Discharge of emitter (lph)	20
Number of emitter per plant	1
Peak operating time (hour)	3.58
Design	
Length of main line	50
Length of manifold	68
Number of plants	144
Discharge of manifold (lps)	0.80
Manifold diameter (mm)	50
Friction head loss (m)	10
Lateral length (m)	75
Discharge of lateral (lps)	0.07
Number of plants per lateral	12
Diameter of lateral (mm)	14
Frictional head loss (m)	1.5
Design of pumping system	
Suction head (m)	2.20
Frictional head loss (m)	
Manifold	10
Lateral	1.5
Connections/bends	5

Table 1. Continues.

Head loss due to slope	3.5
Total frictional head loss (m)	20
Total head loss (m)	22.20
Working head (m)	12
Total head required (m)	34.20
Efficiency of the prime mover (%)	30
Power requirement (hp)	2

Table 2. Cost of trickle irrigation system.

S. no	Description	Unit	Quantity	Rate/unit	Total cost	Total cost (%)
1	PVC PIPE 2 inch	m	160	278	44480	35.34
2	Pressure gauge	No	1	1200	1200	0.95
3	LDPE pipe (12 mm)	m	900	24	21600	17.16
4	GTO Connector, 12 mm	No	100	25	2500	1.99
5	Grooves, 12 mm	no	100	15	1500	1.19
6	PVC Elbow, 2 in	No	10	170	1700	1.35
7	PVC Socket, 2 in	No	20	150	3000	2.38
8	Motor pump, 2 hp	No	1	22000	22000	17.48
9	Gi fittings	No	1	20000	20000	15.89
10	Solvent, 1 L	No	1	1300	1300	1.03
11	Micro tubes, 2 mm	m	400	5	2000	1.59
12	Water meter	No	1	1500	1500	1.19
13	Valve 2 in	No	2	800	1600	1.27
14	Pressure gauge adaptor	No	1	1500	1500	1.19
	Total				125,880	100

The magnitude of x is a measure of the sensitivity of the emitter discharge to pressure. The lower the value of x, the less the flow rate is affected by pressure variations. The value of x varies from 0 to 1, depending on the design of the emitter.

Coefficient of variation

The parameter, which is generally used as measure of emitter flow variation caused by variation in manufacturing characteristics of the emission devices is called coefficient of variation (CV). The CV describes the quality of the material and processes used to manufacture the emission devices. It is determined from flow measurements for several identical emission devices and is computed using the following equation.

$$CV = Sd / q_{avg} \quad (2)$$

Where 'Sd' is the standard deviation of flow and 'q_{avg}' is the mean flow for a sampled number of emitters of the same type tested at a fixed pressure and temperature (20°C). Soloman (1979) and ASAE (1984) provided the following ranges of CV values and their appropriate interpretations (Table 3).

Water application uniformity

The uniformity of water application describes how evenly an irrigating system has disturbed water. The water application uniformity of trickle irrigation system was evaluated using the uniformity coefficient formula developed by Bralts (1986):

$$Us = 100(1 - SDq/q_{af}) \quad (3)$$

Where:
Us = coefficient of uniformity
Vq = coefficient of variation of emitter flow rate
SDq = standard deviation of field emitter flow rate, Lh^{-1} and
q_{af} = average flow rate in the field, Lh^{-1}

The ratio of standard deviation and average flow rate of the emitter is called the coefficient of variation of emitter flow rate (Vq) and presented by Equation 2:

$$Vq = SDq / q_{af} \quad (4)$$

Table 3. Classification of coefficient of variation.

Coefficient of variation, Cv	Classification
> 0.4	Unacceptable
0.4 - 0.3	Low
0.3 - 0.2	Acceptable
0.2 - 0.1	Very good
<0.1	Excellent

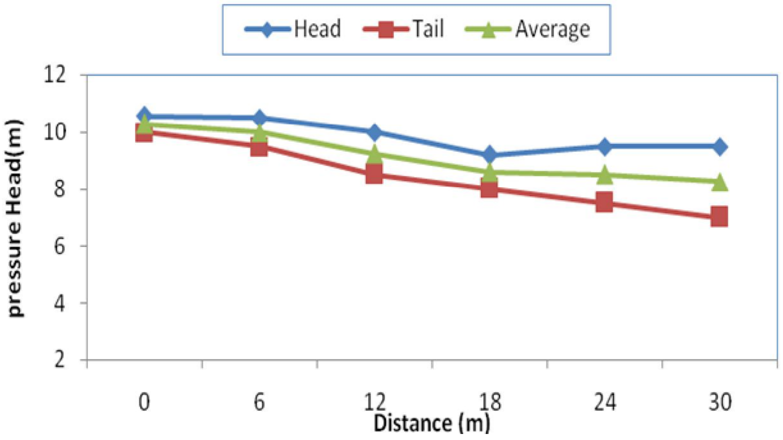

Figure 2. Pressure variation in head and tail reaches of laterals in Block-I.

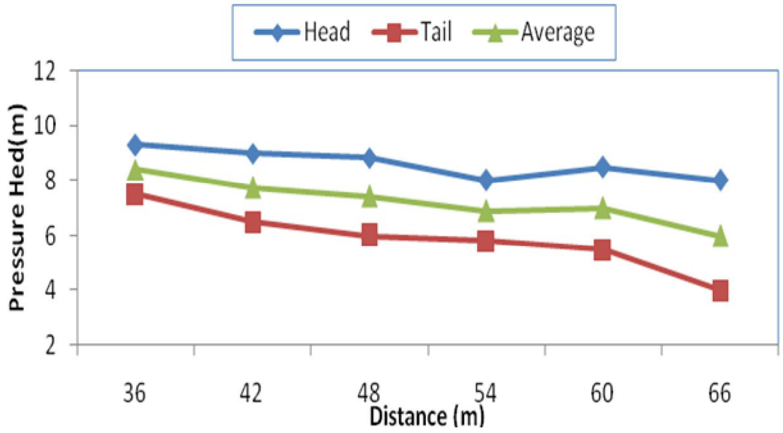

Figure 3. Pressure variation in head and tail reaches of laterals in Block-II.

RESULTS AND DISCUSSION

The present research study was carried out to evaluate the performance of the indigenized trickle irrigation system in order to determine the variations in discharge, pressure of emitters and application uniformity of the trickle irrigation system. In this study, the amount of flow rate through the selected emitters of newly designed drip irrigation has been computed for Block-I and Block-II accordingly. On the basis of design parameters and drip irrigation geometry the unknown parameters was calculated. Finally, by using statistical approach the results are validated graphs was generated accordingly.

Pressure variation in laterals

In Block-I, the average pressure head was 10.28 m in first lateral and it decreased to 8.25 m in the last lateral at a distance of 36 m. There was a drop of 2.03 m in pressure-head. The pressure at head reaches of each lateral varied from 10.56 to 9.5 m and it varied from 10 to 7 m at tail reaches. The percent variation is less at head reaches as compared to tail reaches of the laterals (Figure 2). The average pressure head was 8.4 m in the first lateral of Block-II and it decreased to 6 min the last lateral. There was a drop of 2.4 m pressure head in Block-II showing a little decrease of pressure head than in Block-I. In Block-II the pressure at head reaches of the laterals varied from 9.3 to 8.4 m and it varied from 8 to 4 m at the tail reaches showing a similar trend of decrease at the head and the tail reaches of the laterals (Figure 3).

The overall average pressure in Block-I was 10.28 m and in Block-II was 8.4 m (Tables 3 and 4). The coefficient of variation of working pressure was 12% in Block-I and 27% in Block-II, while the standard deviation was 1.03 in Block-I and 1.92 in Block-II (Table 5). The pressure differences are mainly due to pipe friction, emitter joint losses and change of ground surface elevation as indicated by James (1993). However, large variations in the pressure readings of the laterals may indicate problems, such as blockages or leaks.

Table 4. Performance indices of trickle irrigation system in laterals of block-I.

Lateral number	Distance from pumping unit (m)	Lateral spacing (m)	Lateral performance indices							
			q, L/h			Average q, L/h	H, m	SDq	Vq	Us
			Head	Middle	Tail					
1	70	0	18	13	16	15.67	10.56	2.52	0.16	83.94
2	76	6	17	15	11	14.33	10.5	3.06	0.21	78.69
3	82	12	15	11	13	13.00	10	2.00	0.15	84.62
4	88	18	17	14	9	13.33	9.2	4.04	0.30	69.69
5	94	24	16.5	13	14	14.50	9.5	1.80	0.12	87.57
6	100	30	14	11	10	11.67	9.5	2.08	0.18	82.16
	Average					13.75	9.88	2.58	0.19	81.11

q = emitter flow rate, H = working pressure, SDq = standard deviation of emitter flow rate, Vq = coefficient of variation of the emitter flow rate, us= uniformity coefficient.

Table 5. Performance indices of trickle irrigation system in laterals of block-II.

Lateral number	Distance from pumping unit (m)	Lateral spacing (m)	Lateral performance indices							
			q, L/h			Average q, L/h	H, m	SDq	Vq	Us
			Head	Middle	Tail					
7	106	36	15	13.5	13	13.83	9.3	1.04	0.08	92.48
8	112	42	14	11	10	11.67	9	2.08	0.18	82.16
9	118	48	10	12	11	11.00	8.83	1.00	0.09	90.91
10	124	54	14	10	9	11.00	8	2.65	0.24	75.95
11	130	60	11	10.2	8	9.73	8.5	1.55	0.16	84.04
12	136	66	10	9	7	8.67	7	1.53	0.18	82.37
	Average					10.98	8.44	1.64	0.15	84.65

q = emitter flow rate, H = working pressure, SDq = standard deviation of emitter flow rate, Vq = coefficient of variation of the emitter flow rate, us = uniformity coefficient.

Discharge variation in laterals

The average discharge of emitters was 15.67 L/h in the first lateral and it decreased to11.67 Lh^{-1} in the last lateral at a distance of 36 m in Block-I (Figure 4), whereas in Block-II the average discharge was 13.83 Lh^{-1} in the first lateral and it decreased to 8.67 Lh^{-1} at a distance of 36 m (Figure 5). The overall average discharge of micro-tubing emitter was 13.75 L/h in Block-I and 10.98 L/h in Block-II (Tables 4 and 5). The average coefficient of variation of emitter flow rate was 19% in Block-I and 15% in Block-II, while the standard deviation was 2.58 in Block-I and 1.64 in Block-II (Table 6). The discharge of emitters at the head reaches of each lateral in Block-I varied from 18 to 14 L/h in a 72 m distance. A similar trend of decrease was observed at the tail reaches of the lateral (Figure 5). The emitter discharge variation mainly depends on pressure differences. Other significant factors affecting emitter discharge include water temperature, quality with which the emitter is manufactured (James, 1993). Here, the emitter discharge variation is mainly due to pressure differences and the manufacturing material quality.

Discharge and pressure relationship

Trend of pressure discharge relationship is given in Figure 6. The discharge of the microtube decreased with the decrease in pressure in the laterals. The best fitted curve with the highest value of correlation (R^2) for microtube emitter for the given equation is 0.78, which indicates satisfactory performance. Furthermore results indicated that the discharge within the range of 7-15 Lh^{-1} can be achieved under the pressure head of 7 to 10 m. This relationship can help in determining the discharge of emitters for pressure head varying from 7 to 10 m in the laterals.

Application uniformity of the system

The uniformity of water application describes how evenly an irrigation system has distributed water over a field. The uniformity of application was evaluated using the uniformity coefficient, Us by Equation 2. The performance indices of trickle irrigation system are presented in Tables

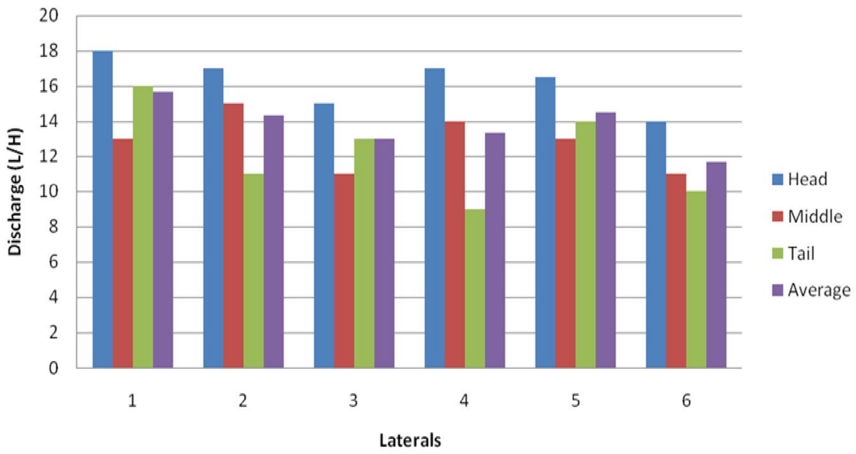

Figure 4. Discharge variation in head and tail reaches of laterals in Block-I.

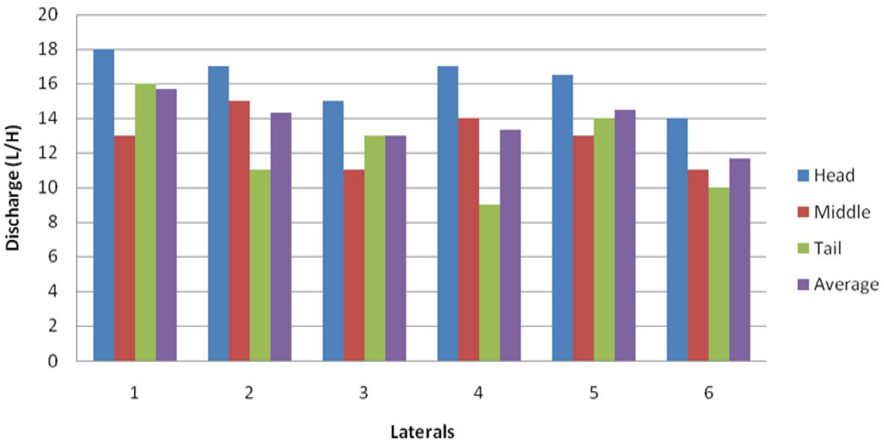

Figure 5. Discharge variation in head and tail reaches of laterals in Block-II.

Table 6. The water application uniformity and statistics of discharge and pressure.

Parameter	Block-I	Block-II
Standard deviation of emitter flow rate (SD_q)	2.58	1.64
Coefficient of variation of emitter flow rate (V_q;%)	19	15
Uniformity coefficient (Us ;%)	81.11	84.65
Standard deviation of working pressure (SD_h)	1.03	1.92
Coefficient of variation of working pressure (V_h;%)	12.00	27.00

3 and 4. The application uniformity was 81% in Block-I and 85% in Block-II. The overall application uniformity was more than 80% in the field that shows a reasonably good performance of indigenized trickle irrigation system. Variation in the application uniformity depends on manufacturing variation in emitters and pressure variation in a system due to pipe friction and elevation changes (Pitts et al., 1986). Large variations in the pressure readings of the laterals may indicate problems, such as blockages or leaks however, the application uniformity above 80% is an indicator of good performance of the system as recommended by Jensen (1981).

CONCLUSION

Micro-irrigation systems can apply irrigation water quite efficiently, but only if they are operated and maintained

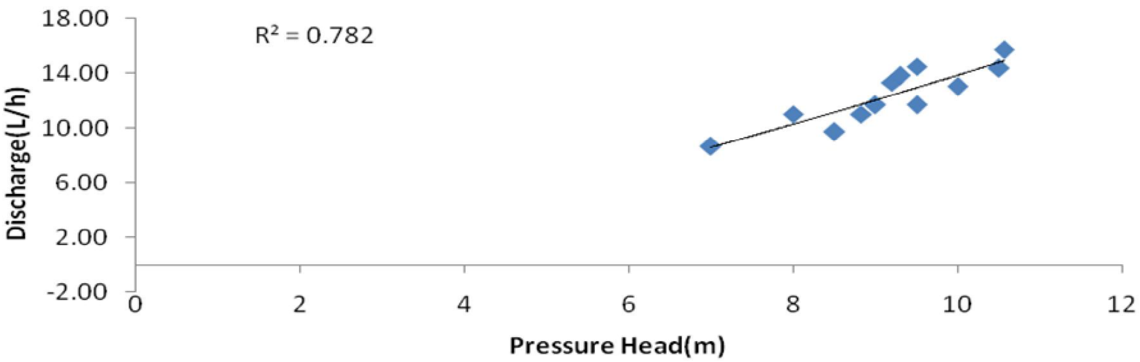

Figure 6. Relationship of discharge and pressure variation in trickle irrigation system.

properly. The drip irrigation can irrigate directly to the crop root zone, it is a popular irrigation method in arid and semi-arid area. The trickle irrigation system can be useful for other crops as well, especially the high value crops and crops grown in green houses and in tunnels. However, the cost is dependent on row to row and plant to plant distance and area required for irrigation. Keeping in view this fact trickle irrigation system using locally produced materials was designed and installed on an area of 1.2 acres for citrus orchard at the field station of water resources research institute, NARC Islamabad, Pakistan.

Results of the study revealed that the discharge of the micro tube emitter varied from 15.67 to 8.67 L/h under the pressure head of 10.56 to 7 m when the drip irrigation system was operated at 10.54 m pressure head. The water application uniformity was found to be above 80% which describes that the drip irrigation was designed on the basis of proper scaling and dimensions. However, it may be improved by removal of clogging. Figures 2 and 3, and Figures 4 and 5 describe the pressure and discharge variation in head, middle and tail reaches of laterals in Block-I and Block II, respectively.

In micro-irrigation system for orchards, the emitter spacing and discharge rate needed depend primarily on the tree spacing and the water needs of the trees. The emission devices must be capable of supplying each tree with enough water during the peak water use periods to satisfy the evapotranspiration (ET) requirement. An irrigation system with uniform water application means each tree will receive nearly the same amount of water during irrigation. More emitters can be developed and tested to get better water application uniformity. The present study encourages trickle installation companies and researchers for further studies on design, installation and evaluation of trickle irrigation system for orchards and other valuable crops.

Suggestions

This research study suggests that water resource engineer should to be proficient and well cognisant with drip irrigation design technology. In orchards where there is a considerable pressure difference, it is necessary that pressure regulating valves be installed in places they are required in order to create a uniform pressure. Regular flushing of the systems will reduce emitter blockage and will increase emission discharge from blocked emitters. Effective irrigation scheduling requires knowing how much water the tree is using or has used since the last irrigation. The infiltration rate of the soil is not easy to determine; it changes during an irrigation and may change across the season. Therefore, it is suggested that while designing a drip irrigation system, it is preferable to choose the correct application rate at the design stage. Furthermore, in order to save time, to simplify the design, and planning of trickle irrigation systems, water resource engineers can also use CAD supported 2D and 3D software's available in market around the globe for analyzing any alternative design hydraulically and economically.

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Citation: Asif M, Islam-ul-Haq C, Mangrio AG, Mustafa N, Iqbal B, (2015). Analysis of application uniformity and pressure variation of microtube emitter of trickle irrigation system. Net J Agric Sci, 3(1): 14-22.