A SEMINAR PAPER ON

Performance Evaluation of Micro-Irrigation System

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ABSTRACT

Micro-irrigation or drip irrigation system can increase the productivity of water since water is applied slowly in the form of droplets to keep soil moisture within the desired range of plant growth. However, due to manufacturing variations in emitters, pressure differences, emitter plugging and frictional head losses a micro-irrigation system can be inefficient. For this reasons, performance evaluation of a micro-irrigation system is necessary. Different field experiments are conducted to analyze the hydraulic performance of drip irrigation system on uniformity coefficient (CU_c), coefficient of variation (CV_m) and emission uniformity (EU´, EU´a and EU_k), statistical uniformity coefficient (U_s), pressure discharge relationship and variation of emitter flow (FV%) regarding to the standards from American Society of Agricultural Engineers (ASAE). The uniformity coefficient of micro-irrigation system gives highest value at a low operating emitter pressure while the others emission uniformity (such as EU´, EU´a and EU_k) provides a higher value at a higher operating pressure. The variation in the values of CV_m depends on the manufacturer's variation, caused by pressure and heat instability during emitter production. The discharge from emitters increases with increase in operating pressure which in turn minimizes emitter flow variation. A system should be designed and maintained with a higher uniformity coefficient (CU_c) since it describes how evenly an irrigation system distributes water over a field.

Keywords: Micro-Irrigation system, Hydraulic performance, Uniformity coefficient, Coefficient of variation, Pressure discharge relationship.

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CHAPTER-1
INTRODUCTION

Water is considered as the most vital natural resource on planet earth and a key component for agricultural production. About 70% of global water utilizes by agricultural sector and about 80% of the water is being used in the developing world (Amoo *et al.* 2019). Traditionally, the surface flood irrigation method along with strip and furrow methods are most commonly used in South Asia and particularly in Bangladesh. Such methods which are practiced extensively in the region, lead to excessive use of irrigation water, and consequently resulting in increased surface runoff, deep percolation and water stagnation, decreased aeration, and reduced water use efficiency (Sraker *et al.*, 2019). These practices will ultimately lead to water scarcity problem. In order to solve the problem of water shortage in agriculture, it is become necessary to reconsider the traditional irrigation methods, with the use of modern systems and technologies in irrigation that achieve an increase in productivity of water volume unit by reducing the water gates during irrigation process (Ismail, 2010). Experiments at different places showed that uniform application of water at or near field capacity of the soil should be applied all over the field for a higher yield (Riza *et al.*,2016). This condition can be achieved by micro-irrigation system precisely drip method of irrigation. Drip irrigation method is the only method which appears to be promising for dry land horticultural crops in Bangladesh (Riza *et al.* 2016).

Drip irrigation method is very efficient for supplying irrigation water to the plant precisely to root zone (Ranjan *et al.* 2018). It helps to keep soil moisture within the desired range of plant growth. The drip irrigation adoption increases water use efficiency (60-200%), saves water (20-60%), reduces fertilization requirement (20-33%) through fertigation, produces better quality crop and increases yield (7-25%) as compared with conventional irrigation system (Kaushal *et al.* 2012). However, due to manufacturing variations, pressure differences, emitter plugging and frictional head losses, irrigation water temperature changes and emitter sensitivity results in flow rate variations even between two identical emitters (Mizyed and Kruse, 2008). A successful performance of drip irrigation system depends on the physical and hydraulic characteristics of the drip tubing (AL Amound, 1995). That is why, performance evaluation of micro-irrigation system is indispensable before set up in the field for crop production. The best and desirable feature of drip irrigation is that uniform distribution of water is possible, which is one of the most important parameters in design, management, and adoption of this system (PK Jamrey *et al.*, 2018). A uniformity coefficient of less than 70% is considered as weak while 70% to 90% is counted for good and higher than 90% the uniformity coefficient is excellent (ASAE, 1999). It is required to achieve high uniformity co-efficient of more than 85% (Pragna *et al.*, 2017). The uniformity coefficient is a function of hydraulic head and slope of lateral and sub-main lines. Likely other performance parameters such as coefficient of variation, emission uniformity, statistical uniformity coefficient and discharge through emitters are also affected by the operating pressure (Sarker *et al.*, 2018). The emitter's discharge in the lateral lines increases by increasing the operational pressure (Al-Mehmdy *et al.*, 2018). Therefore, operating pressure can be considered as a very important element in drip irrigation system design. Due to the lack of knowledge of uniformity parameters, under varied operating pressures, this system is still facing problems of supplying water uniformly throughout the field (Elamin *et al.* 2017). Therefore, considering above matters, two objectives have been drawn up for this review.

Objectives

- To review different methods used for the performance evaluation of a micro-irrigation system.
- To study the effect of operating pressure on different performance parameters.

CHAPTER -2

MATERIALS AND METHODS

This seminar paper is exclusively a review paper so all of the information has been collected from the secondary sources. During preparation of this review paper, I collected key information from various relevant sources such as books, journals, proceedings, reports, and publications. I have also searched related topic by Google scholar through internet to collect desired information. I have received valuable suggestion and information from my course instructors, my major professor and other resource personnel. After collecting all the available information, I myself compiled and prepared this seminar manuscript.

CHAPTER-3
REVIEW OF FINDINGS

Micro-irrigation system is broadly known as drip irrigation or trickle irrigation system. Drip irrigation is a type of micro irrigation is an irrigation method that minimizes the use of water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface referred as surface drip irrigation system or directly onto the root zone, through a network of valves, pipe, tubing and emitters referred as subsurface drip irrigation system (Ahmed *et al.*, 2012). The goal is to place water directly into the root zone and minimize evaporation losses.

A. Performance evaluation parameters of micro-irrigation system

Evaluation is the analysis of any irrigation system based on measurements taken on the field under the conditions and practices normally used. Performance evaluation or hydraulic evaluation of drip irrigation system is basically done based on a method defined by the American Society of Agricultural Engineers (ASAE) in 1999. The system is tested for its uniformity coefficient, emission uniformity, design emission uniformity, statistical uniformity coefficient, manufacturing coefficient of variation, flow variation and pressure-discharge relationship.

1. Uniformity Coefficient (CUc): Christiansen (1942) was developed the equation of Uniformity coefficient, later which was cited by Mofoke *et al.* (2004), Enciso-Medina *et al.* (2009) and Klein *et al.* (2015) for the evaluation of drip irrigation system.

$$CU_c = 100\ [1- \frac{\sum_{i=1}^{n} q_i - \overline{q}}{n\overline{q}}] \quad (1)$$

Where, CU_c = Christian's uniformity coefficient (%), n = Number of emitters used in data analysis, q_i = Discharge or volume weight of water collected in the i^{th} emitter, and q = Arithmetic average discharge/volume of weight caught by all collected emitters (collectors).

2. Manufacturer's coefficient of variation (CV_m): The manufacturer's coefficient of variation (CV_m) introduced by ASAE (1996) is used to measure the variability of discharge of a random sample of a given make, model, and size of the emitter, which is produced by the manufacturer before any field operation. Kirnak *et al.* (2004) and Yavuz *et al.* (2010) used the following equation to evaluate the performance of emitters. The classification of CV_m values according to ASAE standards are shown in Table (1).

$$CVm = \frac{S_d}{\bar{q}} \quad (2)$$

Where, CV_m = Manufacturer's coefficient of variation of emitter flow, S_d = Standard deviation of emitter flow rates at reference pressure head (l/h), and $\bar{q}$= Mean emitter flow rate in the sample at that reference pressure head (l/h).

Table 1. Recommended classification of manufacturer's coefficient of variation (CV_m) for design purpose (ASAE, 1999)

CV_m	**CV_m (%)**	**Classification**
0.05	<5	Excellent
0.05-0.07	5-7	Average
0.07-0.11	7-11	Marginal
0.11-0.15	11-15	Poor
>0.15	>15	Unacceptable

3. Emission Uniformity or Emitter Flow Uniformity (EU´), Absolute Emission Uniformity (EU´a) and Design Emission Uniformity: Emission uniformity (EU´) is defined as the average discharge of 25% or ¼ th of the sampled emitters with the least discharge divided by the average discharge of all sampled emitters, which was used by Keller and Blaisner (1990), Barragan *et al.* (2006) and Popale *et al.* (2011) for assessment of micro-irrigation. The classification of (EU´) values according to ASAE standards are shown in Table (2).

$$EU' = 100 \left(\frac{\bar{q}_{min}}{\bar{q}}\right) \quad (3)$$

Where, EU´= Field emission uniformity (%), $\bar{q}_{min}$ = Measured average of lowest 25% or ¼ th of emitter discharge (l/h), $\bar{q}$ = Measured mean emitter discharge (l/h).

Besides, Mistry *et al.* (2017) and Tahir *et al.* (2017) used the following formula for determination of absolute emission uniformity (EU´a).

$$EU'a = 50 \left(\frac{\bar{q}_{min}}{\bar{q}} + \frac{\bar{q}}{\bar{q}_{max}}\right) \quad (4)$$

Where, EU´a= Absolute field emission uniformity (%), $\bar{q}_{max}$ = measured mean of highest 1/8 of emitter discharge (l/h)

In addition, Design Emission Uniformity (EU_k) has been predefined and modified to include the emitter coefficient of manufacturing variations (CVm) and emitter flow variation (ASAE, 1996), which was also used by Noori and Al Thamiry (2012).

$$EU_k = 100 \left(1- \left(\frac{1.27\ CV_m}{e^{0.5}}\right)\right) \left(\frac{\bar{q}_{min}}{\bar{q}}\right) \quad (5)$$

Table 2. Recommended classification of emission uniformity (EU´) for design purpose (ASAE, 1996)

Classification	EU (%)
Excellent	94-100
Good	81-84
Acceptable	68-75
Poor	56-62
Unacceptable	<50

4. Statistical Uniformity (U_s): Statistical uniformity (U_s) between the emitters is determined by the following equation (Bralts and Kesner, 1983), which was used by Yavuz *et al.* (2010) and Mistry *et al.* (2017) for the performance evaluation of drip irrigation system.

$$U_s = 100 \left(1 - \frac{S_d}{\bar{q}}\right) = 1- CV_m \quad (6)$$

Where, U_s = Statistical uniformity (%), S_d = Standard deviation of emitter flow rates at reference pressure head (l/h), $\bar{q}$= Mean emitter flow rate in the sample at that reference pressure head (l/h), CV_m = Coefficient of variation of emitter flow

This statistical uniformity was also evaluated according to ASAE (1999) and Capra and Scicolone (1998), based on the classification criterion presented in Table 3.

Table 3. System classifications according to statistical uniformity (Us) values

U_s (%)	**Classification**	
	ASAE (1999)	**Capra and Scicolone (1998)**
<60	Unacceptable	Low
60-70	Poor	
70-71	Acceptable	

71-80	Acceptable	Mean
80-89	Good	
89-90	Good	High
>90	Excellent	

5. Pressure discharge relationship: The head discharge relationship was used to determine the rate of discharge for emitters (Thompson *et al.* 2011), which was expressed by the following formula (Karmeli, 1997).

$$Q = K.\ H^X \quad (7)$$

Where, Q = Discharge rate of drippers (l/h), K = Discharge co-efficient, H = Pressure Head, X = Dripper flow exponent

6. Flow variation (FV): Flow variation is also a design parameter to evaluate a trickle lateral design (Mansour, 2012). FV values less than 10% is considered as excellent and acceptable regards to James (1988). The defining equation for flow variation is as follows.

$$FV = (Q_{max} – Q_{min})/\ Q_{max} = 1 – (Q_{min}/Q_{max}) \quad (8)$$

Where, FV = Flow variation (%), Q_{max} =Maximum emitter discharge rate in system (l/h), Q_{min} = The lowest emitter discharge rate in system (l/h)

B. Determination of performance parameters under different operating pressures

1. Effect of operational pressure on the values of uniformity coefficient (CUc)

Figure (1) illustrates that the uniformity coefficient is inversely proportional to the operational pressure with emitter discharge 4 and 8 Lh^{-1} (Al-Mehmdy *et al.*, 2018). For 4 Lh^{-1} emitter discharge, the uniformity coefficient was found 98.85%, 95.86%, and 94.65% for p1= 0.5 bar, p2= 0.7 bar and p3= 1.0 bar respectively. The decrease percentage has reached 3.02% and 4.25% when comparing the value of uniformity coefficient at the operational pressure 0.5 bar with the value of uniformity coefficient for the two operational pressures 0.7 bar and 1.0 bar respectively. Similarly, for 8 Lh^{-1} emitter discharge, the decrease percentages were found about 1.33% and 2.64% when comparing the value of uniformity coefficient at 0.5 bar operational pressure with the values of uniformity coefficient of the two operational pressures previously mentioned respectively. And this may happen due to the increase of operational pressure causes irregular water outflow, and therefore leads to irregular water distribution.

The best value of uniformity coefficient was obtained at the operational pressure 0.5 bar which indicates that the emitter should be used in low operational condition.

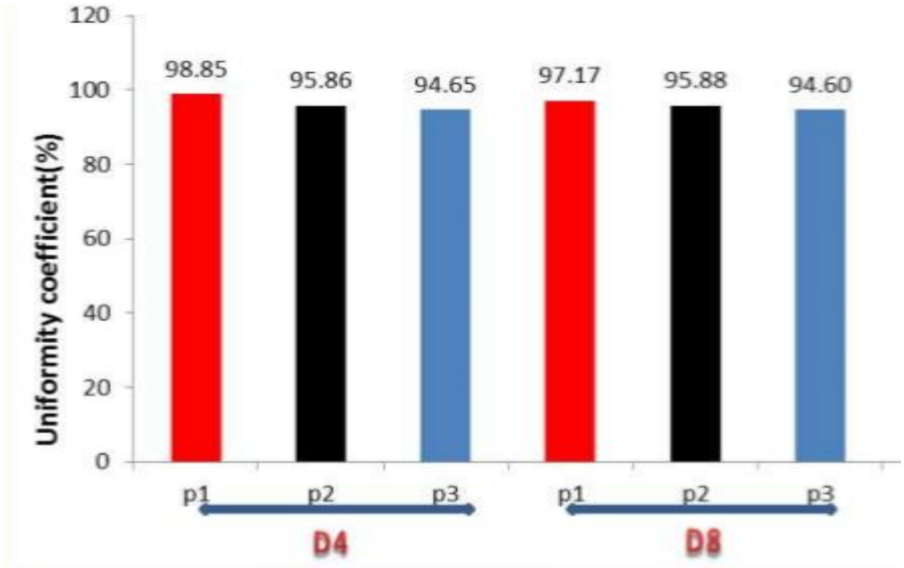

Figure 1. Effect of emitter's discharge and operational pressure in the values of uniformity coefficient. (**Source:** Al-Mehmdy *et al.* 2018)

2. Effects of emitter pressure on coefficient of variation (CV_m)

The coefficient of variation (CV_m) for each operating pressure for various slopes showed the variations (Sarker *et al.* 2019). The results in Table (4) indicates that CV_m for 2 m pressure head with 0% and 1% slope was performed average, while with 1.5% slope it was performed as marginal (Table 1), as recommended by the ASAE, (1999). Similarly, CV_m for the 2.5 m pressure head with 0% and 1.5% slope was 0.06 indicating average performance, but with 1% slope it was less than 0.05. The variation of CV_m depends on the manufacturer's variation, caused by pressure and heat instability during emitter production. In addition, a high CV_m could occur due to a heterogeneous mixture of the local materials used in the production of the emitter (FGR, 2012). The hydraulic performance of drip irrigation system showed that the discharge flow rate of the emitter increased with increase in pressure, and the coefficient of variation increased with decrease in pressure, indicating that the pressure head affects the discharge rate of the emitter.

Table 4. Effects of emitter pressure and sub-main line slope on coefficient of variation (CV_m)

Head (m)	**Slope (%)**	**CV_m**
1.5	0	0.060
	1	0.057
	1.5	0.057
2.0	0	0.045
	1	0.055
	1.5	0.078
2.5	0	0.057
	1	0.04
	1.5	0.057

(Source: Sarker *et al.* 2019)

3. Effects of operational pressure on emission uniformity or emitter flow uniformity (EU´), absolute emission uniformity (EU´a) and design emission uniformity (EU_k)

Figure (2) describes that emitter flow uniformity (EU´) was varied from 79.913 to 94.753% for pressure 0.3 to 1.2 kg/cm^2 (Mistry *et al.* 2017). At pressure 1.2 kg/cm^2 the value of EU´ was 94.753% which is excellent as per the recommendation of ASAE (1996). At 0.6 and 1.1 kg/cm^2 the values of EU´ were 94.04% and 94.546% respectively. The lowest value of EU´ (79.913%) was found at pressure 0.3 kg/cm^2, which is considered as acceptable class. The variation in the values of EU´ happens due to emitter flow variation. In addition, the values of absolute emission uniformity (EU´a) were varied from 82.181 to 94.692% for pressure 0.3 to 1.2 kg/cm^2 (Figure 3) (Pranav et al. 2017). At pressure 1.2 kg/cm^2 the value of EU´a was found 94.692% which shows the excellent. The lowest value (82.181%) was found at 0.3 kg/cm^2. The values of EU´a was ranged from excellent to good class in Table (2).

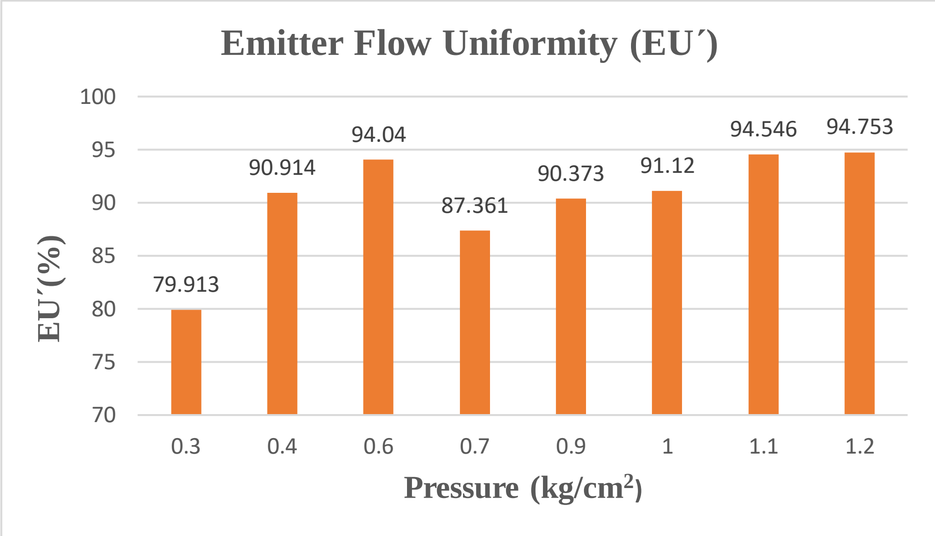

Figure 2. Effects of operational pressure in the value of emitter flow uniformity (EU´). (**Source:** Mistry *et al.* 2017)

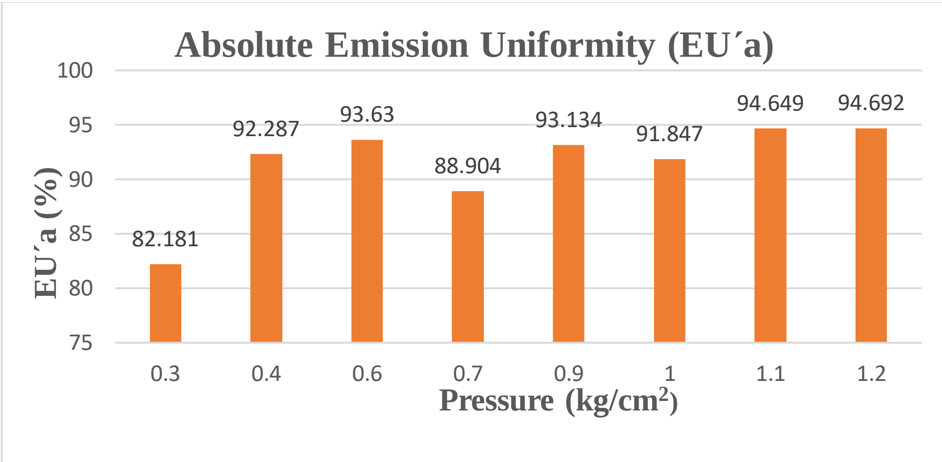

Figure 3. Effects of operational pressure in the value of absolute emission uniformity (EU´a). (**Source:** Mistry *et al.* 2017)

Figure (4) illustrates that the values of design emission uniformity (EU_k) was ranged from 67.707 to 90.464% for pressure 0.3 to 1.2 kg/cm^2 (Mistry *et al.* 2017). The values of EU_k was increased from pressure 0.3 to 0.6 kg/cm^2 with 20.183% and then slightly decreased by 8.276% at 0.7 kg/cm^2. The range was again tending higher from 0.9 to 1.2 kg/cm^2. From the results, it can be noted that the values of EU_k ranges between good to acceptable category. Moreover, it can be identified from figure (2), (3) and (4) that at pressure 1.2 kg/cm^2 the value of emission uniformity was highest while at 0.3 kg/cm^2 it was given a lowest value. Also, the values of design emission uniformity EU_k was comparatively less than the other two emission uniformities. This was happened due to the manufacturer variation that was also considered in case of determining EU_k.

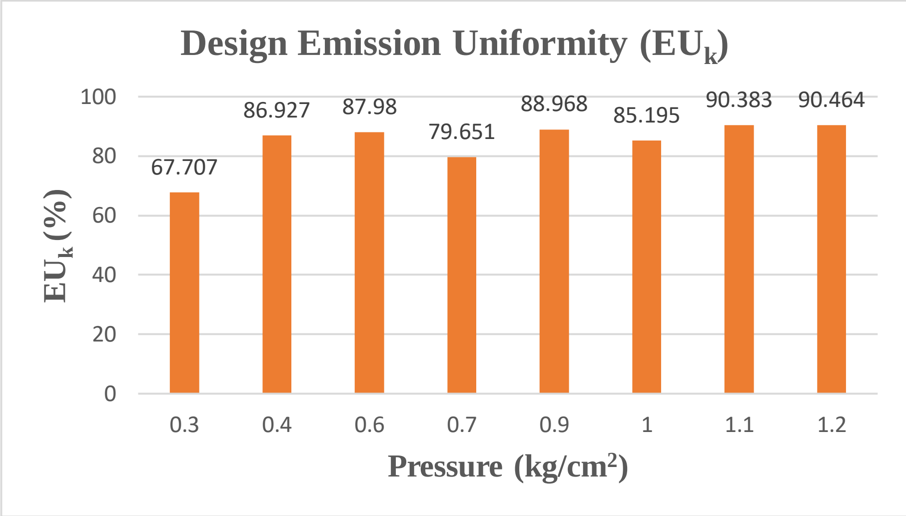

Figure 4. Effects of operational pressure in the value of design emission uniformity (EU_k). (**Source:** Mistry *et al.* 2017)

4. Effects of emitter pressure on statistical uniformity (U_s)

The statistical uniformity (U_s) for each pressure at various slopes showed more than 90 percent for each operating pressure head with various slopes (Table 6) (Sarker *et al.* 2019). At 2 m head with 0% slope the value of U_s was highest which was 95.53% (Table 5). It can be figured out from the values of U_s that the emitters can be considered as excellent (ASAE, 1999 and Capra and Scicolone, 1998), and indicating the acceptable limits for water application.

Table 5. Effects of emitter pressure and sub-main line slope on statistical uniformity (U_s)

Head (m)	Slope (%)	U_s (%)
1.5	0	94.02
	1	94.25
	1.5	92.35
2.0	0	95.53
	1	94.46
	1.5	92.70
2.5	0	94.34
	1	95.15
	1.5	93.31

(**Source:** Sarker *et al.* 2019)

5. Pressure discharge relationship

The experiment was conducted by using randomized block design (RBD) where emitters with different discharge rates of 1.6 l/h, 2.2 l/h, 3.0 l/h and 4.0 l/h were fixed to the lateral as per the treatments (Pragna *et al.* 2017). The emitters were tested at different operating pressure such as 0.5, 0.7, 0.9 1.25 and 1.5 kg/cm^2. From Table (6), it could be seen that the discharge from the different drippers were increased with increase in operating pressure. Logarithmic relationships were developed between pressure and discharge for each of the dripper. The relationship of pressure and discharge of each dripper were shown in Figure (5). The power form of the mathematical relationships presented in Table (7) was found for the pressure-discharge relationships. R^2 value of each dripper discharge was above 0.95 and can be noted that the model fits good. It could also be seen from Table (7) that in case of all the dripper discharge rates, the exponent of the pressure was less than 0.5. This indicated that the nature of flow from the dripper was not an orifice flow. The exponent of power function was decreased with capacity of dripper which indicated that the sensitivity of the dripper to pressure for the discharge was decreased with increase in dripper capacity.

Table 6: Average discharge rate of emitters at different operating pressures

Pressure (kg/cm2)	**Average Discharge of emitters (l/h)**			
	1.6	**2.2**	**3.0**	**4.0**
0.5	0.73	1.01	1.40	1.79
0.7	0.95	1.31	1.82	2.37
0.9	1.23	1.80	2.41	2.98
1.2	1.38	1.93	2.61	3.43
1.5	1.56	2.11	2.99	3.94

(**Source:** Pragna *et. al.* 2017)

Table 7. Developed models for the pressure discharge relationship

Emitter discharge (l/h)	**Developed Model**	**R^2**
1.6	$Q= 1.7485\ P^{0.4895}$	0.9935
2.2	$Q= 1.3723\ P^{0.4769}$	0.9868
3.0	$Q= 0.9954\ P^{0.4797}$	0.9782
4.0	$Q= 0.717\ P^{0.4761}$	0.991
Where, Q= Emitter discharge (l/h), P= Pressure input (kg/cm^2), R^2= Goodness of fit		

(**Source:** Pragna *et.al.* 2017)

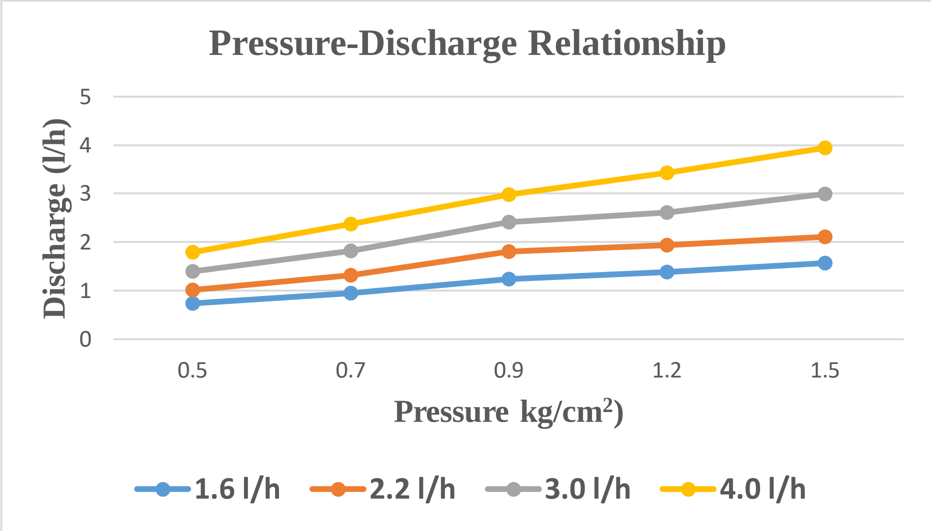

Figure 5. Relation between pressure and discharge of different emitters.

(**Source:** Pragna *et al.* 2017)

7. Effects of operational pressure on flow variation (FV%)

Figure (6) represents the variation in flow under different operating pressure. To determine the flow variation (FV%) emitters were tested under 0.6, 0.8, 1 and 1.2 kg/cm^2 operating pressures. Emitter flow variation (FV%) varied from 5.03 to 2.59 (Ranjan *et al.* 2018) which is within the recommended range. The lowest and highest values of flow variation (FV%) were found at 1 and 0.6 kg/cm^2 respectively. It can be stated that at low pressure the variation in flow is more.

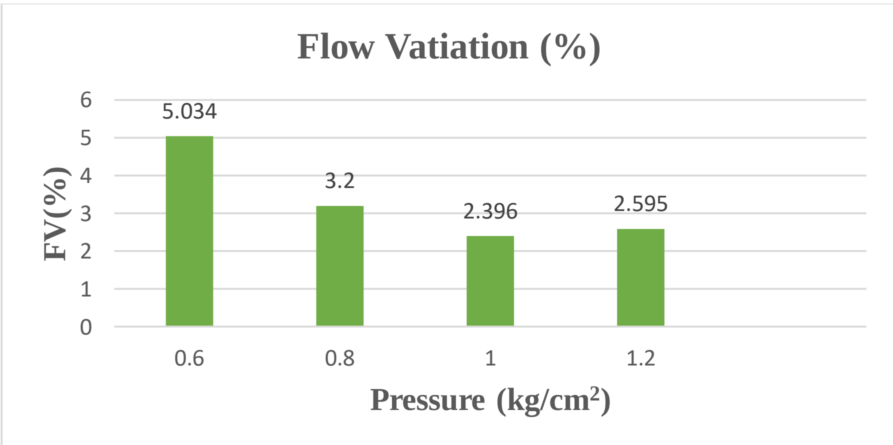

Figure 6. Effects of operational pressure on flow variation (FV%).

(**Source:** Ranjan *et al.* 2018)

CHAPTER 4

CONCLUSION

Water is a precious natural resource which should be utilized efficiently. Micro-irrigation system (MIS) is an effective means of saving water since water apply in the form of droplets directly into the plant roots. To improve the performance of an operating MIS, evaluation is necessary. Different methods regarding the performance evaluation of MIS are modified by American Society of Agricultural Engineers (ASAE) which are used world widely by the researchers and manufacturers. The uniformity coefficient of MIS gives highest value at a low emitter pressure. On the others, different emission uniformity (such as EU´, EU´a and EU_k) provides a higher value at a higher operating pressure. The variation in the values of CV_m depends on the manufacturer's variation, caused by pressure and heat instability during emitter production. The discharge from emitters increases with increase in operating pressure which in turn minimizes emitter flow variation. A micro-irrigation system will be considered as an efficient one if it applies water evenly into the entire field. Therefore, the system must be adopted and maintained with a higher uniformity coefficient.

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