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Full Length Research Paper

Head and lateral length on water distribution uniformity of a PVC drip irrigation system

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Characteristics of emitters under low pressure are essential for the design of low pressure drip irrigation systems. Few data is provided by the manufacturers for drip emitter operating under low pressures. No guidelines regarding the optimum combination of operating pressure head and lateral length available either. A laboratory test was conducted to evaluate the effects of pressure head and lateral length on water distribution uniformity of a PVC drip irrigation system. Five different lengths of lateral were considered under a pressure head of 55 kPa (8.21 psi / 5.6 m). The five lengths were 20, 40, 60, 80 and 100 m. Drip tape tested in this study is a non-pressure compensating (NPC) emiiter with 3.00 L/h discharge rate, 16 mm diameter and 35 cm emitter distance. Evaluation of 10 sampled emitters from the 20 m lateral showed a flow variation (Qvar) of 5%, uniformity coefficient (UC) of 99%, with a coefficient of variation (Cv) of 0.016. The 40 m lateral length showed a flow variation (Qvar) of 9%, UC of 98% with a Cv of 0.024. The 60 m lateral length also showed an average flow variation (Qvar) of 16%, UC of 95% with a Cv of 0.060. The 80 m lateral length showed a flow variation (Qvar) of 23%, UC of 93% with Cv of 0.08 and the 100 m lateral length showed a flow variation (Qvar) of 39%, UC of 89% with a Cv of 0.138. EU for 20, 40, 60, 80 and 100 m were 92, 90, 80, 75 and 58% respectively. Flow discharge vs. sampled emitter points (Q-E curves) was also developed for each length. Q-E curves were fitted to the data resulting in R^2 values of 0.1566, 0.1202, 0.8607, 0.7904 and 0.8998 respectively for 20, 40, 60, 80 and 100m. The operating pressure was 55 kPa (8.21 psi / 5.6 m) for all the tested length. From the statistical analysis, it was observed that as the lateral length increase invariably decreases the average discharge (Qvar). It is therefore recommended to use the 60 m lateral length with a low pressure head of 55 kPa (8.21 psi / 5.6 m), since the 60 m length satisfied the uniformity distribution criteria under a low pressure.

Key words: Pressure head, lateral length, irrigation uniformity.

INTRODUCTION

Water for agricultural use is becoming scarce, both in quantity and quality, not only in the traditionally prone arid and semi-arid zones, but also in regions where rainfall is abundant. Agriculture represent the major user worldwide, and a general perception that agriculture water use is often wasteful and has less value than other

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uses is widespread (Postel, 2000; Jury et al., 2005). Furthermore, energy analysis of agricultural operations has shown that irrigation system consumes a significant amount of energy as compared to other operations (Topak et al., 2005). For these reasons, there is an urgent need to use water resources efficiently by enhancing crop productivity per unit of water.

The drip irrigation systems require intensive capital due to sophisticated technology. Therefore, it is beyond the capacity of the most farmers under small scale farming. If the drip system could be made affordable and within the reach of small and marginal farmers, it will definitely increase the productivity and income of the farmers and also, conserve the scarce precious water resources of the country. International Development Enterprises (IDE) has developed a low cost drip irrigation system, which has been extensively field tested to advance this technology accessible to small and marginal farmers. It has pressure head of 0.5 - 3.0 m with 73 - 84 percent distribution uniformity (Polak et al., 1997). In addition to substantial water saving, the advantage of drip irrigation is that water can be applied where it is most needed in a controlled manner according to the crop requirements.

Drip irrigation has advantages over conventional furrow irrigation as an efficient means of applying water, especially where water is limited. Vegetables with shallow root systems and some crops like corn respond well to drip irrigation with increased yield and substantially higher seed or cob quality with smaller water applications, justifying the use of drip over furrow irrigation (Camp, 1998). However, high initial investment costs of these systems need to be off-set by increased production to justify investment over furrow irrigation systems. The main components of a PVC drip irrigation system are the drip polyethylene tubes with emitters attached to the inside wall and equally spaced according to the crop characteristics of the crop (corn).

Characteristics of emitters (pressure compensating) under low pressure are essential for the design of gravity drip irrigation systems. Few data is provided by the manufacturers for drip emitter operating under low pressures. No guidelines regarding the optimum combination of operating pressure head, lateral length and land slope are available either. The inlet pressure head gained by the attractive flow should be balanced by the total head loss due to friction and emitter insertions along the drip line. If the inlet pressure head becomes greater than the required pressure head at the lateral for uniform emitter flows through the lateral, it may cause back-flow from the lateral downstream closed end to the inlet upstream. On the other hand, if the inlet pressure head becomes lower than the total required pressure head along the lateral, it may yield negative pressure at the emitters at any section of the lateral and it will affect the distribution uniformity (since the inlet pressure and the total required pressure should be the same). The friction loss within the lateral which is a function of the inlet pressure, diameter of laterals, spacing of emitters, and slope of laterals, plays a vital role in the distribution uniformity in drip systems.

The distribution uniformity (DU) of water is one of the most important parameters to characterize drip emitters and design of a drip irrigation system. It is a measure of the uniformity of water application to the area being irrigated, expressed as a percentage between 0 and 100%, although it is practically impossible to attain 100%. DU of less than 70% is considered as poor, 70 to 90% is good, and greater than 90% as excellent. The common measure of DU is the low quarter DU, which is the ratio of the average of the lowest quarter of samples to the average of all samples. Distribution Uniformity in a drip irrigation system is dependent upon manufacturing variation of emitters, operating pressure head, lateral length and land slope. In order to obtain a better DU when designing an efficient drip irrigation system, the combination of operating pressure, lateral length and land slope must be considered. Therefore, all of these factors should be included in designing a drip irrigation system in order to have acceptable distribution uniformity within a certain length of the lateral at a low pressure head.

MATERIALS AND METHODS

Description of study area

The experiment was conducted at the College of Water Conservancy and Civil Engineering at South China Agricultural University, Guangzhou-P. R. China, from November, 2012 to April, 2013.

The following parameters were used to evaluate different drip irrigation products operating under high and low pressure head:

Average emitter discharge rate (Qvar):

$$Q_{var} = \frac{qmax - qmin}{qmax} x100$$

Standard deviation of emitter flow rate (Sq)

$$s_q = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(q_i - q_{var})^2}$$

The variation coefficient of emitter flow (Cv) $C_v = \frac{s_q}{q_{var}}$

Uniformity coefficient (UC)

$$UC = 100\left[1 - \frac{1}{nq_{var}}\sum_{i=1}^{n}|q_i - q_{var}|\right]$$

Emission uniformity (EU)

$$EU = \left[1.0 - \frac{1.27C_v}{\sqrt{n}}\right] \times \left(\frac{q_{min}}{q_{max}}\right) \times 100$$

Where: q_{max}- maximum emitter flow rate, q_{min}- minimum emitter flow rate, n-number of emitters, q_{var}- average discharge, q_i- flow discharge.

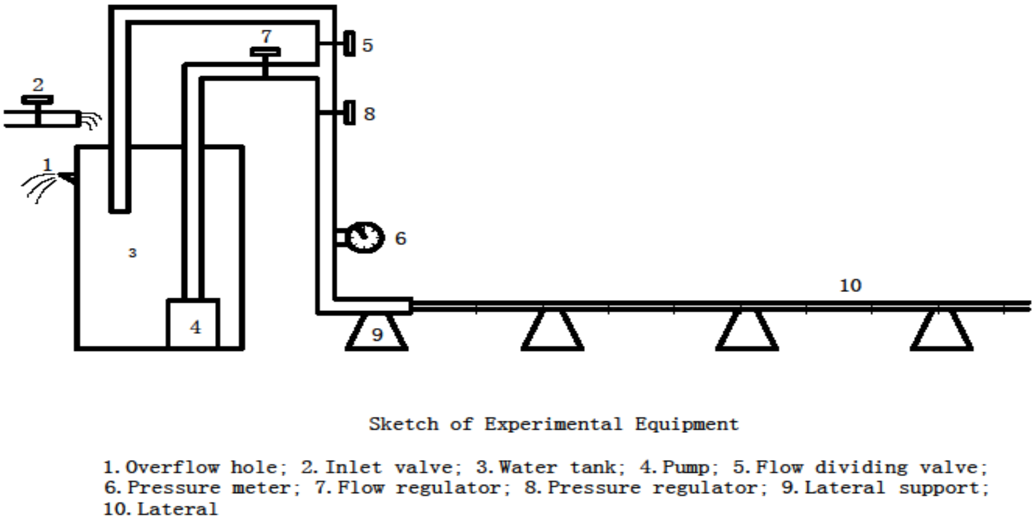

Figure 1. Layout of the test apparatus for discharge (Q) testing.

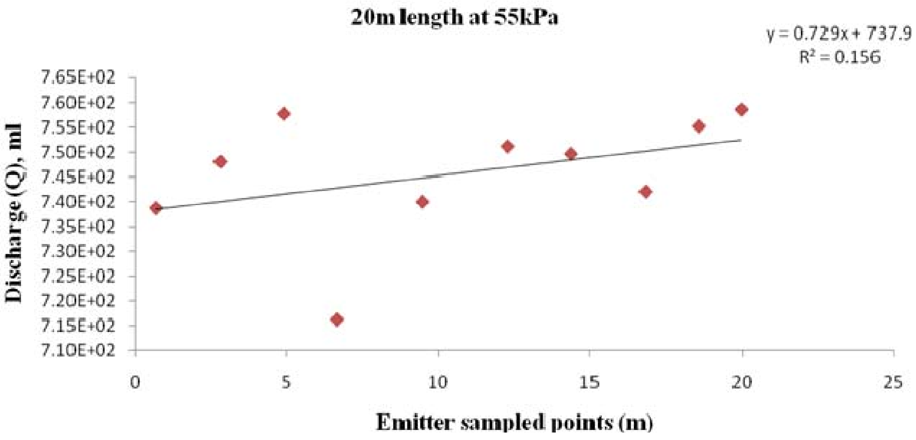

Figure 2. Average discharge under 20 m length at 55 kPa (8.21 psi / 5.6 m).

Computations followed the methodology proposed by Keller and Bliesner (1990) and Kang and Nishiyama (1996).

Testing the apparatus

A laboratory based experiment was set up for this study. A 200 L capacity container was used for the water supply. An immersible pump of HX 8670/8670A was used to supply pressure to the lateral of 16 mm internal diameter in Figure 1.

In this experiment; 10, 20, 30, 30, 30 sampled emitters were randomly selected for five different lateral lengths, 20, 40, 60, 80 and 100 m respectively. The emitters were kept dripping for about 30 min for all the five lengths during the samples collection. On the other hand, after turning on the pump, emitters were allowed to drip for approximately 5 to 10 min to allow for air to escape from the tubing. Samples were collected only after making sure that the last emitter at the laterals end drip out and no air was exiting from the tubes. Water collection period was set in such a way that approximately 700 to 750 ml water samples could be collected to calculate discharge rate per minute. The testing operating pressure was 55kPa (8.21 psi / 5.6m) for all five tested lengths considered.

RESULTS AND DISCUSSION

Performance evaluation on 20 m length

The variation in average discharge of a 16 mm diameter PVC pipe of 20 m long lateral at 55 kPa (Figure 2). For a total emitter, the R^2 value was 0.1566 and the discharge (Q) relationship was Q= 0.7292x + 737.93. From the R^2 value, it can be said that the developed discharge vs. sampled emitter point's relationship did not describe the emitter in terms of lateral length accurately (Figure 2). It was observed that as the pressure was kept constant at 55 kPa (8.21 psi / 5.6 m) along the lateral, and the

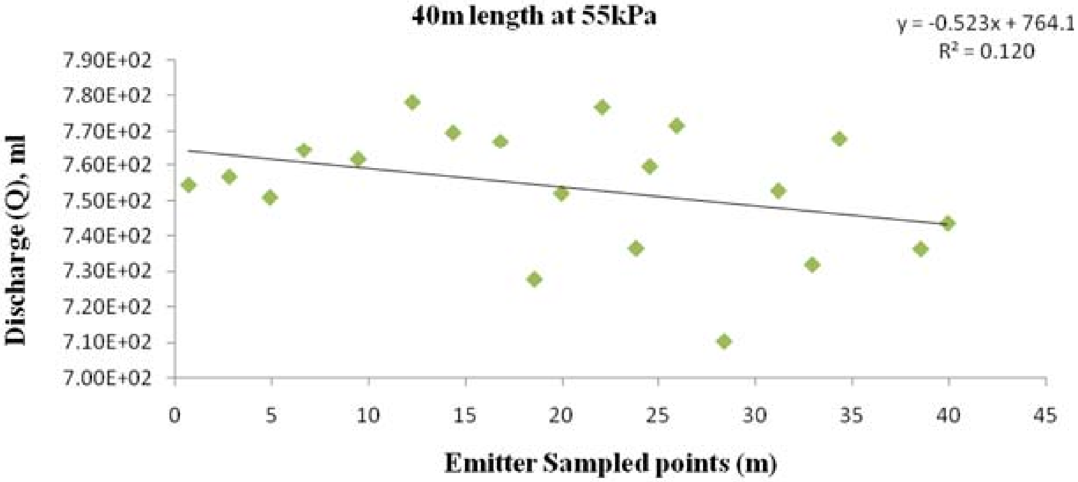

Figure 3. Average discharge under 40 m length at 55 kPa (8.21 psi / 5.6 m).

discharge (Qvar) was 5%. It was reported by Bralts et al. (1987), that emitter flow variation of 10% or less is generally considered desirable. Values of Cv are statistically determined from measured flow rate from a large (>50) sample set of emitters depending on the lateral length all subjected to the same reference pressure head and is the ratio of the standard of deviation of the measured flow rate the mean flowrate. The 20 m long at 55 kPa gave an excellent Cv of 0.016 which was reported by ASAE EP405.1,-(2000), that for point-source emitters, values of Cv less than 0.05 are considered excellent. EU of 92% was also desirable as reported by ASAE EP405.1,-(2000), that it is desirable for most microirrigation systems when design emission uniformity ranges from 85% to 95%. UC was acceptable at 99% as reported by Bralts et al. (1987), that an acceptable UC should be greater than 90%.

Performance evaluation on 40 m length

For a total emitter the R^2 value was 0.1202 and the discharge (Q) relationship was Q= -0.523x + 764.18 (Figure 3). From the R^2 value, it can be said that the developed flow discharge vs. emitter relationship did not describe the emitter terms of lateral length accurately. The discharge (Qvar) of a 16 mm internal diameter PVC lateral of 40 m at 55 kPa (8.21 psi / 5.6 m) was 9%, which confirms what was reported by Bralts et al. (1987), that emitter flow variation of 10% or less is generally considered desirable. The coefficient of variation (Cv) was 0.024, confirms the report by ASAE EP405.1, (2000), that for point-source emitters, values of Cv less than 0.05 are considered excellent. A 90% of desirable EU agrees to the report by ASAE EP405.1, (2000), that it is desirable for most microirrigation systems when design emission uniformity ranges from 85 to 95%. An acceptable UC of 98% confirms the reported by Bralts et al. (1987), that an acceptable UC should be greater than 90%. The variation in average discharge of 40 m lateral length at 55 kPa is shown in Figure 3.

Performance evaluation on 60 m length

For a total emitter, the R^2 value was 0.8607 and the flow discharge (Q) relationship was Q = -2.0745x + 719.96. From the R^2 value, it can be said that the developed flow discharge vs. emitter relationship did not describe the emitter in terms of pipe length accurately (Figure 4) since the slope was negative. The variation in average discharge of a 16 mm diameter PVC lateral of 60 m long lateral at 55 kPa (Figure 4). The 60 m length at 55 kPa (8.21 psi / 5.6 m) gave a 16% average discharge (Qvar), which makes it acceptable as reported by Bralts et al. (1987), that emitter flow variation between 10 to 20% is considered acceptable. An average Cv of 0.06 was obtained which confirm that Cv between 0.05 to 0.10 are considered average as reported by ASAE EP405.1, (2000), for line-source emitters. EU of 82% which is acceptable as reported by ASAE EP405.1, (2000), EU between 80 to 85% is considered to be acceptable. UC was 95% which confirms the reported by Bralts et al. (1987),that an acceptable UC should be greater than 90%.

Performance evaluation on 80 m length

For a total emitter, the R^2 value was 0.7904 and the flow discharge (Q) relationship was Q= -1.9648x + 691.89. From the R^2 value, it can be said that the developed flow discharge vs. emitter relationship, it is also observed that there was a slight reduction in flow discharge in the emitter terms of lateral length (Figure 5). The variation in

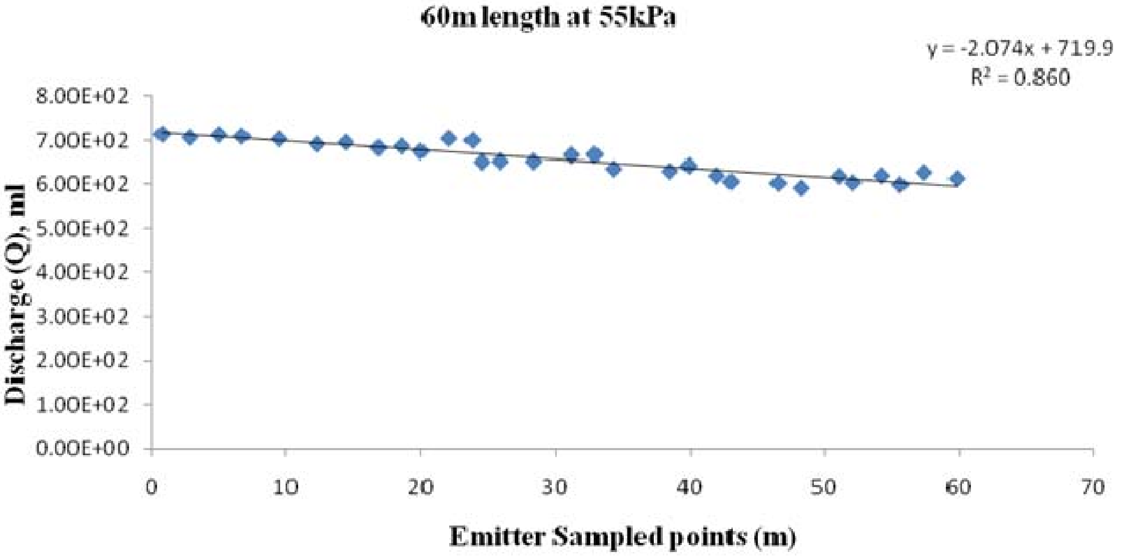

Figure 4. Average discharge under 60 m length at 55 kPa (8.21 psi / 5.6 m).

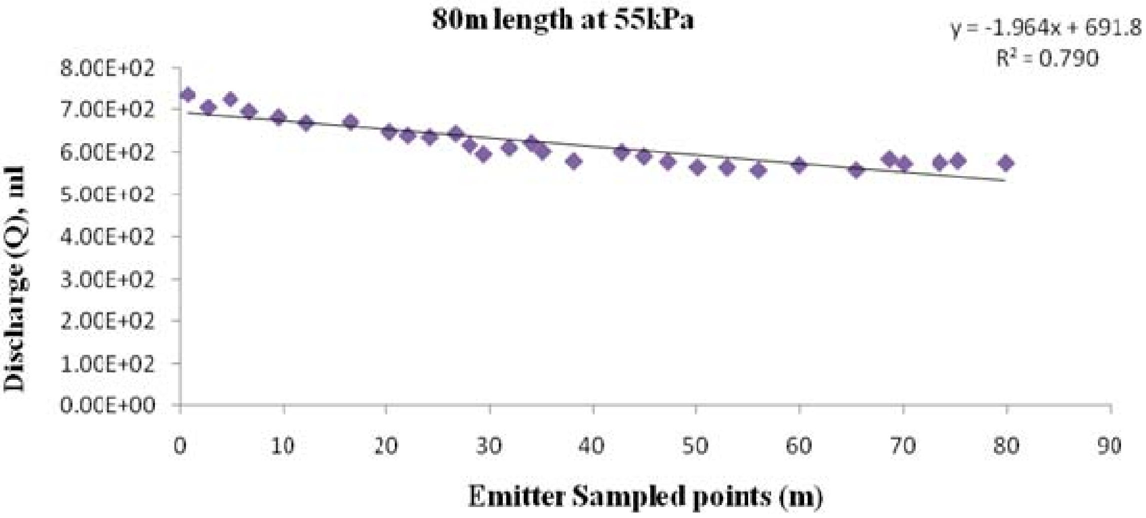

Figure 5. Average discharge under 80 m length at 55 kPa (8.21 psi / 5.6 m).

average discharge of a 16 mm diameter PVC lateral of 80m long lateral at 55kPa (Figure 5). It was observed that as the pressure was kept constant at 55 kPa (8.21 psi / 5.6 m), an unacceptable discharge (Qvar) of 23% was obtained as reported by Bralts et al. (1987), that Qvar greater than 20% is considered unacceptable. There was an average coefficient of variation (Cv) of 0.08, which confirms the report by ASAE EP405.1, (2000), that for point-source emitters, values of Cv between 0.05 to 0.10 are considered average. EU of 75% was also unacceptable as reported by ASAE EP405.1 (2000), that emission uniformity which ranges from 80 to 85% is considered acceptable and below 80% is also considered unacceptable. An acceptable UC was 93% which confirms the report by Bralts et al. (1987), that an acceptable UC should be greater than 90%.

Performance evaluation on 100 m length

For a total emitter, the R^2 value was 0.8998 and the flow discharge (Q) relationship was Q = -2.2404x + 672.01. From the R^2 value, it can be said that the developed flow discharge vs. emitter relationship describes the emitter slightly terms of lateral length (Figure 6). An unacceptable discharge (Qvar) of a 16 mm diameter PVC lateral of 100 m

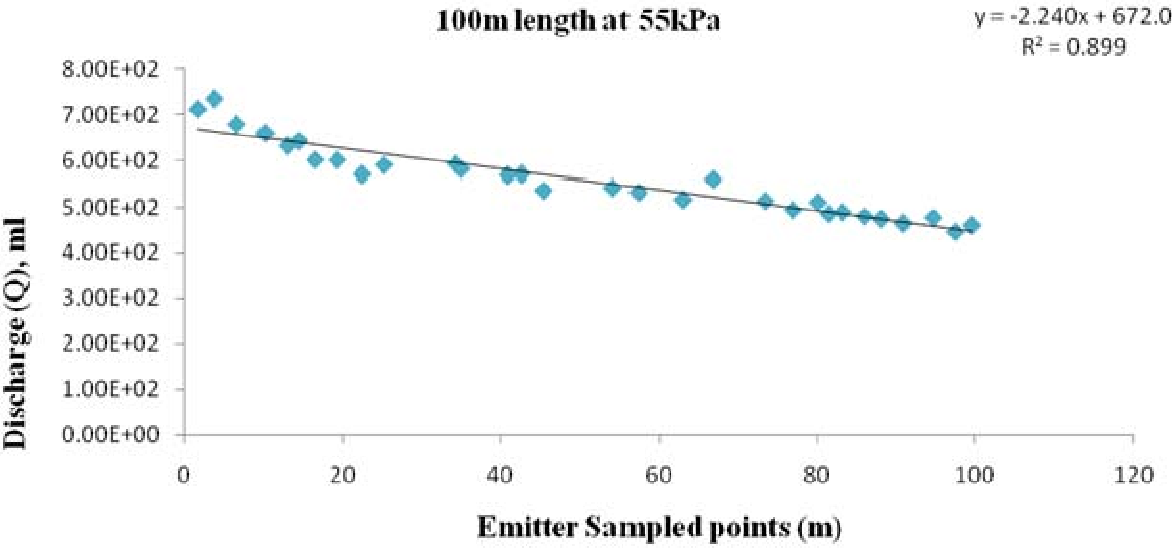

Figure 6. Average discharge under 100 m length at 55 kPa (8.21 psi / 5.6 m).

at 55 kPa (8.21 psi / 5.6 m) was 39% was recorded, which confirms the report by Bralts et al. (1987), that Qvar greater than 20% is considered unacceptable. A marginal Cv of 0.138 was obtained which confirm that Cv between 0.10 to 0.15 are considered marginal as reported by ASAE EP405.1 (2000), for line-source emitters. An unacceptable 58% EU agrees to the report by (ASAE EP405.1, 2000), that emission uniformity which ranges from 80 to 85% is considered acceptable and below 80% is also considered unacceptable. The variation in average discharge of 100 m lateral at 55 kPa (8.21 psi / 5.6 m) (Figure 6) an unacceptable UC of 89% was recorded, which confirms the report by Bralts et al. (1987), that an acceptable UC should be greater than 90% and below 90% makes it unacceptable.

Average discharge (Q) under different lateral length

Irrigation efficiencies of the systems are shown in Table 1. The hydraulic design and component selection of affordable drip system offers satisfactory hydraulic performance. Discharge variation (Qvar) tested under a hydraulic pressure of 55 kPa (8.21 psi / 5.6 m) of a 16 mm diameter PVC lateral was better in terms of shorter length of the pipes 20, 40, 60, 80 and 100 m as 5, 9, 16 23 and 39%, respectively. Table 1 shows that shorter lateral gives desirable flow discharges (Qvar). For the purpose of uniformity of distribution, it is recommended to use shorter laterals under low pressure heads to achieve a desirable average discharge flow as reported by Bralts et al. (1987) (Figure 7).

The Cv obtained for 20, 40, 60, 80 and 100 m are 0.016, 0.024, 0.06, 0.08 and 0.138 respectively under a hydraulic pressure of 55 kPa (8.21 psi / 5.6 m). It can be inferred that, the shorter the lateral the better the coefficient of variation (Cv) as reported by Bralts et al. (1987). Since 20, 40, 60, 80 and 100 m produced; excellent, excellent, average, average and marginal Cv's, respectively. 92, 90, 82, 75 and 58% was obtained for 20, 40, 60, 80 and 100 m respectively for the emission uniformity EU of the pipe. This can also be inferred that, the shorter the lateral, the better the emission uniformity (EU) as reported by Bralts et al. (1987) (Table 1).

It was also observed that in the 20 and 30 m, the average discharge (Qvar) along the lateral form the 1st emitter was not far from the Qvar sampled at the 10 and 20th emitter respectively. This showed a uniform distribution along the later in terms of the length considered at a pressure head of 55 kPa (8.21 psi / 5.6 m). But for the 60, 80 and 100 m, the Qvar along the lateral from the 1st emitter were far from the Qvar sampled at the 30th emitter respectively for 60, 80 and 100 m at a pressure head of 55 kPa (8.21 psi / 5.6 m). This shows that as the lateral length increases, it invariably decreases the average discharge (Qvar).

Conclusion

This experiment characterized five length of lateral of 16 mm diameter product by measuring their flow rates under a pressure of 55 kPa (8.21 psi / 5.6 m). From evaluation of 10, 20, 30, 30, 30 emitters from 20, 40, 60, 80 and 100 m respectively, the 20 m showed a flow variation (Qvar) of 5%, uniformity coefficient (UC) of 99%, with a coefficient of variation (Cv) of 0.016, 40 m showed flow variation (Qvar) of 9%, UC of 98% with a Cv of 0.024, 60 m showed an average flow variation (Qvar) of 16%, UC of 95% with a Cv of 0.060, 80 m showed a flow variation

Table 1. Micro-irrigation system uniformity classification based on tested performance evaluation of 16 mm diameter lateral at 55kPa (8.21 psi / 5.6 m).

Pipe Length (16 mm θ)	Pressure (kPa)	Qvar %	Sq	Cv	UC%	EU%
20	55	5	12.49	0.016	99	92
40	55	9	17.86	0.024	98	90
60	55	16	39.93	0.060	95	82
80	55	23	52.24	0.080	93	75
100	55	39	76.77	0.138	89	58

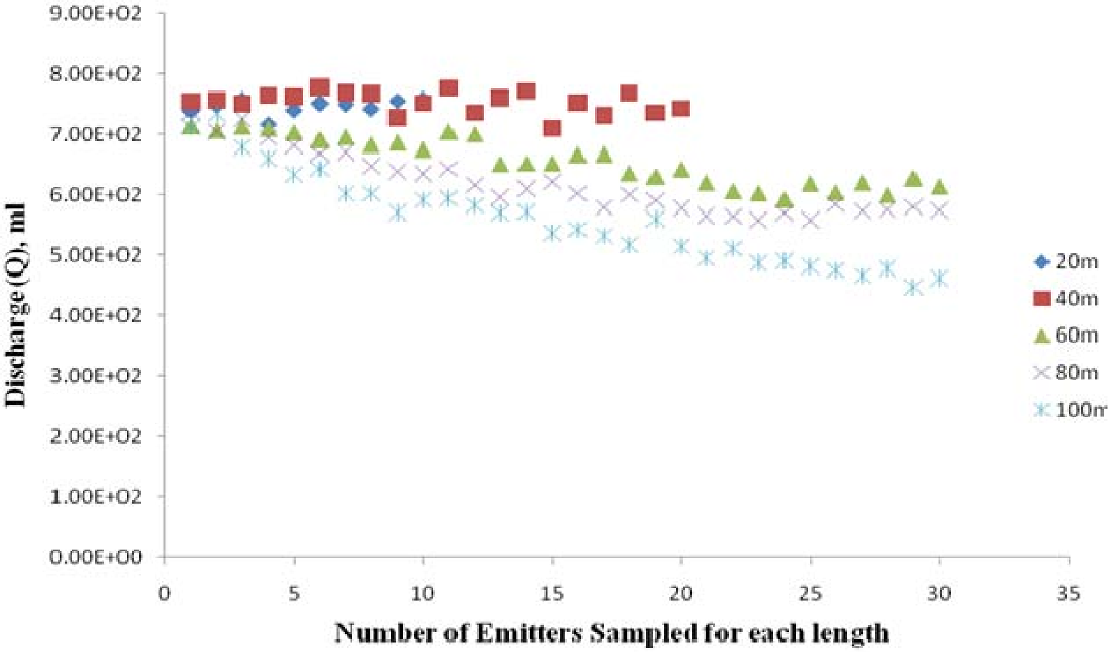

Figure 7. Comparism of average discharge (Q) under different lateral length at 55 kPa.

(Qvar) of 23%, UC of 93% with Cv of 0.080 and 100 m showed a flow variation (Qvar) of 39%, UC of 89% with a Cv of 0.138. EU for 20, 40, 60, 80 and 100 m were 92, 90, 80, 75 and 58% respectively.

Flow discharge vs. emitter (Q-E curves) was also developed for each length. Q-E curves were fitted to the data resulting in R^2 values of 0.1566, 0.1202, 0.8607, 0.7904 and 0.8998 respectively for 20, 40, 60, 80 and 100 m. The operating pressure was 55 kPa (8.21 psi / 5.6 m) for all the tested length.

From the statistical analysis, it was observed that as the lateral length increases, it invariably decreases the average discharge (Qvar).

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Alam A, Kumar A (2001). Micro-irrigation system-past, present and future. In: Proceeding of International Conference on Micro and Sprinkler Irrigation System held at Jalgaon, Maharashtra during 8-10 Februry, 2000, Jain Irrigation Hills, India, Singh H.P, Kaushish S.P., Kumar A., Murthy T.S., Samuel J. C. (Eds). Micro-irrigation. pp. 1-15.

Camp CR (1998). Subsurface drip irrigation: A review, Transactions of ASAE 41(5):1353-1367. http://dx.doi.org/10.13031/2013.17309

Christiansen JE (1942). Irrigation by Sprinkling. Calif. Agric. Exp. Stn. Bull. No. 670. Univ. of Calif., Berkeley, California. P. 124.

Jury WA, Vaux H (2005). The role of science in solving the world's emerging water problems. Proc. Natl. Acad. Sci. 102:15715-15720. http://dx.doi.org/10.1073/pnas.0506467102

Kang Y, Nishiyama S (1996). Analysis of micro irrigation systems using a lateral discharge equation. Transactions of ASAE 39(3):921-929. http://dx.doi.org/10.13031/2013.27577

Keller J, Bliesner RD (1990). Sprinkler and Trickle Irrigation. New York: Van Nostrand Reinhold. http://dx.doi.org/10.1007/978-1-4757-1425-8

Postel S (2000). Entering an era of water scarcity: the challenges ahead. Ecol. Appl. 10:941-948. http://dx.doi.org/10.1890/1051-0761(2000)010[0941:EAEOWS]2.0.CO;2

Polak PBN, Adhikari DA (1997). Low cost drip irrigation system for small farmers in developing countries. J. Am. Water Resources Assoc. 33(1):119 -124. http://dx.doi.org/10.1111/j.1752-1688.1997.tb04088.x

Topak R, Süeri S, Çalişir SC (2005). Investigation of the new energy efficiency for raising crops under sprinkler irrigatios in a semi-arid area. Appl. Eng. Agric. 21(5):761-768. http://dx.doi.org/10.13031/2013.19701