Analysis of Trickle / Drip Irrigation Uniformity by IRRIPRO Simulations

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Abstract

An interactive computer enabled software namely IRRIPRO was used in order to design and plan viable drip irrigation systems. This software is proficient enough in planning network layout, hydraulic designing and above all simulations to obtain results. This software can also provide requisite cost estimation of new as well as existing drip irrigation. IRRIPRO has the diverse quality to calculate and design many other hydraulic parameters. It is a helping tool for water resource engineers in designing, testing, analyzing any other alternative design on precision and economical parameters. It is equally useful in cost estimation of those systems which are not designed with the help of IRRIPRO software. The research study has been conducted in a greenhouse at western region of Abu Dhabi UAE to check the operational reliability, efficiency, dependability and harmony of the existing drip irrigation system.

The comparative study revealed that the drip irrigation achieved high CU and DU which imply that the existing drip irrigation system was designed on the basis of proper scaling and dimensions. The CU on average basis for the system was found to be 96.4990% (observed) and 99.9796% (simulated) respectively. Similarly, the DU on average basis for the system was found to be 94.3605% (observed) and 99.8822% (simulated) respectively. EU_a of the system using pressure compensated type emitters with the length of laterals 16 meters with an average observed and simulated value was found 99.2192% and 99.99316% respectively.

The comparison of experimental and simulated results confirms that the application uniformity seems to be satisfactory and the existing drip irrigation unit was designed properly.

The design of the existing drip irrigation network was checked by the interactive computer software i.e. IRRIPRO which was found acceptable. The uncertainty in results was found less than 10% which indicates its accuracy. IRRIPRO software also predicts that the ideal pressure for existing drip irrigation was 13.353 m c.a (1.29 atm) which gives 3.655 lit / hr flow rate for all emitters. Figure 4 (a) and Figure 4 (b) describes the simulation of pressure and flow rate distribution pattern. Hence, IRRIPRO is helpful for water resource engineer to use it in testing and analyzing any alternative design hydraulically and economically. As IRRIPRO is providing the ideal results for the existing drip irrigation system it will be more as compared to the field results. This software could also be used to calculate the annual costs of any system even if it is not designed by IRRIPRO.

Keywords: Design parameters, emitters, drip irrigation, uniformity coefficient, distribution uniformity, IRRIPRO Software.

INTRODUCTION

Everyone is very well conversant with the open secret that water is a lifeline for all living things around the globe. All echo system is dependent on this priceless gift of God, especially for agriculture sector for which water occupy pivotal position. Drip irrigation is the slow application of water on, above or below the soil by surface drip or subsurface drip systems (ASAE, 2001). This method consists of water source pumping unit, mixing chamber, mainline, sub-main, laterals and emitters. The main line conveys 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 (Bhatnagar and Srivastava, 2003).

At a particular spacing, the CU and EU are increased, while coefficient of variation is decreased as the operating pressure head is increased for all emission devices (Sandeep and Pratap, 2007). The productivity of drip irrigation system was 23% higher than that under the flood method of irrigation, with water saving of about 44% per hectare and electricity saving of about 1059 kwh/ha (Narayanamoorthy, 2004). A system with uniformity co-efficient of at least 85% is considered appropriate for standard design requirements (Al-Amound, 1995). However, the DU and CU are function of hydraulic head and slope of lateral and sub-main lines. The CU generally follows a linear relationship either with head or slope. The CU and DU decreases substantially at sub-main slopes steeper than 30 % (Ella et al., 2009).

The emitted EU can be augmented through latest layout by using sophisticated software's as compared to the traditional system. The modern computer software's has effectively plays their role in hard computations and simulation to improve system capability by giving appropriate inputs and data in less time. This results in less error frequency and more detailed analysis when compared to non-computer aided design. IRRIWORKS (2007) had developed new software i.e. "IrriPro Version 1.0" for the promotion of new and advanced solutions for agriculture. IrriPro is windows based and most advanced computer software in market able to design irrigation systems of any complexity and size in an easy, powerful and innovative way. This software is an ultimate tool meant for water resource professionals to compute the water distribution uniformity and different hydraulic parameters for drip irrigation network (IrriPro, 2007).

It is imperative to make use of available water resources efficiently by controlling conveyance and field losses. One of the alternate methods to control field losses and increase water productivity at the farm is to replace the traditional flood irrigation with the high efficiency irrigation (HEI) method. The HEI method includes the use of sprinkler and drip irrigation methods. Although, these systems are expensive, but their adoption has become imperative to meet the increasing demand of irrigation water. In view of all discussed facts, the present research work is designed to determine the behavior of an existing drip irrigation network and for this purpose the IRRIPRO software is used.

OBJECTIVE

The objective of this research work is to evaluate the effectivity of different irrigation uniformities of an existing trickle / drip irrigation system by using IRRIPRO Software and to compare the simulated results with experimental observations.

MATERIALS AND METHODS

Location

The research work was conducted using an existing drip irrigation system installed in green house for tomatoes plot at Western Region of Abu Dhabi, UAE in the month of May 2014. The experiment site was located in the Liwa Oasis which is about 95 km south of the Persian Gulf coast and 145 km SSW of the city of Abu Dhabi in the Al Gharbia (Western) Region, on the northern of Rub' al Khali desert. The soil of the green house was mostly sandy and the farmer mixed some amount of organic manure in order to increase the soil moisture holding capacity. The ground water table was around 60 meter deep due to which farmer was utilizing the fresh water provided by municipality.

Farm Size and Existing Drip System Design

The green house comprises of 5 hectares which is divided into several small sub plots with 1 water storage pond in order to store water for at least three days requirements. Mostly the farmer was growing tomato round, tomato beef, cucumber, capsicum (different varieties), red and green chilies, egg plant and koosa (Marrow). The existing drip irrigation system for the tomato plot consists of 8 laterals with 20 mm internal diameter and each lateral contain 30 online pressure compensating emitters while the internal diameter of submain and mainline was 40 mm and 60 mm respectively. The water source was at the distance of 10 m from the submain line. The spacing of emitters along the lateral was 0.50 m, and spacing of laterals was 0.66 m. Water was supplied to the drip unit at constant present head 20 psi (1.36 atm) pressure with 2 inch water pump.

Field Experiment

Hydraulic estimation of drip irrigation 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. Almost 72 emitters out of 240 i.e. 9 emitters for each laterals were randomly selected to conduct the experiment. Along each lateral, flow volumes were collected at three points, corresponding approximately to the head, mid-point and tail-end of each lateral. The irrigation system was then pressurized and 250 ml 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. Based on existing design the IrriPro software version 3.1 is used to generate drip layout and to carry out simulation. Finally obtained results from the field for each lateral were compared with the simulated data obtained from the IrriPro software.

Discharge of the flow through selected emitters was calculated by volumetric method simply, the collected volume of water was divided by the time. In this method the volume of water collected was kept constant. The discharge rate for each emitter after finishing the experiment was converted from milliliters per seconds to liters per hour.

Discharge Rate = Volume Collected (L) / Collecting Time (Hr) …. 1

The values of discharge rate were computer generated to calculate emitter flow rate variation, standard deviation and coefficient of variation.

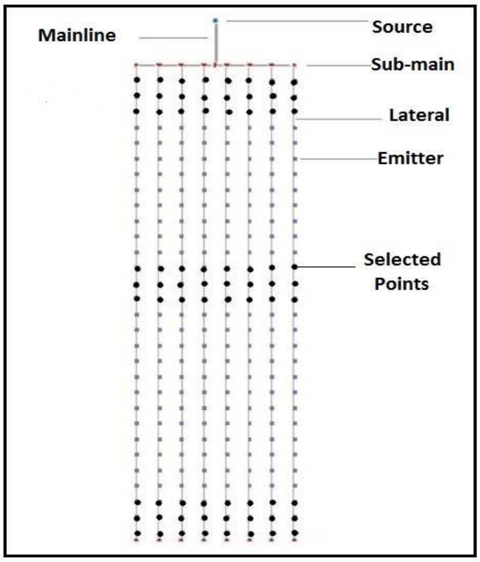

Figure 1. The layout of existing drip irrigation system

Governing Equations

In this research work, step by step (SBS) procedure is used to design an existing drip irrigation network in order to determine the behavior of the drip irrigation network and for this purpose the IRRIPRO software is used. IRRIPRO is a powerful product in the international context and it is based on an innovative algorithm allowing designing, managing and analyzing even complex irrigation systems; the proposed algorithm assures the correct and fast design of the irrigation systems, maintaining the necessary scientific accuracy with a sensible reduction of the computation time. The resolution algorithm, by means of an iterative calculation procedure, solves the continuity and motion equations managing the movement of water in pressure pipes (Savona et al, 2008).

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The SBS is usually used to design a single drip irrigation lateral and the results are then extended to all the laterals of a submain unit even if local conditions are different. Despite the SBS procedure allows detailed results and an exact solution for each lateral, it results time consuming for complex submain units for which the terrain altitude can sensibly vary from a point to another of the field. For this reason dedicated software can be considered a helpful tool to quickly solve the analytical problems related to complex irrigation networks, with the advantage to avoid tedious calculus (Savona et al, 2008).

The drip irrigation systems should be designed to attain relatively high values of the field emission uniformity coefficients (EU), which are affected by the variation of pressure head due to the elevation changes and to the head losses along the lines, as well as by manufacturer's variation, grouping of emitters, clogging, variability in soil hydraulic characteristic and emitter spacing (Wu, 1997). For a certain emitter model for which is known the manufacturer's coefficient of variation, CV, once established the number of emitters per plant and the emitter spacing, limitation of the pressure head along the laterals in a pre-fixed range of variability, can contribute to obtain high EU values, that can be expressed as

Christiansen's uniformity coefficient (CU) or lower quarter distribution uniformity coefficient (DU) calculated as:

$$CU = 1 - \frac{1}{Nq_{av}} \sum_{i=1}^{N} |q_i - q_{av}| \quad (2a)$$

$$DU = \frac{4}{Nq_{av}} \sum_{i=1}^{N/4} (q_{low})_i \quad (2b)$$

were qi, qav, qlow, are the generic, the average and the lowest flow rate of the emitters installed in a submain and N is the number of emitters. DU measures the consistency of water application across a field during irrigation, expressed as a percentage. DU of less than 70% is considered poor, between 70 - 90% is good, whereas DU greater than 90% is excellent. In short, poor DU means that either too much water is applied, costing unnecessary expense, or too little water is applied, causing stress to crops.

The uniformity distribution of discharge rate can be calculated by different statistical equations i.e. (i) Emission uniformity (EU), (ii) Statistical Uniformity (Us), and (iii) Absolute Uniformity Emission (EUa).

Karmeli e Keller (1975) defined the emission uniformity design coefficient, EU, as a function of the lowest and average discharge (qlow and qav) along the lateral or in the submain unit, due to the different pressure values along the laterals and the variation in discharge between emitters operating at the same pressure head. EU can be calculated as:

$$EU = 100 * \left[1 - 1.27 \frac{CV}{\sqrt{n}}\right] \left[\frac{q_{low}}{q_{av}}\right] \quad (2c)$$

Where; CV is the manufacturer's coefficient of variation, n is the number of emitters per plant, Qlow and Qav the minimum and average emitter discharge along the lateral or in the submain unit. According to index of emission uniformity, EU should not be less than 90% the values below 90% show poor emission uniformity.

The uniformity of water application can be calculated from the statistical distribution, (Us) of emitter flow rates that are measured in the field by Bralts and Kenser (Nakayama and Bucks, 1980).

$$U_s = (1 - Vq) = 100\,(1 - Sq / q) \quad (2d)$$

Where; Vq the total coefficient of variation for discharge, Sq standard deviation of discharge, and q mean emitter discharge. In statistical uniformity, Us values have categorized in different ranges. Us in between 60% - 70% is considered poor, between 70 - 80% is well, between 80% - 90% is very good, whereas DU greater than 90% is excellent.

This is defined by Keller and Karmeli (1974), and it focuses not only the possible effects derived from the lack of water in certain points of the emitters, but also the excess produced as a consequence of the application heterogeneity of the system. Mathematically it can be calculated by using the equation:

$$EUa = (100/2)(Qn / Qa + Qa / Qx) \quad (2e)$$

Where; EUa is absolute emission uniformity, Qx is average discharge rate for highest 1 / 8 of flowing emitters, Qa is average discharge rate for lowest 1 / 8 of flowing emitters, and Qn is average discharge rate. Absolute emission uniformity (EUa) should be greater than 90% to be accepted as the uniformity in the system.

RESULTS AND DISCUSSION

The present research study was carried out to determine the CU and DU of discharge through emitters by using software approach. In this study the amount of flow rate through the selected emitters of existing drip irrigation has been computed, simulation of drip network is determined and compared with the observed data. For this purpose IrriPro software is used to ensure its compatibility. Data pertaining to design parameters and drip irrigation geometry are provided to the software to compute the unknown parameters. Finally by using statistical approach the results are validated by comparing them with the observed data.

Average discharges (LPH) using pressure compensated type emitter when the length of the laterals was 16 meters.

The results of the observed average discharges (LPH) using pressure compensated type emitter by keeping length of the lateral 16 m are depicted in table 01. The average discharges of first, second, third, fourth, fifth, sixth, seventh and eighth laterals of nine randomly selected emitters at the head were 3.63, 3.63, 3.62, 3.63, 3.63, 3.63, 3.62 and 3.63 (LPH) respectively with an overall average discharge of 3.63 (LPH), while at the middle average discharges was slightly decreased to 3.55, 3.51, 3.52, 3.55, 3.58, 3.52, 3.54, 3.56, and 3.54 (LPH) with an overall average discharge of 3.54 (LPH). But at tail end average discharges variation was more and were measured 3.42, 3.38, 3.08, 3.23, 3.29, 3.18, 3.21, and 3.15 (LPH) with an overall average discharge of 3.24 (LPH).

Table 01: Average discharges (LPH) using pressure compensated type emitter when the length of the laterals was 16 meters.

Section of	Lateral 1	Lateral 2	Lateral 3	Lateral 4	Lateral 5	Lateral 6	Lateral 7	Lateral 8	Average

lateral									
Head	3.63	3.63	3.62	3.63	3.63	3.63	3.62	3.63	3.63
Middle	3.55	3.51	3.52	3.55	3.58	3.52	3.54	3.56	3.54
Tail	3.42	3.38	3.08	3.23	3.29	3.18	3.21	3.15	3.24

In view of all above given field results it has been observed that the mean discharge rate of all emitter was 3.47 Lit / hr and 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. The flow volumes along the lateral length are fairly consistent and the variation is small. The average flow rate (q_{var}) volumes fluctuation for field experiment was 0.1888 L and the standard deviation (Sd) was 0.1558 L. The observed 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. Table 2, illustrates the different irrigation uniformities of the system using pressure compensated type emitters when the length of laterals was kept 16 meters. The flow of emitters was used to calculate CU, DU, Us and EUa achieved the results are given in Table 2. The CU, DU, Us and EUa of randomly selected emitters for observed data with an average value of 96.4990%, 94.3605%, 95.6238%, 99.2192% respectively.

Table 2: Field Experiment Results

Results	**No of emitters**	**Standard deviation**	**Flow rate variation**	**Coefficient of uniformity**	**Distribution uniformity**	**Statistical uniformity**	**Abs uniformity emission**
		Sd	**q_{var}**	**Cu**	**DU %**	**Us %**	**Eua %**
Observed	72	0.1558	0.1888	96.4990	94.3605	95.6238	99.2192

The findings of this research work were quite similar to those reported by Bagdatlı and Acar (2009), the UC varied between 79.2% and 94.5% in their study. And also, in a study Safi et al., (2007) observed 96.9% and 91.8% UC values of the unused and used tapes, respectively. Finally the data of the design parameters and drip irrigation network geometry were put in to the IrriPro software for verification and the results are compared with the actual one.

IrriPro Simulations

The observed data was compared with the results given by IrriPro software. The predicted profile under estimated the actual one, especially at the lateral far end. This occurs due to the uncontrollable parameters which affects flow rate such as undulating of filed topography, emitter wear, temperature, emitter clogging, and velocity head.

The data of the design parameters and drip irrigation network geometry were put in to the IrriPro software for verification. The following problems are to be considered for analysis and computation

- Verification of the design of drip irrigation network by determining the legend colors i.e. Green (acceptable), Yellow (limit of acceptability) and Red (not acceptable),
- Computation of discharge rate by using IrriPro software,
- Acceptability of the input data and results according to software analysis, and
- Predictions of ideal pressures and Flowrate for the existing trickle / drip irrigation network.

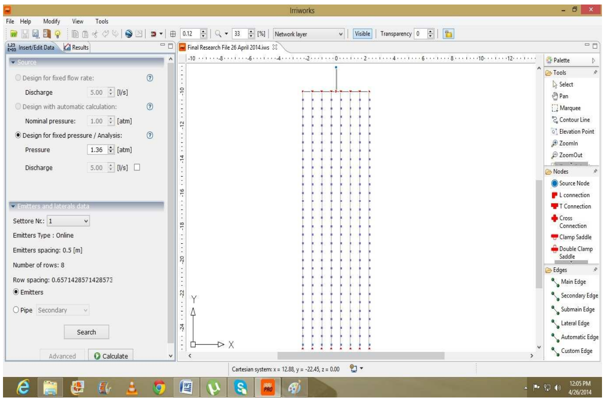

Fig 2 (a) Main screen showing the design of existing drip irrigation network

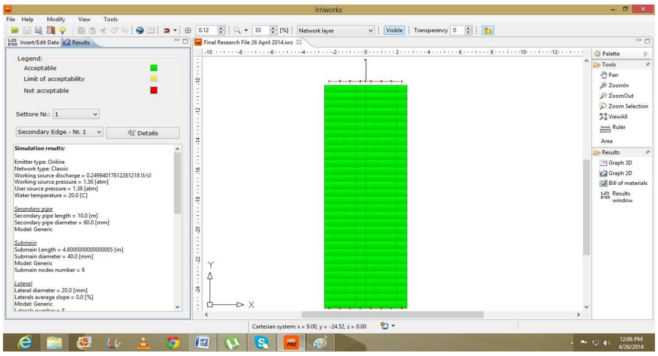

Fig 2 (b) Simulation screen showing that the design is within range

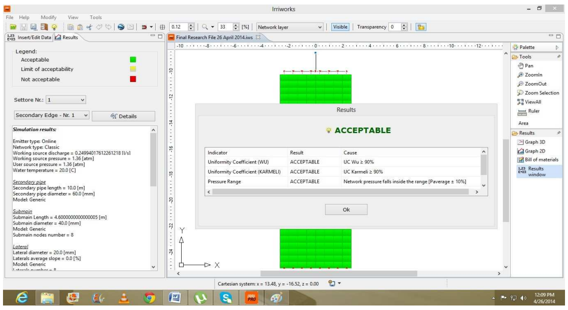

Fig 2 (c) Results screen showing that hydraulic data (input) is acceptable

The screen page of the software in which the design parameters are inserted is shown in Fig 2 (a). The program displayed the output regarding the verification of the design of existing drip irrigation network. The software analyzed the data by using hydraulic principles and reported that the design is acceptable. In Fig 2 (b) the software simulated the picture with Green Legendary color which describes that the input data and designing of drip irrigation network is acceptable. And the Fig 2 (c) describes the uniformity coefficient results given by software.

The detail analysis and report made by the software is depicted as under.

Simulation results given by the IrriPro software;

Input Parameters

- Emitter type: Online
- Network type: Classic
- Working source discharge = 0.24928848914927668 [l/s]
- Working source pressure = 1.36 [atm]
- User source pressure = 1.36 [atm]
- Water temperature = 20.0 [C]

Secondary pipe

- Secondary pipe length = 10.0 [m]
- Secondary pipe diameter = 60.0 [mm]
- Model: Generic

Submain

- Submain Length = 4.6000000000000005 [m]
- Submain diameter = 40.0000000000002 [mm]
- Model: Generic
- Submain nodes number = 8

Lateral

- Lateral diameter = 20.0 [mm]
- Laterals average slope = 0.0 [%]
- Model: Generic
- Laterals number = 8

Emitters

- No of emitters = 240
- No of maximum of emitters per lateral = 30
- No of minimum of emitters per lateral = 30
- Model: Generic

Crop arrangement

- Emitters spacing = 0.5 [m]
- Row spacing = 0.66 [m]

Results

- Uniformity coefficient (WU)= 99.92333618226714 [%]
- Uniformity coefficient (Keller e Karmeli)= 99.79764690338061 [%]

Evaluation of design criteria for drip emitters

- Maximum flow rate = 3.747848514956421 [l/h]
- Minimum flow rate = 3.736099321379795 [l/h]
- Average flow rate = 3.7393269386262906 [l/h]
- Maximum pressure head = 14.046368491061049 [m c.a.] (1.36 [atm])
- Minimum pressure head = 13.958438139214564 [m c.a.] (1.35 [atm])
- Average pressure head = 13.982577646970872 [m c.a.] (1.35 [atm])
- Sector surface = 0.007885714285714288 [mm/h] (78.85714285714288 [m²])
- Average intensity of water distribution = 11.380560247993056 [mm/h]
- Maximum head loss compared to source = 0.10751105278543704 [m]

Comparison of observed vs. simulated results

On the basis of all above given facts Table 3, illustrates the EU of the system using pressure compensated type emitters when the length of laterals was kept 16 meters. The results show that the IrriPro software has evaluated the design data of existing drip irrigation system and concluded that the design is acceptable with all other hydraulic parameters such as Uniformity Distribution (DU), Uniformity coefficient (CU), Maximum flow rate, Minimum flow rate, Average flow rate, Maximum pressure head, Minimum pressure head, Average pressure head, and Average intensity of water distribution which indicate the operational viability of IRRIPRO.

Table 3: Comparison of observed vs. simulated results

Results	No of emitters	Standard deviation	Flow rate variation	Coefficient of uniformity	Distribution uniformity	Statistical uniformity	Abs uniformity emission
		Sd	q_{var}	Cu	DU %	Us %	Eua %
Observed	72	0.1558	0.1888	96.4990	94.3605	95.6238	99.2192
Simulated	72	0.0003	0.0031	99.9796	99.8822	99.9087	99.9316

Mean emitter flow rates measured verses simulated at head point; midpoint and tail end for all eight laterals are presented in Fig 3. The statistical analysis did not imply any significant differences between the predicted and measured mean flow rates of emitters along laterals. Additional analysis was also carried out to find out the relation between the simulated flow rate at the inlet and far end of laterals to the actual measurements of the flow rate at the same locations in filed. The results displayed no significant difference between them except at the tail end, the variation was mainly due to clogging of emitters. Results of the statistical analysis which correlate predicted flow and pressure by the model with measured flow in field are presented in Table 4:

Table 4: Comparison of Actual verses Simulated mean emitter flow rates of all eight laterals

Parameters	Lateral Relative Length		
	Head Lit / Hr	Mid point Lit / Hr	Tail Lit / Hr
Mean Flow Rate (Actual)	3.63	3.54	3.24
Mean Flow Rate (Simulated)	3.75	3.74	3.73

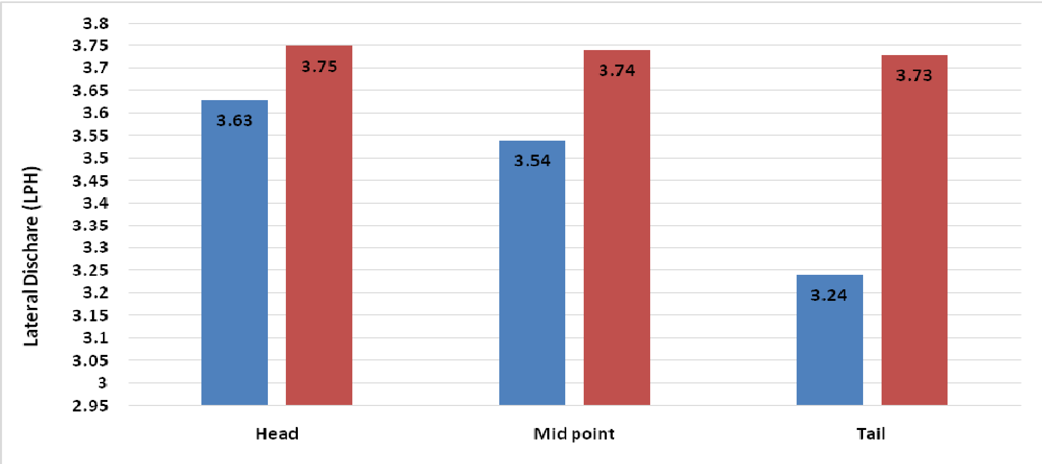

Fig 3: Comparison of Actual vs Simulated mean emitter flow rates of all eight laterals

Predictions of Flowrate and Pressure Head for Existing Drip Irrigation System by IRRIPRO Software

IrriPro software also predicts the different flow rate and pressure conditions for the drip irrigation system. According to software analysis the ideal pressure for existing drip irrigation was 13.353 m c.a (1.29 atm) which gives 3.655 lit / hr flow rate for all emitters. However, if the pressure maintained between 13.25 m c.a (1.28 atm) to 12.65 m c.a (1.25 atm) which gives the flow rate of 3.655 to 3.555 lit / hr respectively to the emitters which is also somehow acceptable. But, if the pressure exceed 15.561 m c.a (1.50 atm) or decreased up to 12.55 m c.a (1.21 atm) which give the flow rate of 4.037 lit / hr and 3.462 lit / hr respectively, then the system will not work properly and uniform distribution of discharge rate and uniformity coefficient suffers. Figure 4 (a) and Figure 4 (b) describes the simulation of pressure and flow rate distribution pattern respectively where green block shows acceptability, yellow shows somehow acceptable and red shows not acceptable.

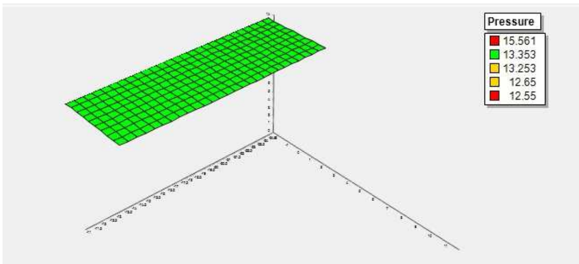

Fig 4 (a): Pressure acceptability limits for existing drip irrigation network

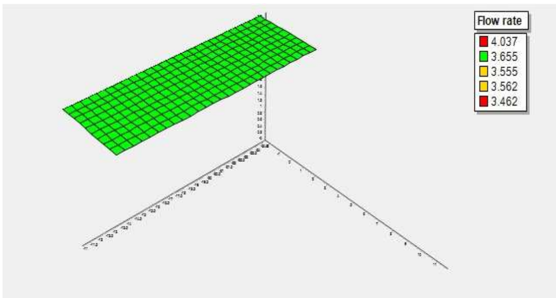

Fig 4 (b): Flow rate acceptability limits for existing drip irrigation network

Conclusions

Abundant water supply is imperative to enhance good crop growth. As the drip irrigation can irrigate directly to the crop root zone, it is a popular irrigation method in arid and semi-arid area. Keeping in view this fact an experiment was conducted at Western Region of Abu Dhabi, UAE in order to evaluate the different irrigation uniformities of the existing trickle / drip irrigation system and to idealize the behavior of the irrigation network by using IrriPro software for simulations.

Results of the study revealed that the drip irrigation achieved high uniformity coefficient and distribution uniformity which describes that the existing drip irrigation was designed on the basis of proper scaling and dimensions. The CU on average basis for the system was found to be 96.4990% (observed) and 99.9796% (simulated) respectively. Similarly, the DU on average basis for the system was found to be 94.3605% (observed) and 99.8822% (simulated) respectively. EUa of the system using pressure compensated type emitters with the length of laterals 16 meters with an average observed and simulated value was found 99.2192% and 99.99316% respectively. The comparison of experimental and simulated result shows that the application uniformity seems to be satisfactory and the existing drip irrigation unit was designed properly. However, it may be improved by removal of clogging. As the irrigated water is free of dissolved salts, proper filtration may help to improve application uniformity of the system.

The design of the existing drip irrigation network was checked by the interactive computer software i.e. IRRIPRO which was found acceptable. The uncertainty in results was found less than 10% which indicates its accuracy. In both methods i.e. experimental and simulated methods the values of irrigation uniformities and flowrate are within range and very close to each other by keeping very low the computational time. IRRIPRO software also predicts that the ideal pressure for existing drip irrigation was 13.353 m c.a (1.29 atm) which gives 3.655 lit / hr flow rate for all emitters. Figure 4 (a) and Figure 4 (b) describes the simulation of pressure and flow rate distribution pattern where green block shows acceptability, yellow shows somehow acceptable and red shows not acceptable. The uniformity analysis could be modified by restricting the irrigation domain to the most effected boundary in order to get more significant comparing results.

From this research work we can conclude that IRRIPRO can help the water resource engineer to use it in testing and analyzing any alternative design hydraulically and economically. As IRRIPRO is providing the ideal results for the existing drip irrigation system it will be more as compared to the field results. This software could also be used to calculate the annual costs of any system even if it is not designed by IRRIPRO.

Suggestions

This research study suggests that IRRIPRO requires that the user be proficient in design concepts and well cognizant with drip irrigation design technology. For the safe keeping of the drip irrigation subunit the farmers should also give suitable training(s) for installation and maintenance of trickle / drip irrigation system, so that they may become self –dependant for installation and may carry out maintenance work when in need.

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