

Study of Wetting Pattern under Drip Irrigation with Varying Discharge and Irrigation Interval for the Soil of Dediapada

Sondarva, K. N.^{1*}, Jayswal, P.S.², Hadiya J. V.³ and Dodiya V. R.⁴

¹Assistant Professor, College of Agril. Engg. & Tech., NAU, Dediapada-393040

²Subject Mater Specialists (Agril. Engg.), Krishi Vignan Kendra, JAU, Amreli-365601

³&⁴B.Tech Students, College of Agril Engg. & Tech., NAU, Dediapada-393040

*Corresponding Author E-mail: ketansondarva@nau.in

Received: 5.02.2020 | Revised: 13.03.2020 | Accepted: 23.03.2020

ABSTRACT

Drip irrigation system should be designed so that the soil volume being wetted should match the root characters. To achieve this, the shape and the dimensions of the wetted soil volume underneath drip irrigated crops, should be accurately determined. This is used for better understanding of the movement of water in soil in response to a surface point source. To understand the wetting pattern of drip irrigation under soil of Dediapada the experiment was conducted at the field of College of Agricultural Engineering & Technology, Dediapada during year 2017. The treatments of the experiment were 3 levels of emitter discharge i.e., 2, 4 & 8 LPH and 3 levels of irrigation duration i.e., 1, 2 & 3 hours. The results revealed that the horizontal wetting is higher than vertical wetting; using 8 LPH emitter with irrigation time of 3 hours gave highest horizontal and vertical wetting. From the results obtained under this study, it could be concluded that during summer season, using low emitting dripper are more beneficial due to higher vertical wetting then horizontal wetting.

Keyword: Drip irrigation system, Water, Soil, Crops

INTRODUCTION

In India per capita water availability in the years 1991 and 2001 were 2309 and 1902 m³ and these are projected to reduce to 1401 and 1191 m³ by the years 2025 and 2050 respectively. Hence, there is a need for proper planning, development and management of the greatest assets of the country, viz. water and land resources for raising the standards of living of the millions of people, particularly in the rural areas. (<http://www.indianetzone.com>).

The total available water resources (surface and ground water) of Gujarat are estimated to be about 55,600 MCM (38,100 MCM surface water and 17,500 MCM ground water). About 88 % water is supplied for irrigation, 10% for domestic uses and 2 % for industries. The current trend of increase in water supply from all users will outstrip available supplies significantly by the year 2025.

Cite this article: Sondarva, K. N., Jayswal, P. S., Hadiya, J. V., & Dodiya V. R. (2020). Study of Wetting Pattern under Drip Irrigation with Varying Discharge and Irrigation Interval for the Soil of Dediapada, *Ind. J. Pure App. Biosci.* 8(5), 227-239. doi: <http://dx.doi.org/10.18782/2582-2845.7513>

For effective design of drip irrigation systems, knowledge on the water dynamics in the soil particularly horizontal and vertical wetting front below the dripper is essential. Information about temporal evolution of the wetted volume in specific soil texture can help in establishing the optimal spacing between the emitters and the irrigation duration as a function of the soil volume where the crop roots are located (Provenzano, 2007). Drip method of irrigation helps to reduce the over-exploitation of groundwater that partly occurs because of inefficient use of water under surface method of irrigation. More information about the moisture distribution pattern under a drip emitter source is necessary for efficient drip irrigation design (Hammani et al., 2002). Environmental problems associated with the surface method of irrigation like water logging and salinity are also completely absent under drip method of irrigation (Narayanamoorthy, 1997). Drip method helps in achieving saving in irrigation water, increased water-use efficiency, decreased tillage requirement, higher quality products, increased crop yields and higher fertilizer-use efficiency (Qureshi et al., 2001; Sivanappan, 2002; & Namara et al., 2005).

Evidences show that many researchers have attempted to study the impact of drip irrigation (Magar et al., 1988; Qureshi et al., 2001, Dhawan, 2002, Narayanamoorthy, 2003, Verma et al., 2004, Kulecho & Weatherhead, 2005, Narayanamoorthy, 2005, & Namara et al., 2005) and have found that drip irrigation produces the desired positive impacts. It is evidenced that the drip irrigation technology is

technically feasible, particularly when the farmers depend on groundwater sources (Dhawan, 2000).

Keeping these issues in view, the present paper has addressed the following important issues:

1. To evaluate the wetting pattern of varying emitter discharge with drip irrigation system.
2. To evaluate wetting pattern of drip irrigation with varying irrigation time.
3. To develop models for horizontal and vertical wetting for drip irrigation.

MATERIALS AND METHODS

The experiment was carried out at the field of College of Agricultural Engineering & Technology, Navsari Agricultural University, Dediapada during year 2017.

3.2 Field Experiment

3.2.1 Experimental design

(a) Treatments

The experiment comprising of 2 treatment and treatment combination were laid out in two replications. The details of the treatment are presented in as below

First factor: Dripper discharge – 3 levels, i.e. 2LPH, 4LPH and 8LPH

Second factor: Irrigation time- 3 levels- 1 hour, 2 hour and 3 hour.

(b) Layout

Plot design with 9 treatments replicated at two times was employed in this study. The treatments were assigned to entire design of each replication by randomization process. The detailed layout is presented in Table 1.

Table 1: Details of treatment plots

Sr. No	Particulars	Details
1	No of replication	2
2	Total no. of treatment combinations	9
3	Total number of plots	3
4	Gross plot size	2.5X15 m
5	Experimental field area	112.5 m ²

Source of Irrigation

The source of water for the experiment was ground water. The diameter and depth of the bore well were 15 cm and 50 m respectively.

Measurement of emitter discharge

In drip irrigation layout employed for the study three types of emitter with different discharge rates were used, namely 2 litres/

hour, 4 litres/ hour and 8 litres/ hour. The rate of discharge from each emitter was measured using a beaker for a given time of 15 minutes. Then discharge rate of the emitter per hour was calculated..

Wetting pattern

- Soil profile was dug up to 1m and lateral was spread on each profile. Wetting front was determined by the following methods
- Wetted depth and wetted diameter was measured during irrigation at every 10 minutes to obtain data on spread of water movement in the soil profile.
- Readings of wetted depth and wetted diameter were taken 24 hours after irrigation under emitters with different discharge rates by applying same amount of water to know about moisture distribution below the soil surface.
- System was operated for different durations i.e., 1, 2 and 3 hours and measured the wetted depth and wetted diameter 24 hours after water application.

RESULTS AND DISCUSSION

The results of the field experiment entitled “Study of wetting pattern under drip irrigation with varying discharge emitter for the soil of Dediapada” conducted during rabi season, 2017-18 at College of Agricultural Engineering & Technology, Navsari Agricultural University, Dediapada were presented in this chapter. The wetting dimensions in clay soil under drippers of different discharge capacities during different durations with equal amount of water applied were observed. The effects of different dripper discharge capacities on wetting pattern horizontally and vertically were studied. The results were presented under the following categories.

Infiltration test

To check the infiltration capacity and infiltration rate, infiltration test was carried out for the field. The infiltration test lasts for 10 hours; it can be observed from Fig. 1 & 2 that in initial time infiltration rate was greater than the two hour later. It becomes stable about 9 to 10 hours of infiltration test.

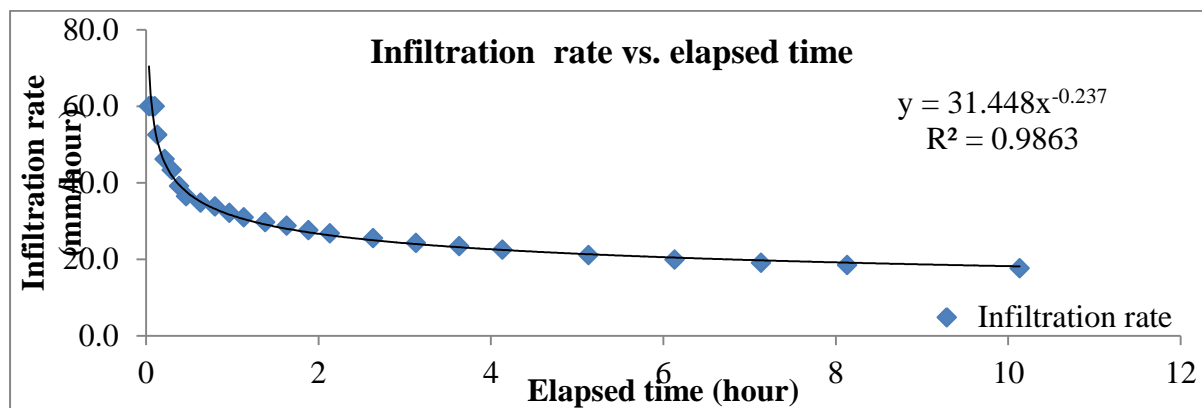


Fig. 1: Graph of infiltration characteristic of soil

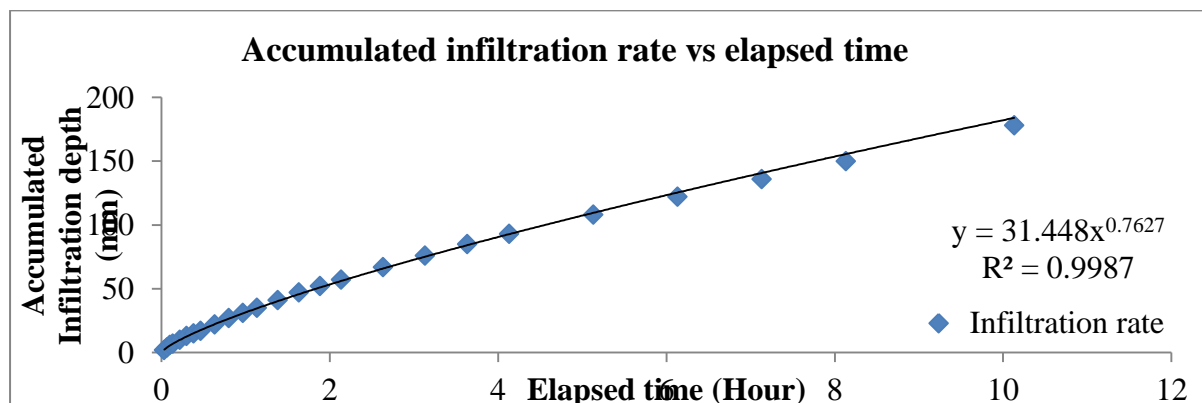


Fig. 2: Graph of accumulated infiltration depth vs. elapsed time

Effect of irrigation duration on wetting pattern

The surface wetted diameter as a function of time for different discharge rates is shown in Fig. 3, 4 and 5. Results showed that the higher discharge rate produces more wetted diameter when the duration of irrigation is same. As the irrigation time increased the wetted diameter is also increased as compared to low discharging emitter. Surface wetted diameter rapidly increased in first 2.0 hours, after that it increased slowly. It increased with increase in time. Further, the asymptotic tendency of the curve indicated that at long time scale wetted diameter may take a finite value. This lateral advance behavior of wetting front is attributed to the capillary predominance effect for small

discharge at the opposite of gravity effect which is more important with high discharge rates (Thabet & Zayani, 2008).

The data recorded for the various emitter discharges are given below in Table No. 2, 3 and 4. It is observed that the vertical spreading can be observed after 20 minutes. The highest wetted diameter and depth observed 47.60, 53.60, 67.00 and 7.00, 11.40, 15.40 respectively for 1 hour irrigation duration. The highest wetted diameter and depth observed 63.00, 65.00, 96.00 and 21.20, 30.40, 38.00 cm respectively for 2 hour irrigation duration. The highest wetted diameter and depth observed 70.00, 72.80, 99.60 and 36.40, 47.00, 56.80 cm respectively for 3 hour irrigation duration.

Table 2: Horizontal and Vertical spreading under drip irrigation for 1 hour irrigation time

Irrigation Time (min)	Horizontal diameter (cm)			Vertical depth (cm)		
	Emitter Discharge (LPH)			Emitter Discharge (LPH)		
	2	4	8	2	4	8
10	27.20	31.80	41.40	0.00	0.00	0.00
20	36.00	39.80	51.80	0.00	0.00	0.00
30	39.80	44.80	58.80	2.60	4.80	6.60
40	43.80	48.40	62.20	4.20	7.60	10.00
50	46.00	51.60	65.60	5.80	10.00	13.40
60	47.60	53.60	67.00	7.00	11.40	15.40

Table 3: Horizontal and Vertical spreading under drip irrigation for 2 hour irrigation time

Irrigation Time (min)	Horizontal diameter (cm)			Vertical depth (cm)		
	Emitter Discharge (LPH)			Emitter Discharge (LPH)		
	2	4	8	2	4	8
10	36.40	37.00	54.40	0.00	0.00	0.00
20	40.60	43.80	60.80	1.00	3.40	3.80
30	43.40	46.60	65.60	2.00	9.00	8.00
40	46.00	48.80	69.80	2.80	11.60	11.20
50	49.00	50.80	73.60	5.60	13.40	14.60
60	49.80	53.20	76.80	8.40	15.40	20.00
70	52.40	55.80	81.20	13.20	19.60	25.20
80	54.20	57.80	83.40	15.40	22.00	29.20
90	55.80	59.80	86.40	16.60	24.40	31.80
100	58.40	62.00	89.60	18.20	26.00	34.20
110	61.00	63.60	93.00	19.60	28.80	36.40
120	63.00	65.00	96.00	21.20	30.40	38.00

Table 4: Horizontal and Vertical spreading under drip irrigation for 3 hour irrigation time

Irrigation Time (min)	Horizontal diameter (cm)			Vertical depth (cm)		
	Emitter Discharge (LPH)			Emitter Discharge (LPH)		
	2	4	8	2	4	8
10	38.60	39.60	56.80	0.00	0.00	0.00
20	42.60	45.00	64.00	1.00	5.20	4.00
30	45.60	48.80	68.60	2.60	11.60	10.40
40	48.80	52.60	73.20	3.40	13.80	14.20
50	51.20	55.40	76.20	6.00	16.00	18.80
60	53.20	58.40	79.00	13.40	19.20	26.20
70	55.80	60.80	82.20	17.00	24.20	29.40

80	57.80	62.40	85.00	19.60	27.80	33.40
90	59.60	63.60	87.20	22.60	31.40	38.20
100	62.00	65.00	88.80	25.40	34.20	41.80
110	64.20	66.40	90.80	27.40	36.60	44.20
120	65.40	67.80	92.20	29.40	38.80	46.40
130	66.20	69.20	94.00	30.80	40.40	48.80
140	67.00	70.00	95.40	32.20	41.60	50.60
150	67.60	70.80	96.60	33.40	43.00	52.20
160	68.40	71.60	97.80	34.60	44.40	54.20
170	69.20	72.40	99.00	35.60	45.60	55.60
180	70.00	72.80	99.60	36.40	47.00	56.80

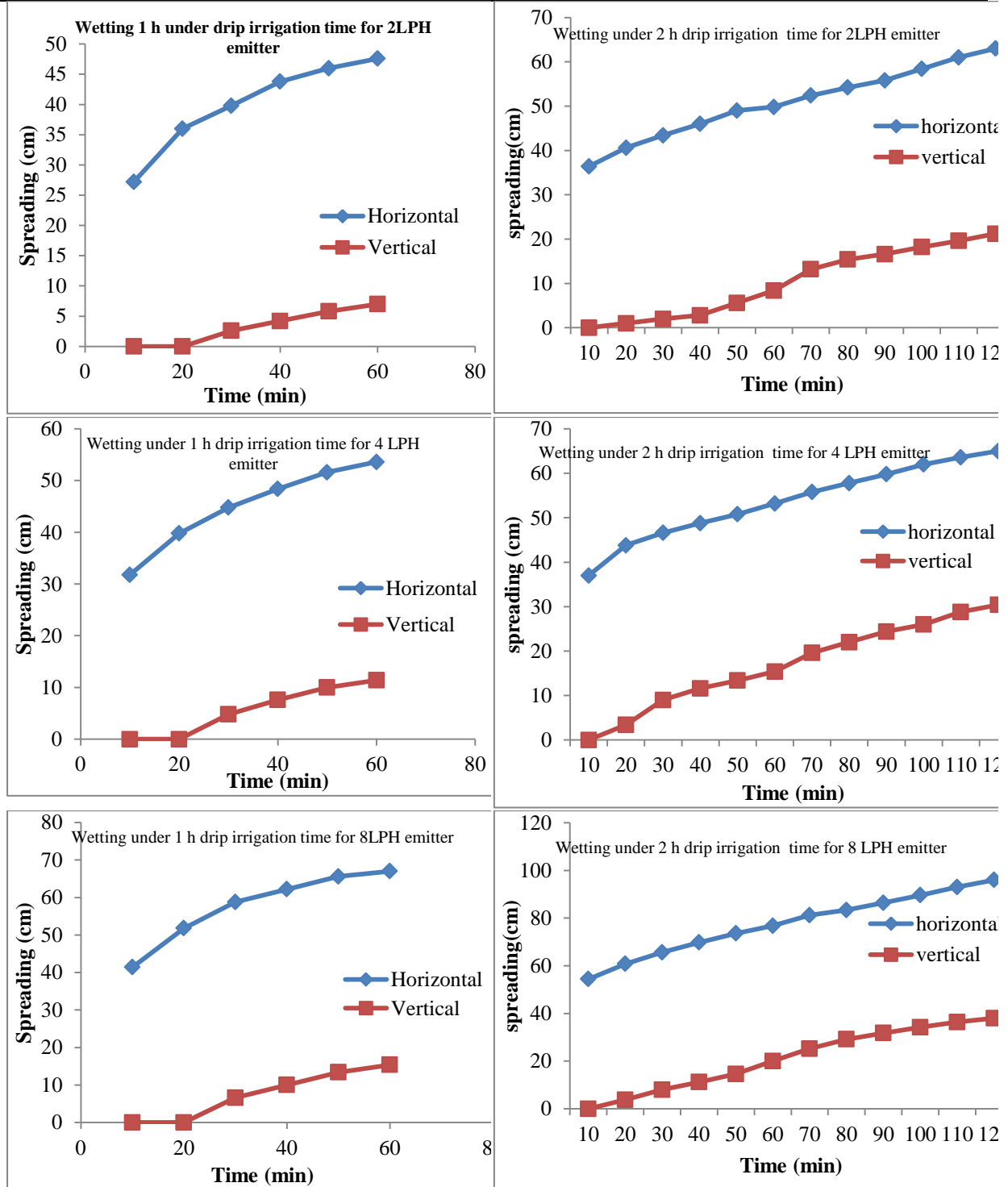


Fig. 3: Graph of spreading under 1 & 2hour irrigation time for 2, 4 & 8 LPH emitter discharge.

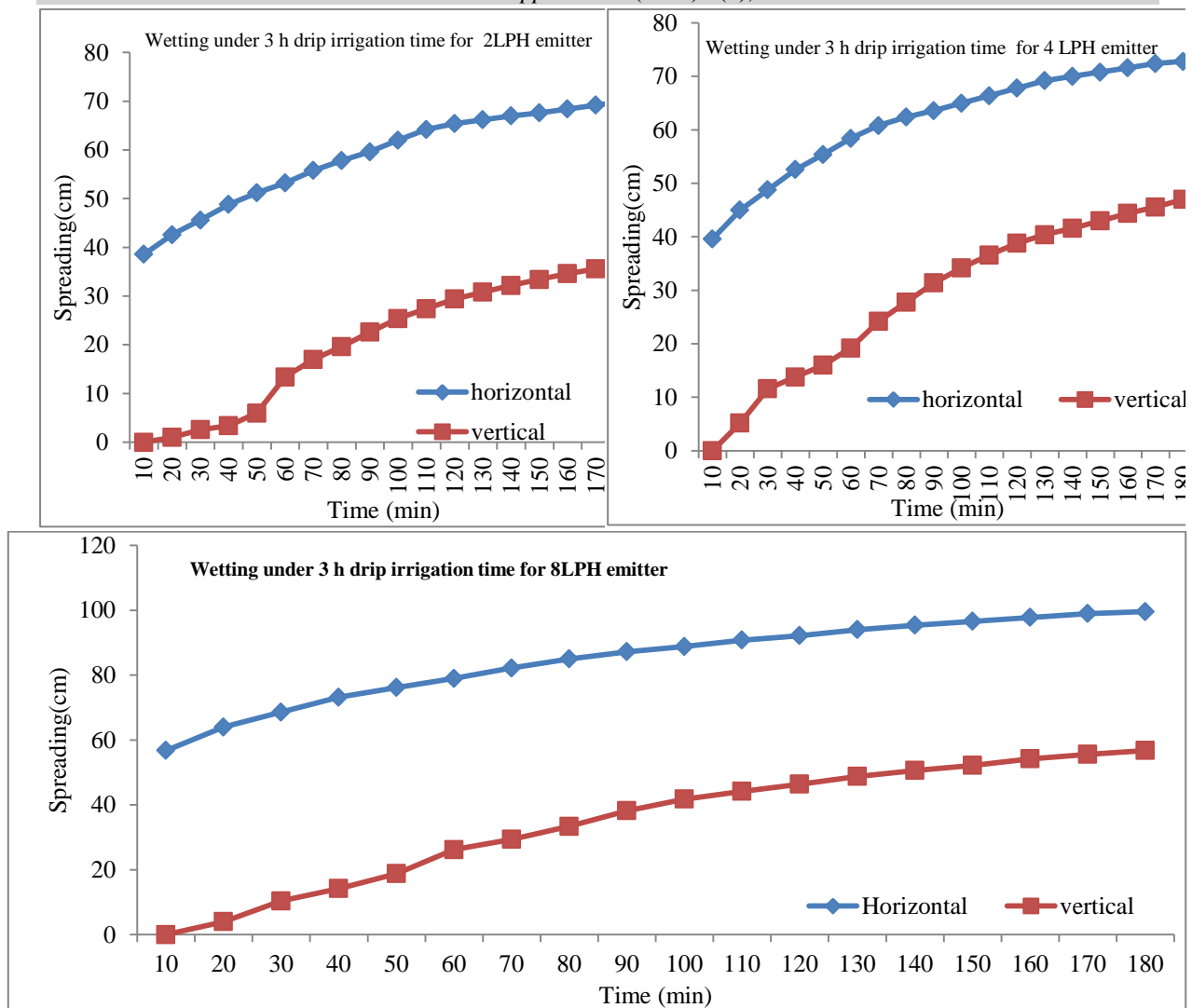


Fig. 4: Graph of spreading under 3 hour irrigation time for 2, 4 & 8 LPH emitter discharge.

Wetted depth at different discharge rates with respect to similar irrigation time was presented in Fig 1 and 2. It indicated that with increase in the discharge rates, wetted depth increased. Maximum wetted depth was observed for 3.0 l h⁻¹ discharge rate while minimum wetted depth was observed for 2.0 l h⁻¹ discharge rate. The results obtained shows strong relation with results obtained by Brandt et al. (1971), Bresker et al. (1971), Kaul (1979), Mostaghimi et al. (1982), Rema Devi (1983), Vasantha Kumar (1984), Alikhan et al. (1996), Higher discharge rate had shown more wetted depth than lower discharge rate due to speed of water Haghghati (1998), Mondal et al. (2007), Pelangi and Akhondali (2008). With increase in time, spreading of water is independent of discharge rate. This behavior is attributed to the predominance of gravity effects.

2. Effect of emitter discharge on horizontal and vertical spreading

The diameter of wetted diameter and wetted depth were measured for different irrigation times with dripper discharge rate of 2 LPH. It was observed that the diameter was increased rapidly in the beginning and increased very slowly at later times shows correlation with the results obtained by Howell et al. (1981). Similar trend was observed for 4.0 and 8.0 LPH capacity drippers. The measured average diameters for different times were presented in Fig. 4.4 and 4.5. With increase in duration i.e., 1 hr, 2 hr and 3 hr wetted diameter and wetted depth was increased in 1.0 LPH, 2 LPH and 8LPH dripper. Maximum diameter (120 cm) and maximum depth (69 cm) were observed at 3 hr duration for the 8 lph⁻¹ dripper. It was also observed that the horizontal wetting rate was similar for low discharging dripper while it was observed higher in case of high

discharging dripper. Vertical wetted depth was found about 10 minutes after initiation of irrigation till that amount of water applied were spreader over the soil surface. When the water applied to a soil of higher initial

moisture content i.e. frequent water application, the moisture moved more both in the radial as well as in the vertical directions. Kheper et al. (1983) and Kyada and Munjarappa (2013).

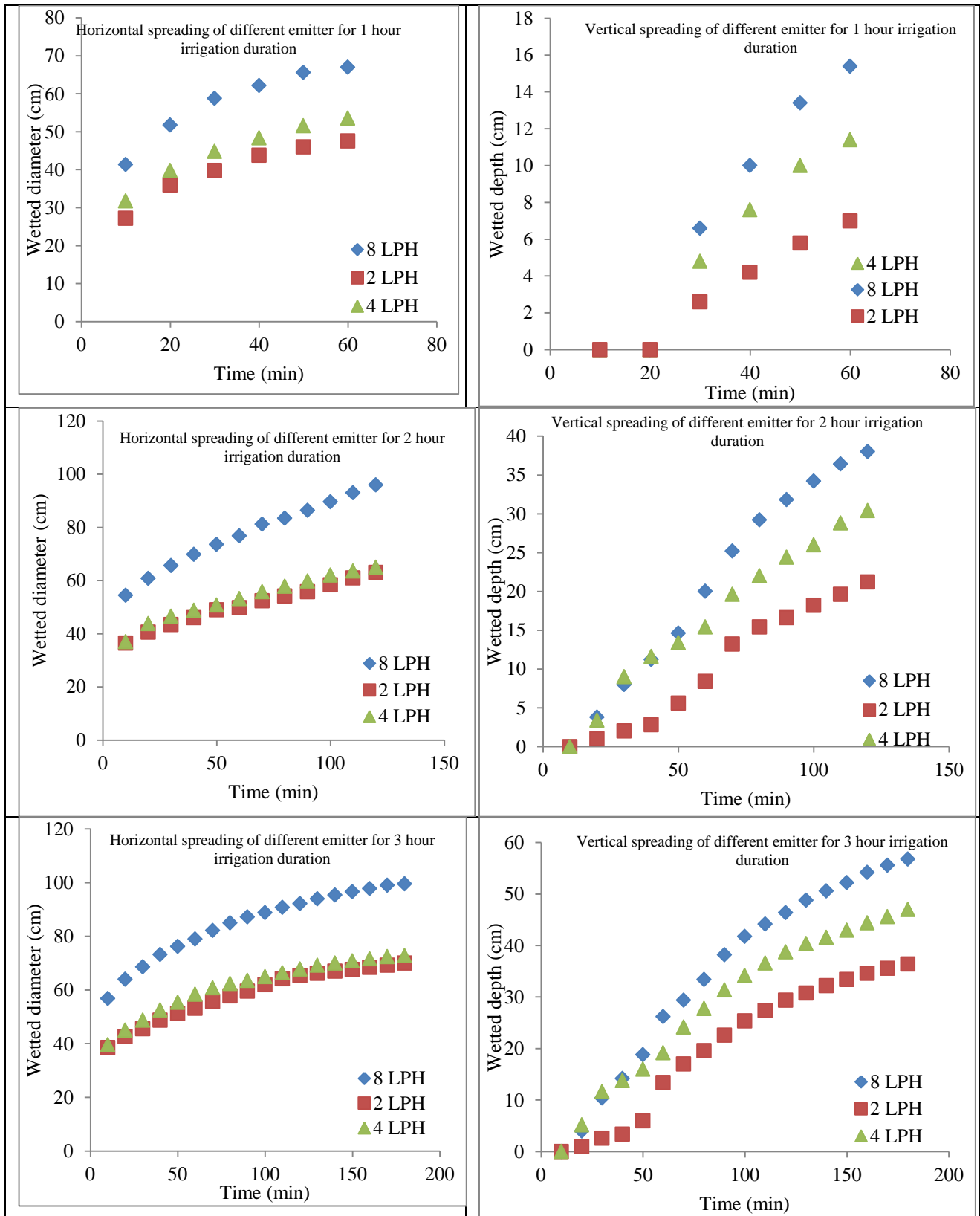
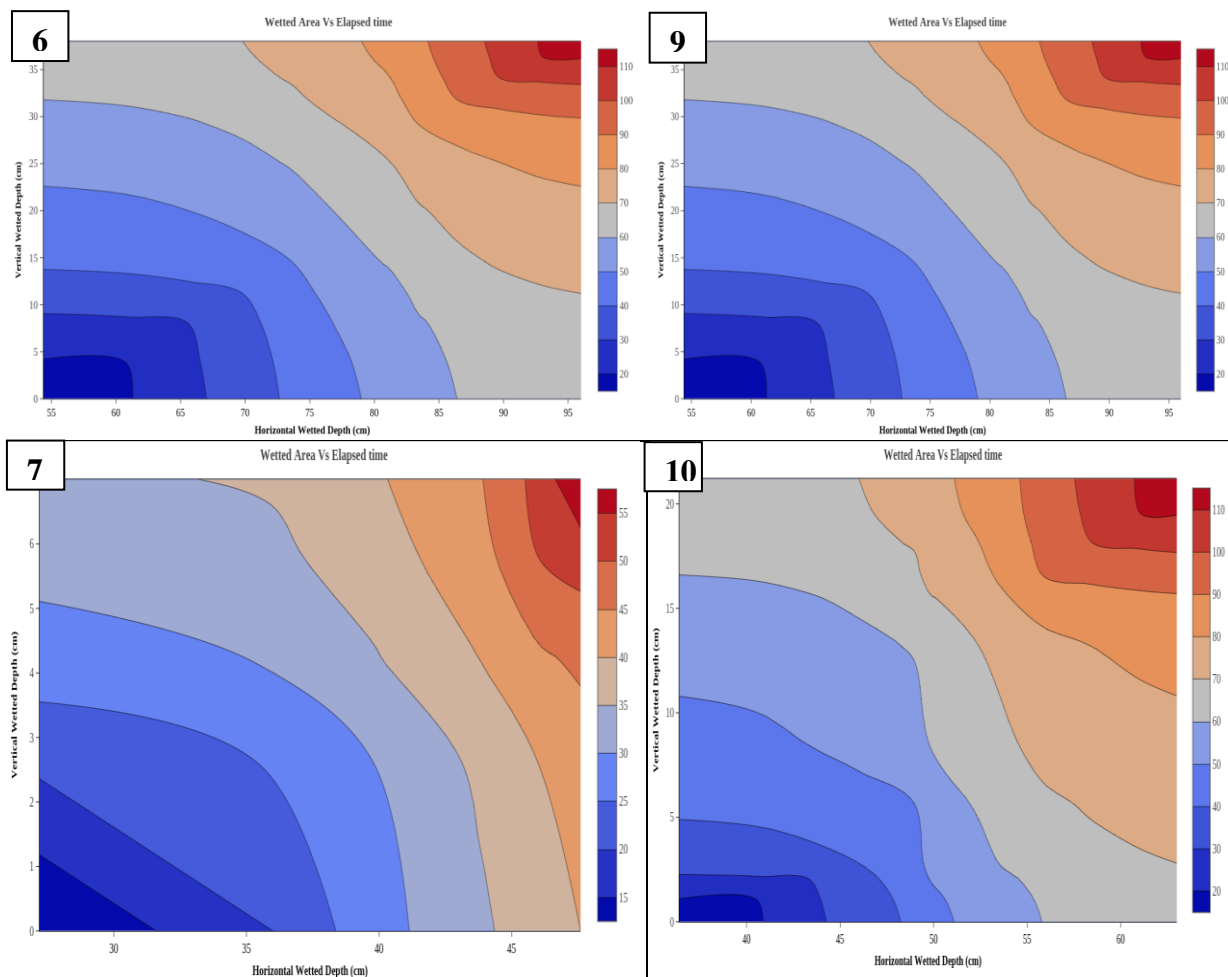


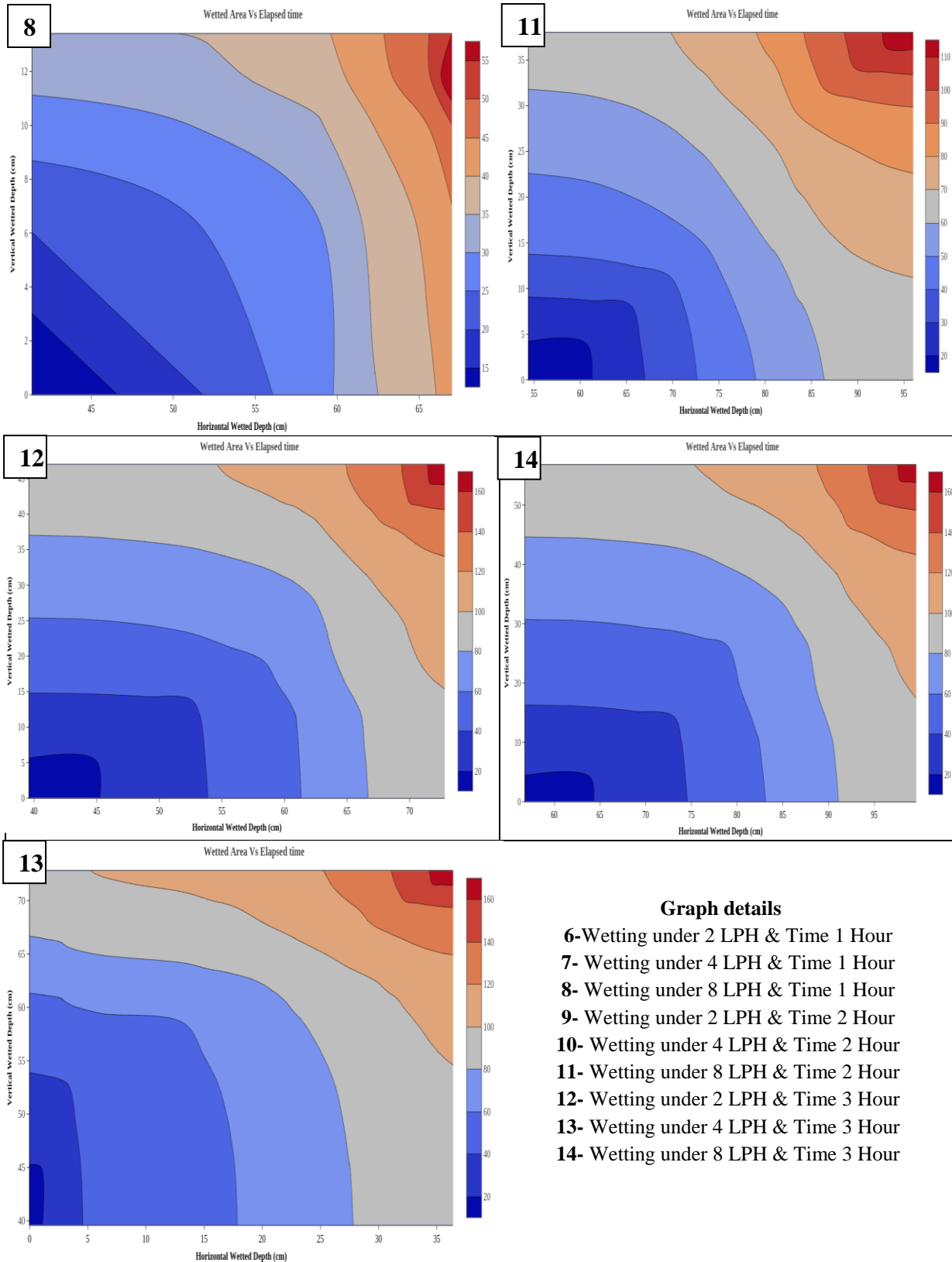
Fig. 5: Graph of horizontal & vertical spreading of different emitter discharge & irrigation time

4.1 Effect of irrigation duration and emitter discharge on wetting pattern

Correlation between maximum wetting front advance (horizontal and vertical direction) and the elapsed time is presented in Fig. 6 to Fig. 14. The maximum horizontal wetting front was observed 6.7cm, 53.6cm and 47.6cm for 1 hour irrigation duration under 8, 4 & 2 LPH. The maximum vertical wetting front was observed 15.4cm, 11.4cm and 7.0cm for 1 hour irrigation duration under 8, 4 & 2 LPH. The maximum horizontal wetting front was observed 96cm, 65 cm and 63 cm for 2 hour irrigation duration under 8, 4 & 2 LPH. The maximum vertical wetting front was observed 38 cm, 30.4 cm and 21.2 cm for 2 hour irrigation duration under 8, 4 & 2 LPH. The maximum horizontal wetting front was observed 99.6 cm, 72.8 cm and 70 cm for 3 hour irrigation duration under 8, 4 & 2 LPH.

The maximum vertical wetting front was observed 56.8 cm, 47 cm and 36.4 cm for 3 hour irrigation duration under 8, 4 & 2 LPH. Results showed that the higher discharge rate produces more wetted diameter when the duration of irrigation is same. Surface wetted diameter rapidly increased in first 2.0 hours, after that it increased slowly. It increased with increase in time. Further, the asymptotic tendency of the curve indicated that at long time scale wetted diameter may take a finite value. This lateral advance behavior of wetting front is attributed to the capillary predominance effect for small discharge at the opposite of gravity effect which is more important with high discharge rates Peries et al.(2007) , (Thabet & Zayani, 2008), Acar et al. (2009), Skaggs et al. (2010), Rui et al. (2012).





Graph details

- 6- Wetting under 2 LPH & Time 1 Hour
- 7- Wetting under 4 LPH & Time 1 Hour
- 8- Wetting under 8 LPH & Time 1 Hour
- 9- Wetting under 2 LPH & Time 2 Hour
- 10- Wetting under 4 LPH & Time 2 Hour
- 11- Wetting under 8 LPH & Time 2 Hour
- 12- Wetting under 2 LPH & Time 3 Hour
- 13- Wetting under 4 LPH & Time 3 Hour
- 14- Wetting under 8 LPH & Time 3 Hour

The observed and plotted data is indicating nearly uniform distribution between vertically and horizontally in Graph. 6to14. With shifting to higher discharge emitter, i.e, 2 LPH to 8 LPH, the horizontal movement or the horizontal wetted area was found greater. As

the soil of the field is clay soil, the water movement below the emission point was more pronounced in horizontal direction rather than in vertical direction. As the elapsed time increase the horizontal movement is decreasing and the vertical movement is

speeding up. The deeper water movement suggests more water available to the roots, which is necessary for plant growth. A horizontal movement of water will generally result in evaporation losses. Almost similar results have been reported in a numerical analysis of the different experiment by Elmaloglou and Diamantopoulos (2009), Xiao et al. (2013), Wang et al. (2014).

Modeling

With varying discharge with irrigation time, the results obtained were used for modeling purpose. By using regression analysis, various models developed for 1 hour, 2 hour and 3 hour irrigation time and also 2LPH, 4LPH and 8 LPH emitter discharge to simulate the horizontal wetted diameter and vertical wetted depth.

Table 5: Developed models for horizontal wetted diameter of various irrigation time and emitter discharge.

Irrigation duration (Hour)	Emitter discharge (Liter/hour)	Developed model for vertical wetted depth	Coefficient of Determination
1	8	$D = 0.293t - 3.293$	0.878
	4	$D = 0.256t - 3.346$	0.957
	2	$D = 0.154t - 2.133$	0.968
2	8	$D = 0.366t - 2.757$	0.984
	4	$D = 0.271t - 0.636$	0.984
	2	$D = 0.215t - 3.693$	0.971
3	8	$D = 0.339t + 2.454$	0.953
	4	$D = 0.271t + 3.113$	0.957
	2	$D = 0.240t - 2.239$	0.955

Where, D is the wetted depth and t is elapsed time from the initiation of irrigation

Table 6: Developed models for horizontal wetted diameter of various irrigation time and emitter discharge.

Irrigation duration (Hour)	Emitter discharge (Liter/hour)	Developed model for horizontal wetted diameter	Coefficient of Determination
1	8	$d = 0.493t + 40.52$	0.906
	4	$d = 0.422t + 30.20$	0.947
	2	$d = 0.388t + 26.46$	0.917
2	8	$d = 0.360t + 54.09$	0.987
	4	$d = 0.235t + 38.39$	0.972
	2	$d = 0.226t + 36.09$	0.989
3	8	$d = 0.230t + 62.87$	0.932
	4	$d = 0.178t + 44.87$	0.913
	2	$d = 0.179t + 41.46$	0.944

Where, d is the wetted diameter and t is elapsed time from the initiation of irrigation

Validation of developed models

Developed models for horizontal wetted diameter and vertical wetted depth give very good performance when checking for the validation. For validation of all models, observed data of horizontal wetted diameter and vertical wetted depth for 1 hour, 2 hour and 3 hour with combination of 2 LPH, 4 LPH and 8 LPH emitter discharge were used. The predicted values were derived for horizontal

wetted diameter and vertical wetted depth. These values of predicted wetted diameter plotted against observed wetted diameter and predicted wetted depth against observed wetted depth. A model of 2 hour irrigation time and 2 LPH emitter discharge for the horizontal wetted diameter was found best with coefficient of determination of 0.989. And similarly models for vertical wetted depth, 2 hour irrigation duration with 8 LPH

and 4 LPH was found best with coefficient of determination of 0.984 as shown in graph 16

& 17 for horizontal and vertical wetting pattern respectively.

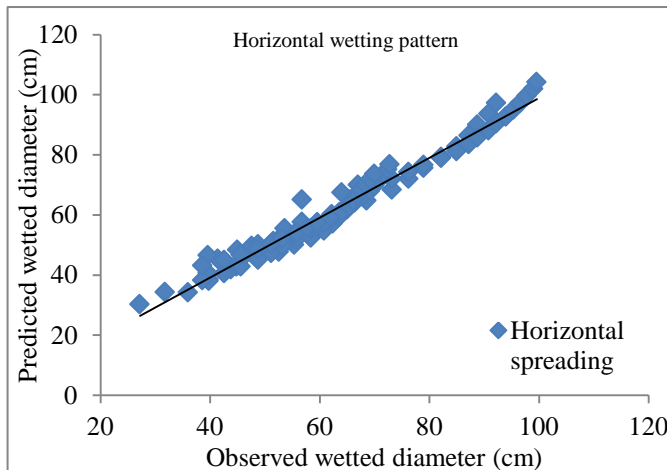


Fig. 16: Graph of observed wetted diameter against predicted wetted diameter for horizontal wetted diameter (cm).

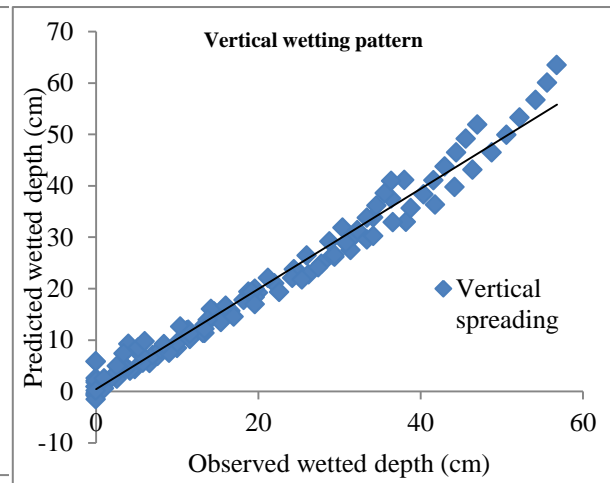


Fig. 17: Graph of observed wetted depth against predicted wetted depth for vertical wetted depth (cm).

SUMMARY

An experiment was conducted at field of College of Agricultural Engineering & Technology, Navsari Agricultural University, Dediapada to determine the wetting pattern of drip irrigation. The experiment was comprised with total 8 treatments. 3 levels of irrigation time (i.e. 1, 2 and 3 hours) and 3 levels of emitter discharge (i.e. 2, 4 and 8 LPH) were adopted. The soil type of the field was clay type. The experiment was conducted during October-November-2017. The results found that due to clay type soil, vertical penetration of water was found slow. The maximum wetted depth 56.8 cm was found less than 8 LPH emitter discharge for the irrigation time of 3 hours. The maximum wetted diameter 56.8 cm was found for 8 LPH emitter discharge for 3 hours. The maximum wetted depth and wetted diameter was found 38 cm and 96 cm respectively for the 2 hours irrigation time and 8 LPH emitter discharge. The maximum wetted depth and wetted diameter was found 15.4 cm and 67 cm respectively for the 2 hours irrigation time and 8 LPH emitter discharge.

CONCLUSION

- The horizontal wetting is higher than vertical wetting using higher emitter discharge than lower emitter discharge.

- In summer crop low emitter discharge will be beneficial due to low horizontal spreading and higher vertical spreading to the crop root zone.
- 8 LPH emitters with 3 hours irrigation time gives highest horizontal and vertical wetting profile.
- The horizontal wetting and vertical wetting can be best described by 2nd order polynomial functions.
- Model developed for horizontal wetting diameter (d) for the CAET, NAU, Dediapada field is

$$d = 0.003t^2 + 0.557t + 12.94$$

- Model developed for vertical wetting depth (D) for the CAET, NAU, Dediapada field is

$$D = 0.004t^2 + 0.739t + 1.956$$

REFERENCES

- Acar, B., Topak, R., & Mikailsoy, F. (2009). Effect of applied water and discharge rate on wetted soil volume in loam or clay-loam soil from an irrigated drip source. *African Journal of Agricultural Research*. 4(1), 49-54.
- Alikhan, A., Yitayev, M., & Warrick, W. (1996). "Field evaluation of water and solute distribution from a point

- source.” *J. Irrig. Drain Eng.*, 122(4), 221–227.
- Brandt, A., Bresler, E., Diner, N., Ben-Asher, I., Heller, J., & Goldberg, D. (1971). Infiltration from a trickle source. *Soil Science Society of America Proceedings* 39, 604-613.
- Bresler E., Heller, J., Diner, N., Ben-Asher, J., Brandt, A., & Doldberg, D. (1971). Infiltration from a trickle source: II. Experimental data and theoretical predictions. In proceeding of the *American Soil Science Society*, pp 683-689.
- Dhawan, B. D. (2002). *Technological Change in Irrigated Agriculture: A Study of Water Saving Methods*. Commonwealth Publishers, New Delhi.
- Dhawan, B. D. (2000). Drip irrigation: Evaluating returns, *Economic and Political Weekly*, 35(42), 3775-3780.
- Elmaloglou, S., & Diamantopoulos, E. (2009). Soil water dynamics under surface trickle irrigation as affected by soil hydraulic properties, discharge rate, dripper spacing and irrigation duration. *Irrigation and Drainage*. 59(3), 254 - 263.
- Haghighati, B. (1995). The effect of irrigation parameters on the percent of wetted area of soil (in Persian). M.sc thesis, Agricultural Faculty, Technology University of Esfahan, pp: 118.
- Hammami, M., Hedi, D., Jelloul, B., & Mohamed, M. (2002). Approach for predicting the wetting front depth beneath a surface point source: Theory and numerical aspect. *Irrigation and Drainage*. 51, 347-360.
- Kaul, R. K. (1979). Hydraulics of moisture front advance in drip irrigation. Unpublished Ph. D. Thesis submitted to Indian Agricultural Research Institute, New Delhi.
- Kheper, S. D., Neogy, P. K., & Kaushal, M. P. (1983). Moisture and salt distribution pattern under drip irrigation. Proc. Second National Seminar on drip irrigation. TNAU, Coimbatore.
- Kulecho, I. K., & Weatherhead, E. K. (2005). Reasons for smallholder farmers discontinuing with low cost micro irrigation: A case study from Kenya, *Irrigation and Drainage Systems*, 19(2), 179-188.
- Kyada, K. M., & Munjarappa, B. J. (2013). Study on pressure-discharge relationship and wetting pattern under drip irrigation system. *International Journal of Science and Nature*. 4(2), 274-283.
- Magar, S. S., Firke, N. N., & Kadam, J. R. (1988). Importance of drip irrigation. *Sinchan*, 7(2), 61–62.
- Mondal, P., Biswas, R. K., Tewari, V. K., Kundu, K., & Manisha B. (2007). Investigation on soil wetting patterns of low cost drip irrigation system developed in India. *Trends in Applied Sciences Research*. 2(1), 45-51.
- Mostaghimi, S., Mitchel, J. K., & Lembke, W. D. (1981). Effect of discharge rate on distribution of moisture in heavy soils irrigated from a trickle source. *American Society of Agricultural Engineers. Paper No. 81*, 2081.
- Namara, Regassa, E., Upadhyay, Bhawana & Nagar, R. K. (2005). Adoption and Impacts of Microirrigation Technologies: Empirical Results from Selected Localities of Maharashtra and Gujarat States of India, Research Report 93, International Water Management Institute, Colombo, Sri Lanka.
- Narayanamoorthy, A. (1997). Drip irrigation: A viable option for future irrigation development, *Productivity*, 38(3), 504-511.
- Narayanamoorthy, A. (2003). Averting water crisis by drip method of irrigation: A study of two water intensive crops, *Indian Journal of Agricultural Economics*, 58(3), 427-437.
- Narayanamoorthy, A. (2005). Economics of drip irrigation in sugarcane cultivation: Case study of a farmer from Tamil Nadu, *Indian Journal of*

- Agricultural Economics*, 60(2), 235-248.
- Padmakumari, O., & Sivanappan, R. K. (1998). Moisture movement pattern under drip irrigation systems. Water Tech. Cent., Tamil Nadu Agric. Univ., Coimbatore, India. Proceedings 4th International Micro-Irrigation Congress. 1988, 4C-1, 3 ref.
- Pelangi, A., & Akhondali, A. (2008). A semi experimental model in order to estimate the dimension of wet barrier in the drip irrigation under point source. Techniques and sciences of agricultural magazines and natural sciences. Twelfth year. pp: 44.
- Peries, W. M. K., Gunasena, C. P., & Navaratne, C. P. (2007). Comparative study of wetting patterns of drip emitters developed for micro-irrigation systems. Proceedings of The Fourth Academic Sessions.
- Provenzano, G. (2007). Using HYDRUS-2D Simulation Model to Evaluate Wetted Soil in Subsurface Drip Irrigation Systems. *J. Irrig. Drain. Eng.* 133(4), 342–349.
- Qureshi, M. E., Wegener, M. K., Harrison, S. R., & Bristow, K. L. (2001). Economic evaluation of alternate irrigation.
- Rema Devi, A. N. (1983). Soil moisture distribution under drip irrigation system. In. Proceeding Second National Seminar on Drip Irrigation held at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu in March 5-6, 1983 pp. 86-93.
- Zhang, R., Cheng, Z., Zhang, J., & Xuwei, J. I. (2012). Sandy loam soils wetting patterns of drip irrigation: a comparison of point and line source. 2012 International Conference on Modern Hydraulic Engineering, *Procedia Engineering* 28, 506-511.
- Sivanappan, R. K. (1994). Prospects of micro-irrigation in India, *Irrigation and Drainage Systems*, 8(1), 49-58.
- Sivanappan, R. K. (2002). Strengths and weaknesses of growth of drip irrigation in India, In: Proc. of Micro Irrigation.
- Skaggs, T. H., Thomas, J. T., & Youri, R. F. (2010). Drip irrigation water distribution patterns: effects of emitter rate, pulsing, and antecedent water. *Soil Science Society of American Journal*. 74, 1886–1896.
- Thabet, M., & Zayani, K. (2008). Wetting patterns under drip source in a loamy sand soil of South Tunisia. *American Eurasian Journal of Agriculture and Environmental Sciences*. 3(1), 38-42.
- Vasanthakumar, G. K. (1984). Efficiency and adoption of drip irrigation in cultivation of tomato (*Lycopersicon esculentum* Mill.). Ph. D. Thesis submitted to Univ. of Agril. Sciences, Bangalore.
- Wang, X., Li, Z., & Xing, Y. (2014). Effects of dripper discharge and irrigation frequency on growth and yield of maize in loess plateau of northwest China. *Pakistan Journal of Botany*. 46(3), 1019-1025.
- Xiao, G. M., Shen, Z. Z., Zhang, W. J., Wang, W., Gan, L., & Ren, J. (2013). Experimental study of wetted soil volumes in a sandy loam under subsurface drip irrigation in the East Sandy Land of the Yellow River. *Journal of Food Agriculture and Environment*. 11(1), 987-992.
- Zhang, R., Cheng, Z., Zhang, J., & Xuwei, J. I. (2012). Sandy loam soil wetting patterns of drip irrigation: a comparison of point and line sources. *Engineering*. 28, 506- 511.