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STUDY ON PRESSURE-DISCHARGE RELATIONSHIP AND WETTING PATTERN UNDER DRIP IRRIGATION SYSTEM

[1]Kyada, P. M. & [2]Munjapara, B. J.
[1]G. B. Pant University of Agriculture and Technology, Pantnagar (UK), India
[2]Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India

ABSTRACT
The experiment was conducted to determine the coefficient of manufacturing variations in emitting rates of drippers of different rating, pressure discharge relationships and wetting front movement for various emitter rating and durations. The pressure of 0.25, 0.5, 0.75, 1.0, and 1.25 kg cm-1 was set turn wise and the volume of water dripped out from the different drippers was collected separately from each of five drippers for one hr and the discharge rates were calculated separately for all set pressures. The various forms of the mathematical models were fitted to these data of pressure-discharge and the best fitted model was proposed for the pressure discharge relationships for all the emitter ratings. The co-efficient of manufacturing variation of commonly used drippers of 2, 4, 8, 14 and 20 lph, were determined by measuring the discharge of drippers at 1.0 kg cm-1 operating pressure. The drippers of different discharge capacity were fitted on the lateral separately at required operating spacing to measure the wetted bulb. The system was run for one hr and the dimensions of the vertical section of the wetted bulb were measured after 24 hr of termination of the water application. The location of the laterals with drippers was changed each time and the water application was made for 2 hr, 3 hr, 4 hr and 5 hrs separately. The vertical and horizontal dimensions of the wetted bulb were measured for various dripper capacity and water application times. The power form was found best fitted for the pressure-discharge relationship for all drippers of the different emitter rating. The coefficient of manufacturing variations in emitting rate for 2 lph (Netafim), 4 lph (EPC), 8lph (JISL), 14 lph (JISL) and 20 lph (Netafim) drippers could be found as 7.95%, 4.95%, 2.85%, 0.89% and 0.86%, respectively. The horizontal and vertical movements of the wetted bulb were found increased with time and also with emitting rates. The best fitted power form of the models could be developed to predict the horizontal and vertical movement of wetting front for the sound design of drip irrigation system and planning schedule for various crops to match their varying root zone temporally.

KEYWORDS: Drip Irrigation, Pressure-Discharge Relationship, Manufacturing Variation, Wetting Pattern.

INTRODUCTION

Water resources of a country constitute one of its vital assets. India occupies only 3.29 million sq. km geographical area, which forms 2.4% of the world's land area; it supports over 15% of the world's population. India receives annual precipitation of about 4000 km^3. The rainfall in India shows very high spatial and temporal variability and paradox of the situation is that Mousinram near Cherrapunji, which receives the highest rainfall in the world, also suffers from a shortage of water during the non-rainy season, almost every year. The total average annual flow per year for the Indian rivers is estimated as 1953 km^3. The total annual replenish able groundwater resources are assessed as 432 km^3. Water resources in Gujarat are concentrated primarily in the southern and central part of the mainland. Saurashtra and Kutch in the western mainland, with exceptionally high irrigation needs, have limited surface and groundwater resources. Groundwater and surface water are the two different sources from which water is utilized for irrigation purposes. These two sources are mainly replenished by rainfall and stream flow. Gujarat mainland region receives an average annual rainfall of 800 to 2000 mm, while Saurashtra has an average annual rainfall of 400 to 800 mm. The annual rainfall in Kutch is less than 400 mm. The incidence and distribution of rainfall, particularly in Saurashtra and Kutch regions and in the northern part of Gujarat region, is highly erratic.

The efficient use of water and the safe reuse of waste water are the most economical and often the only sources of additional water and, at the same time, the most effective means of controlling water pollution. The drip irrigation is one of the efficient MIS. It applies the water directly to the root zone as per the crop requirements. With the help of the drip irrigation it is easy to control the water applications matching the temporal variability of the crops water requirements The drip irrigation has several advantages over the rest methods of the irrigation but its adoption requires technical knowhow in selection of types of system, its components, design, installation, operation and maintenance. Among these, the selection of the dripper discharge and its spacing requires due technical cares as it serves the important function of dripping the water for the plant root zone. Therefore, the best combinations of the dripper discharge and spacing should be made so that it can provide the enough moisture to the plant keeping in view the temporal variations of the root zone area during the growing period of the crop.

The relevant literature and past works done on various aspects related to the study like pressure discharge relationships, manufacturing variations, and wetting front movements and model ling were reviewed and are discussed hereunder in the following subheads. The testing of seven emitters for their pressure discharge relationship, manufacturing coefficients and emission uniformity coefficients were conducted, and result indicated that pressure-discharge relationship followed a power function Sharma *et al.* (2005). Thabet and Zayani (2008) conducted the experiment to determine the effect of different discharge values on the wetting patterns of a loamy sand soil under trickle source. The experiment was conducted in two undisturbed monoliths, equipped with a transparent Plexiglas front to make easy learning and measuring the wetting front coordinates. Ozekici and Sneed (1990) conducted an experiment and collected discharge rates from different types of drip irrigation emitters at five different pressure level. Krnak *et al.* (2004) conducted the experiment on the efficiency of trickle irrigation systems which depends on system uniformity, which can be determined by water discharge uniformity from emitters. Kumar and Singh (2007) conducted the experiment to evaluate the hydraulic performance of drip irrigation system with four emission devices viz dripper, micro-tube, drip-in and drip tape. Gil *et al.* (2008) determined the emitter coefficient of flow variation CVq which was measured in laboratory experiments with drippers of 2 and 4 lph that were laid both on the soil and beneath it. Hezarjaribi *et al.*(2008) conducted the study to collect discharge rates at 4 different pressure levels of 50, 100, 150 and 200 kPa to assess the hydraulic performances of various kinds of emitters (including Mono-tandem, Hydrogol, In line-168, Matic, Katif 4 and Katif 8), for determining the coefficient of manufacturing variation, emitter discharge coefficient and emitter discharge exponent, to establish the emitter's flow rate sensitivity to pressure and comparing the results to the manufactures' specifications. Zhu *et al.* (2010) conducted the experiment to study influence on the uniformity of drip irrigation system water application.

Shein *et al.* (1988) found that the location and shape of the wetting profile produced by trickle irrigation is governed by the pre-irrigation moisture tension distribution in the horizontal and vertical directions. Gontia (1990) studied the moisture distribution pattern under drip source. He has obtained the relationship between horizontal and vertical advances of water front with time of supply. Singh *et al.* (1990) studied the horizontal and vertical advances of moisture fronts in fallow land for different discharges. Catzflis and Mortononi (1993) suggested that while designing the trickle irrigation system a proper combination of type of dripper its discharge, time of supply, spacing between two drippers should be there for a given set of crop. Soil and climatic conditions should be taken in to account. Hammami *et al.*(1994) represented that a simple approach to estimate the maximum depth of wetting front under drip irrigation was studied by observing the wetting front radius evolution at the soil surface. Dhanapal *et al.* (1995) determined wetting fronts and volume of active root zone in coconut basins (manufacturing-circular area around the bole) wetted with three quantities of water application. Maheswarappa *et al.*(1997) studied that the wetting front under drip [trickle] irrigation in a coconut garden on littoral sand in Kasaragod, India. Raats,P. A. C.(1974) found that the steady state theory is here extended to provide an approximate analysis of the transient pattern of wetting around a point source. Battam *et al.* (2002) developed new method in Sydney, Australia, for the accurate design and management of drip irrigation systems. Rosa *et al.*(2004) studied the soil water movement of a soil layer irrigated by a drip emitter, and determined the optimum irrigation for Pupunha palm tree (Bactrisgasipaes) cultivation. Mashru *et al.* (2005) studied the size and shape of wetted bulb formed by drip irrigation method in two layered soil profile in relation to soil properties (i.e., infiltration), water application rate and time for a given soil. Li-MingSi *et al.* (2006) studied the effect on soil wetting pattern, the dripper discharge influences the root development of crops. In the design of drip irrigation system, the dripper discharge should be reasonably determined according to the relationships between dripper discharge and soil wetting pattern. Wang-ChengZhi *et al.* (2006) studied to analyze the laws of soil water movement of point source interference infiltration and evaporation using super absorbent polymer. Elmaloglou and Diamantopoulos (2007) suggested that increased use of trickle irrigation is seen as a way to improve the sustainability of irrigation systems around the world. Thabet and Zayani (2008) conducted the experiment to determine the effect of different discharge values on the wetting patterns of a loamy sand soil under trickle source. Padmakumari and Sivanappan (1998) studied to identify how best to adjust the drip system to the soil hydraulic properties and the crop requirements.

Keeping in view the above facts, the present study has been planned for the objectives given in subsequent chapter. The present study is planned for the following objectives. (i)-To determine the pressure discharge relationship for the drippers of different capacity. (ii)-To determine the coefficient of manufacturing variations in emitting rate of the drippers of different capacity. (iii)-To determine the wetting front movement under dripper of different capacity at various times of water application. (iv)-To develop the mathematical model for the wetting front movement under dripper.

MATERIALS & METHODS

Location: The Experiments were conducted at Instructional Farm of College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh. It is located at 21.5° N latitude and 70.1° E longitude with on altitude of 60 meter above mean see level.

Climate of area: The climate of area is subtropical and semi-arid type with an average annual rainfall of 900 mm and average annual pan evaporation of 6.41 mm day^{-1}. May is the hottest month with mean weekly pan evaporation of 10.95 cm and mean monthly temperature varying between 35 °C to 45 °C and January is the coolest month with mean monthly minimum temperature varying between 7 °C and 10 °C as observed from the 10 years data collected by meteorological observatory, Krushigadh, JAU, Junagadh.

Soil properties: The soil properties of the soil were determined by Rank (2006). As the experiment was conducted in the same plot, the soil properties were not determined. As reported by Rank (2006), the texture of the soil of the study area was clay loamy. The proportions of sand, silt and clay were 22.9 %, 38.42 % and 38.68 %, respectively. The dry bulk density of soil was 1.44 g cm^{-3}. The particle density of the soil was 2.54 gm cm^{-3}. The PH, EC, Field capacity and wilting point of the study area were 8.85 (1:2.5), 0.30 (ds m^{-1}), 24.8 % and 12.9 %, respectively. The N, P and K of the study area were 256 (kg ha^{-1}), 30 (kg ha^{-1}) and 290 (kg ha^{-1}), respectively.

Materials: Materials which were required for conducting the experiments studies are described here under with detail specifications:

Water source: The water tank size of 1m×1.5m×2m was used as source for the water supply.

Pumping Set: The 25mm x 25mm single phase 1 hp pump was used to supply the water for the drip irrigation. The delivery line was PVC having size of 25 mm.

Conveyance Pipe: The plastic pipe of 32 mm × 2 kg cm^{-2} was used for conveying the water to the experimental site.

By pass Assembly: The bypass assembly of 32 mm size was fitted on main line after the conveyance pipe connection with the main line.

Pressure Gauge: The pressure gauge of 0 to 6 kg cm^{-2} was fitted on the main line before bypass valve and was used.

Main Line/Submain Line: The main line of 32mm plastic pipe was connected with 25mm pump outlet of drip system of the experimental set up. The 32mm X 4 kg $cm^{-2.}$ PVC was used as main/sub main.

Lateral: The blacked colored LLDPE of 16 mm diameter was used. The online dripper of 2, 4, 8, 14 and 20 lph was fitted at 1.5 m spacing on lateral. The one end of the lateral of 6 m length was connected to the sub main line with the help of 16 mm gromate takeoff and other end of the lateral was closed by end stop of 16 mm.

Experimental set up

The experimental set up is as shown in Fig.1 and 2, respectively. The experiment was conducted at Instructional Farm of College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh. The water tank size of 1m×1.5m×2m was used as source for the water supply. The 25mm x 25mm single phase 1 hp pump was used to supply the water for the experiment set up. The necessary fittings have been used to connect flexible 32mm plastic pipe with 25mm pump outlet to the mainline of drip system of the experimental set up. The 32mm X 4 kg cm^{-2} PVC was used as main/sub main. The required laterals of 16mm LLDPE laterals were connected with sub main using gromate take off. The 32 mm valve was used to control the inflow and pressure to the system. The 16mm cock was fitted on lateral to regulate the flow in the lateral.

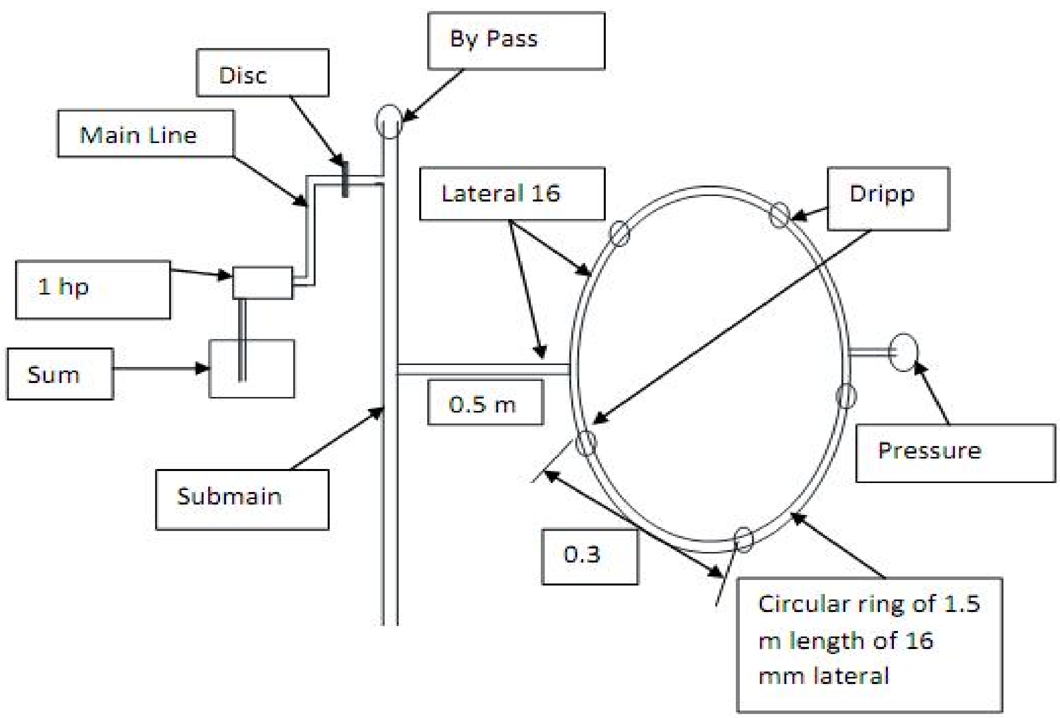

FIGURE1. Experimental set-up for determining the pressure-discharge relationships and coefficient of manufacturing variations in dripper discharge

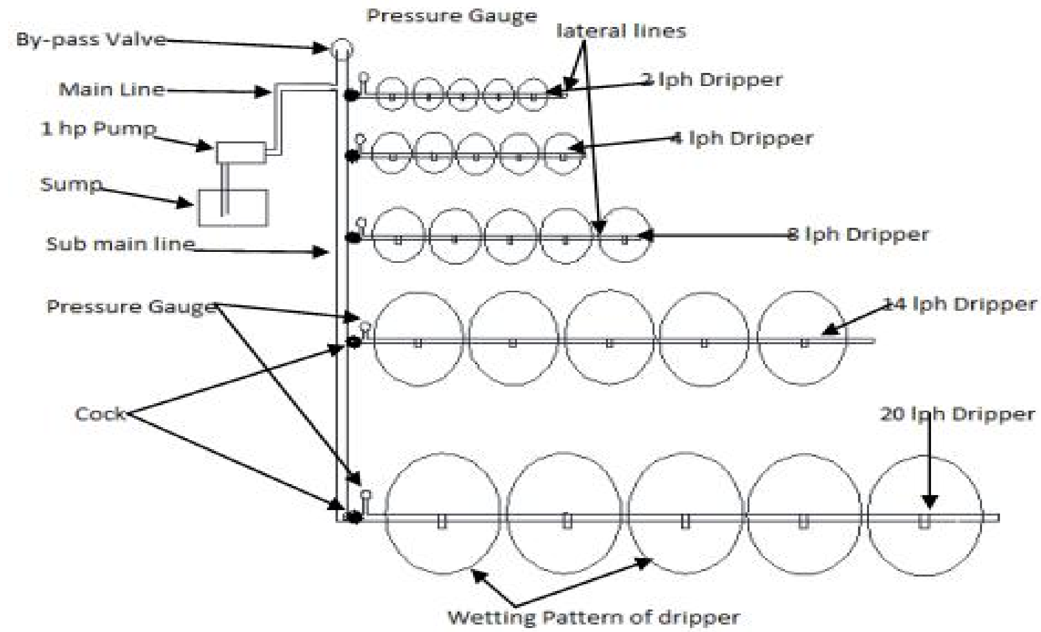

FIGURE 2. Experimental Set-up for determining the wetting front movement

Pressure Discharge Relationship

The experimental set up as presented in Fig.1 was used for the study. The 16 mm lateral of 1.5 m was connected to sub main of 40 mm×4 kg cm^{-2} PVC pipe. The circular ring from 1.5 m lateral of 16 mm was made and both ends were connected 16 mm Tee. The Third end of Tee was connected to 16 mm lateral of 0.5 m length, are end of which was connected with sub main by gromate take-off.

The five drippers of same capacity (say either of 2, 4, 8, 14 and 20 lph) were taken and fitted at 0.3 m on circular ring of 16 mm lateral. The pressure of 0.25 kg cm^{-2} was set and the volume of water dripped cut from the dripper was collected separately from each of five drippers for 1 hr and the discharge rate was calculated for the 0.25 kg cm^{-2}. The average of their five discharges of dripper was taken as discharge rate for the set pressure of 0.25 kg cm^{-2}. Similarly the discharge rates were obtained for 0.5, 0.75, 1.0 and 1.25 kg cm^{-2}. Similarly, the pressure discharge data were obtained for each of 2, 4, 8, 14 and 20 lph dripper.

The discharge rates at various operating pressures were measured and the time was noted for collecting the volume of water in a beaker. The discharges were calculated by following formula:

Q=(V/t)………………………………………………..(1)

Where , Q=Dripper discharge (lph)

V=Volume of water collected in beaker, literst

t=Time taken to collect volume (V) of water (hr)

The input pressure to dripper was measured by pressure gauge connected at inlet lateral. Pressure of 0.25 kg cm^{-2}, 0.5 kg cm^{-2}, 0.75 kg cm^{-2} 1.0 kg cm^{-2} and 1.25 kg cm^{-2} was maintained and discharge was measured. The mathematical and graphical relationship developed using observed data on pressure-discharge.

Dripper flow rate will be expressed as a function of pressure in the following manner:

$Q=KP^X$………………………………………………….(2)

Where, Q= dripper discharge (lph),

P= operating pressure (kg cm^{-2}),

K=Coefficient of proportionality that characterize dripper and depend on nozzle size and shape and

X= emitter discharge exponent which characterize the flow regime.

The observed data of Q and P was plotted through Excel and the best fitted model with highest R^2 was determined.

Coefficient of Manufacturing Variations

The experimental set up as shown in Fig. 1 was used for this part of study. The co-efficient of manufacturing variation of commonly used drippers of 2, 4, 8, 14 and 20 lph, were determined.

5 nos. of each of 2, 4, 8, 14 and 20lph drippers were fitted separately on the circular ring of 16mm lateral line and the required operating pressure of 1.0 kg cm^{-2} was applied and the discharge of the each of five drippers was calculated. Manufacturing variability for 2, 4, 8, 14 and 20 lph was obtained using following formula:

$C_V=(S/q)\times100$………………………………………..(3)

Where,

Cv = co-efficient of manufacturing variation in percent,

S = sample standard deviation (lph) and

q= mean emission rate of sample (lph).

Wetting Front Movement:

The experimental set up as presented in Fig.2 was used for the study. The drippers of different discharge capacity were fitted on the lateral separately at required operating spacing. The system was run for 1hr and the dimensions of the vertical section of the wetted bulb were measured after 24 hr of termination of the water application. The location of the laterals with drippers was changed each time and the water application was made for 2 hr, 3 hr, 4 hr, and 5 hrs separately. The vertical and horizontal dimensions of the wetted bulb were measured for various dripper capacity and water application times.

Mathematical Modeling

The mathematical model was developed for the horizontal and vertical movements of wetting front movements for the inputs of time and dripper discharge as below.

$X = f(Q, t) = C_x Q^{ax} t^{bx}$

$Y = f(Q, t) = C_y Q^{ay} t^{by}$

Where, X = horizontal spread of the wetted bulb at surface (cm),
Y = vertical depth of the wetted bulb below dripper point (cm),
Q=dripper discharge (lph),
t=water application time (hr) and
C_x, C_y, ax, bx, ay and ay = empirical constants.

RESULT AND DISCUSSION

The experiment was conducted at Instructional Farm, CAET, JAU, Junagadh to determine the pressure discharge relationship, coefficient of manufacturing variations and soil wetting front movement for emitters of different rating. The observed data was analyzed, and the results so obtained are discussed in the following subsequent heads. The Mathematical models were also developed and discussed.

Pressure discharge relationship:

Different drippers with different discharge rating were selected for measuring the discharge at each operating pressure. The observed data of discharge of different drippers at various operating pressure are presented in Table 1. From Table 1 it could be seen that the discharge from the different drippers of all rating was increased with increase in operating pressure. The power form of the mathematical relationships as presented in Table 2 was found for the pressure-discharge relationships.

TABLE 1. Pressure discharge relationship for different dripper discharge rating

Pressure	Dripper Discharge(lph)				
(kg cm^{-2})	2	4	8	14	20
0.25	0.82	2.68	5.86	10.61	15.16
0.50	1.27	2.81	6.63	12.24	17.49
0.75	1.66	3.63	7.42	13.29	19.23
1.00	1.81	4.06	7.91	14.07	20.09
1.25	2.02	4.31	8.29	14.83	21.19

TABLE 2. Developed models for the pressure discharge relationship

Dripper discharge rating (lph)	Developed Model	R^2
2	$Q = 1.841P^{0.564}$	0.989
4	$Q = 3.940P^{0.320}$	0.901
8	$Q = 7.874P^{0.219}$	0.993
14	$Q = 14.11P^{0.206}$	0.999
20	$Q = 20.22P^{0.207}$	0.998

Where,Q= Dripper discharge (lph),
P= Pressure input (kg/sq. cm) and
R^2= Goodness of fit.

It could be seen from Table 2 that in case of all the dripper discharge rating, the exponent of the pressure was less than and equal to 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.

Coefficient of Manufacturing Variations:

The co-efficient of manufacturing variations was determined using observed data on emitting rate at 1.0 kg cm^{-2} operating pressure through the experiment. The results obtained through analysis are given in Table 3. The maximum co-efficient of manufacturing variations of 7.95 % was obtained for 2 lph dripper rating (Netafim) while that was minimum of 0.86% for 20 lph dripper rating (Netafim).

TABLE 3. Coefficient of manufacturing variation of selected drippers of different discharge rating

Selected Dripper Capacity(lph)	Average Discharge at 1.0 kg cm^{-2} (lph)	Coefficient of manufacturing variation (CV %) in emitting rate	Make
2	2.00	7.95	Netafim
4	4.06	4.95	EPC
8	7.91	2.85	JISL
14	14.07	0.89	JISL
20	21.19	0.86	Netafim

Wetting Front Movement:

The diameter of wetted surface and depth were measured for different times in two dimensions namely N-S and E-W with dripper flow rates of 2lph. The measured average diameters for different times are presented in Fig. 3. Similar data for 4 lph, 8 lph, 14 lph and 20 lph are presented in Fig. 4, 5, 6 and 7. From Fig. 3, it is seen that for 2 lph discharge dripper, the radius was increasing very rapidly in the beginning and increasing very slowly at later times. Similar trend was observed for 4, 8, 14, 20 lph discharge drippers also.

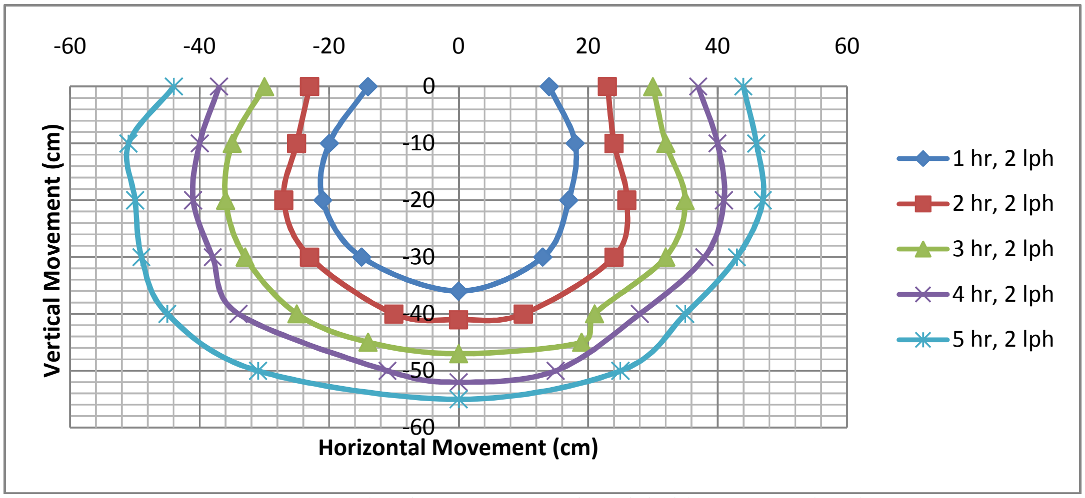

FIGURE 3. Wetting front movement for 2 lph dripper at varying time

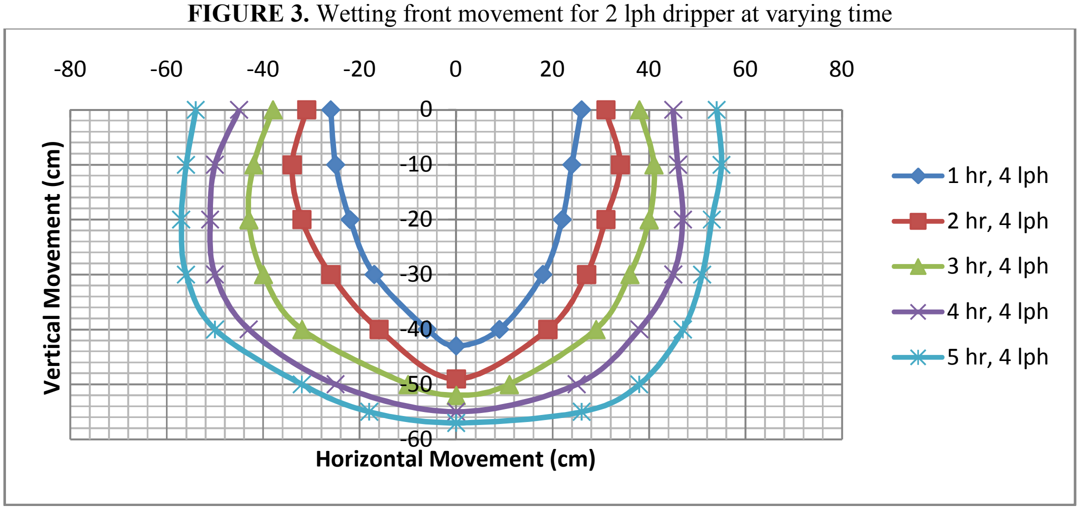

FIGURE 4. Wetting front movement for 4 lph dripper at varying time

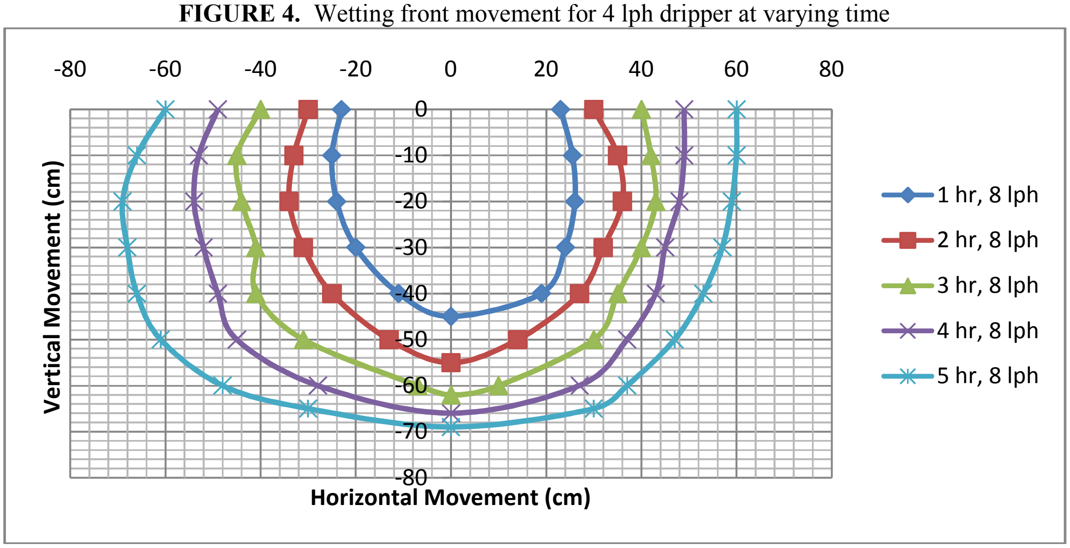

FIGURE 5. Wetting front movement for 8 lph dripper at varying time

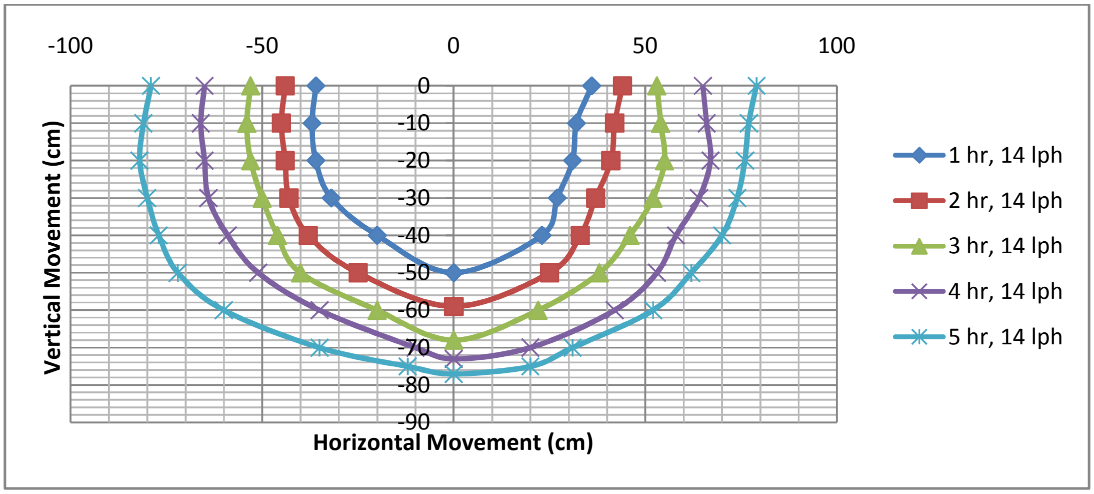

FIGURE 6. Wetting front movement for 14 lph dripper at varying time

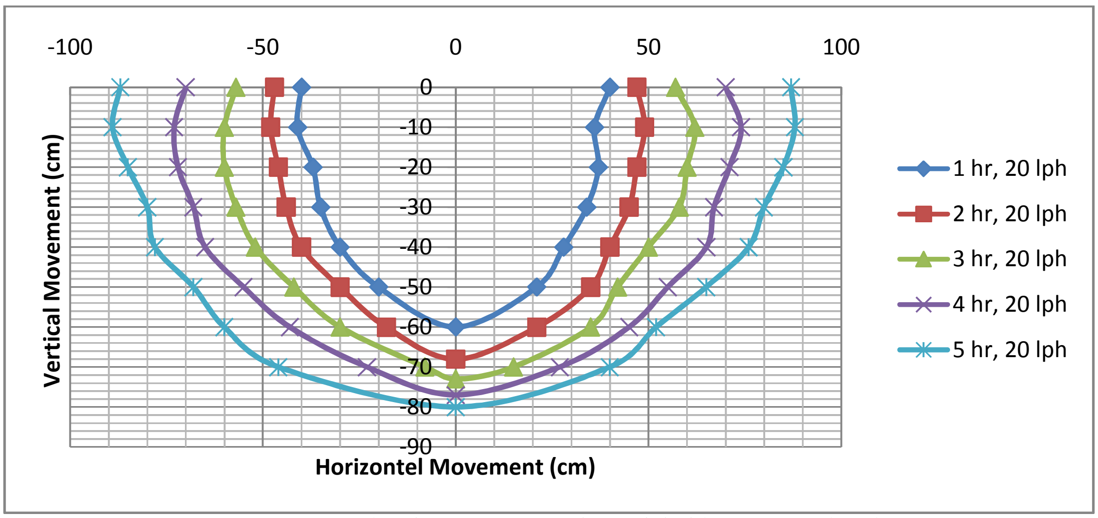

FIGURE 7. Wetting front movement for 20 lph dripper at varying time

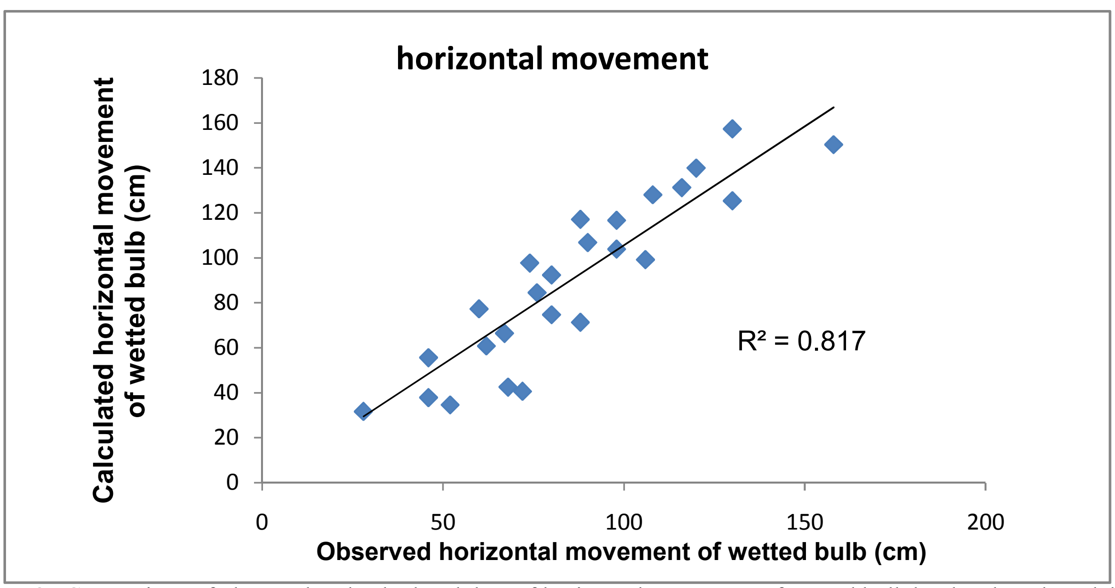

FIGURE 8. Comparison of observed and calculated data of horizontal movement of wetted bulb by developed model $X = 28.9308 \times Q^{0.1283} \times T^{0.8137}$.

Mathematical Modeling

The data of diameter of wetted bulb at surface and depth of wetted bulb below point source observed at various times for different discharge drippers were utilized to develop the models separately for the horizontal and vertical movement. The following models were found best to determine the observed data of horizontal and vertical movement of wetted bulb. The Fig. 8 and Fig. 9 shows the R^2 values below.

$\mathbf{X = 28.9308 \times Q^{0.1283} \times T^{0.8137}}$ with ($R^2 = 0.817$)

$\mathbf{Y= 18.3943 \times Q^{0.4996} \times T^{0.1954}}$ with ($R^2= 0.672$)

Where,
X=horizontal movement of water (cm),
Y= vertical movement of water (cm),
Q=dripper discharge capacity (lph) and
T=time duration (hr).

The R^2 values show that the developed models can be used to predict the size of the wetted bulb for various emitters rating and water application. The models can be very useful for sound design of drip irrigation system for various crops of temporal varying rooting zone.

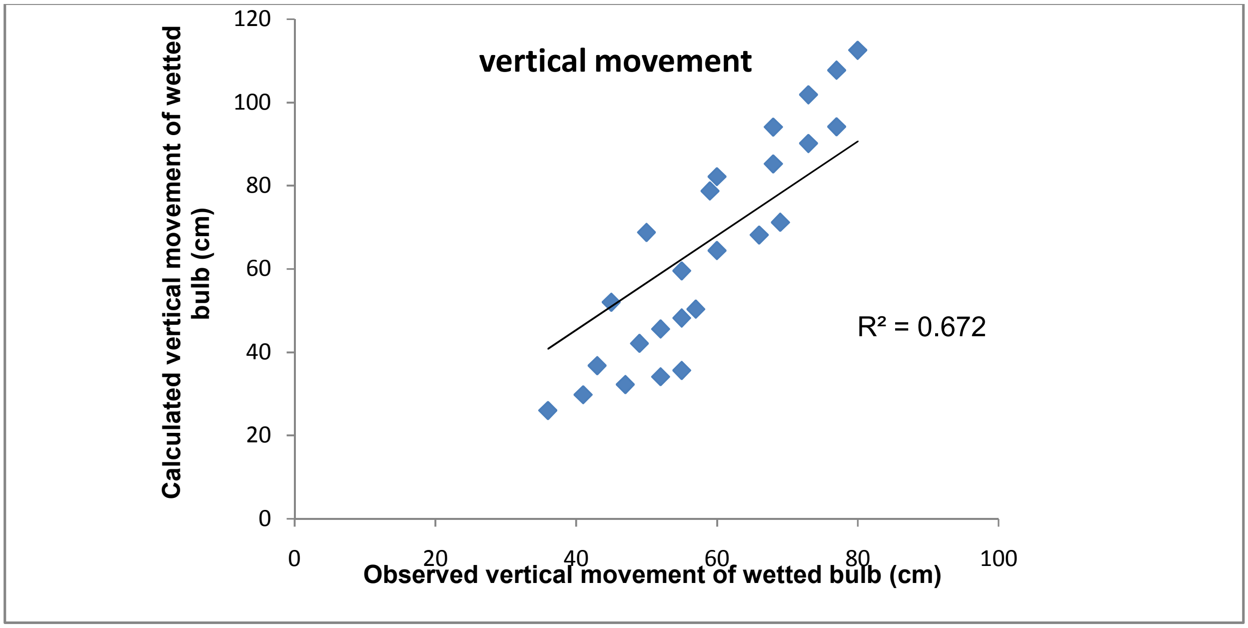

FIGURE 9. Comparison of observed and calculated data of vertical movement of wetted bulb by developed model $Y= 18.3943 \times Q^{0.4996} \times T^{0.1954}$

CONCLUSION

The following conclusion could be skimmed out after churning the results obtained through analysis of observed data.

1. The pressure discharge relationship of different emitter rating can be modeled as below.
   a. $Q = 1.841P^{0.564}$ ($R^2= 0.989$) for 2 lph dripper.
   b. $Q = 3.940P^{0.320}$ ($R^2=0.901$) for 4 lph dripper.
   c. $Q = 7.874P^{0.219}$ ($R^2=0.993$) for 8 lph dripper.
   d. $Q = 14.11P^{0.206}$ ($R^2=0.999$) for 14 lph dripper.
   e. $Q = 20.22P^{0.207}$ ($R^2=0.998$) for 20 lph dripper.

   Where, Q= Dripper discharge (lph), P= Pressure input (kg cm^{-2}) and R^2= Goodness of fit.
2. The coefficient of manufacturing variations in emitting rate for 2 lph(Netafim), 4 lph(EPC), 8lph(JISL), 14 lph(JISL) and 20 lph(Netafim) drippers can be 7.95 %, 4.95 %, 2.85 %, 0.89 % and 0.86 %, respectively.
3. The water applications through 2 lph drippers for the 1, 2, 3, 4 and 5 hrs duration can yield wetted bulb having maximum radius of 21cm, 27 cm, 36 cm, 41 cm and 51 cm respectively and maximum depth of 36 cm, 41 cm, 47 cm, 52 cm and 55 cm, respectively.
4. The water applications through 4 lph drippers for the 1, 2, 3, 4 and 5 hrs duration can yield wetted bulb having maximum radius of 25 cm, 34 cm, 43 cm, 51 cm and 57 cm respectively and maximum depth of 36 43 cm, 49 cm, 52 cm, 55 cm and 57 cm, respectively.
5. The water applications through 8 lph drippers for the 1, 2, 3, 4 and 5 hrs duration can yield wetted bulb having maximum radius of 24 cm, 34 cm, 44 cm, 54 cm and 69 cm respectively and maximum depth of 45 cm, 55 cm, 62 cm, 66 cm and 69 cm respectively.
6. The water applications through 14 lph drippers for the 1, 2, 3, 4 and 5 hrs duration can yield wetted bulb having maximum radius of 36 cm, 44 cm, 53 cm, 65 cm and 82 cm respectively and maximum depth of 50 cm, 59 cm, 68 cm, 73 cm and 77 cm, respectively.
7. The water applications through 20 lph drippers for the 1, 2, 3, 4 and 5 hrs duration can yield wetted bulb having maximum radius of 37 cm, 46 cm, 60 cm, 74 cm and 89 cm respectively and maximum depth of 60 cm, 68 cm, 73 cm, 77 cm and 80 cm, respectively.
8. The following models can be used to predict the horizontal and vertical movement of wetting front for the sound design of drip irrigation system and planning schedule for various crops to match their varying root zone temporally.

$X = 28.9308 \times Q^{0.1283} \times T^{0.8137}$ with ($R^2 = 0.817$)

$Y= 18.3943 \times Q^{0.4996} \times T^{0.1954}$ with (R^2= 0.672)

Where, X=horizontal movement of water (cm), Y= vertical movement of water (cm), Q=dripper discharge capacity (lph) and T=time duration (hr).

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