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Evaluation of Uniformity Coefficient and Soil Moisture Distribution under Drip Irrigation System

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Authors' contributions

This work was carried out in collaboration among all authors. Author AS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ES and IM managed the analyses of the study. Author IM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Drip irrigation system uniformity can preserve a higher crop yield and deplete the initial investment of cost. The experiment was conducted at precision farming development centre research farm, Tamil Nadu Agricultural University, Coimbatore, to evaluate the uniformity coefficient and soil moisture distribution under drip irrigation system. The experiment was designed under Factorial Randomized Block Design (FRBD) which included three fertigation levels 80%, 100% and 120% of Recommended Dose of fertilizers which were replicated thrice. The Coefficient of Variation (CV) was obtained as 0.0207 per cent kept at a constant pressure of 50.66 kPa, Statistical Uniformity (SU) as 97 per cent and Coefficient of Uniformity (CU) as 0.9518. As the elapsed time increased, the rate of increase of wetted zone diameter decreased. A high R^2 value of 0.97 shows the goodness of fit for the horizontal movement. The mean soil moisture distribution 39.2 per cent was observed below the emitter at the depth of 10 cm immediately after irrigation.

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Keywords: Coefficient of variation; drip irrigation; soil moisture distribution; uniformity coefficient.

1. INTRODUCTION

In India, the irrigated area consists of about 36 per cent of the net sown area. Presently the agricultural sector accounts for about 83 per cent of all water uses. Increasing competition with the other water users in the future would limit the water availability for expanding irrigated area. In 2025, 33 per cent of India's population will live under absolute water scarcity condition [1]. The per capita water availability in terms of average utilizable water resources in the country was 6008 m^3 in 1947 and is expected to dwindle to 760 m^3 by 2025 [2]. In traditional surface irrigation methods, the losses in water conveyance and application are large. These losses can be considerably reduced by adopting drip and sprinkler irrigation methods. Among all the irrigation methods, the drip irrigation is the most efficient and it can be practiced in a large variety of crops, especially in vegetables, orchard crops, flowers and plantation crops. Drip irrigation involves supplying water to the soil very close to the plants at very low flow rates (0.5 to 10 lph) from a plastic pipe fitted with outlets (drip emitters). The basic concept underlying the drip irrigation method is to maintain a wet bulb of soil in which plant roots suck water. Only the part of the soil immediately surrounding the plant is wetted. The volume and shape of the wet bulb irrigated by each drip emitter are a function of the characteristics of the soil (texture and hydraulic conductivity) and the discharge rate of the drip emitter. Applications are usually frequent (every 1 to 3 days) to maintain soil water content in the bulb close to field capacity [3,4,5,6]. The soil moisture is kept at an optimum level with frequent irrigations. Drip irrigation results in a very high water application efficiency of about 90 to 95 per cent. In India, there has been a tremendous growth in the area under drip irrigation during the last 15 years. This may be as low as 30 per cent of the volume of soil wetted by other methods. The wetting pattern varies with the emitter and soil type.The wetting patterns during application generally consist of two zones: (i) a saturated zone close to the drippers and (ii) a zone where the water content decreases toward the wetting front [7]. Increasing the discharge rate generally results in an increase in the wetted soil diameter and a decrease in the wetted depth. Hence the present study had been proposed to fulfill the following objectives are

1. To evaluate the uniformity coefficient under drip irrigation system in Chilli.
2. To study the soil moisture distribution pattern in drip irrigation system.

2. MATERIALS AND METHODS

The experiment was laid out during 2013 to 2014 under irrigated condition, to evaluate the uniformity coefficient and soil moisture distribution under drip irrigation system on sandy clay loam soil,(sand = 58%, silt =15%, clay=27%) at Precision Farming Development Centre Research Farm, Tamil Nadu Agricultural University, Coimbatore. The soil type of experimental site was sandy clay loam texture at a pH 8.07 of with good electrical conductivity of 0.78 dS m^{-1}. The initial physical and chemical properties of soil are presented in Table 1.

2.1 Experiment Layout

The experiment was carried out in the open field of PFDC Research Farm. The field layout plan for the experiment is shown in Fig. 1. The length and width of the field is 15 m and 15 m respectively. The total area is divided into various strips of 4.5 m x 1.2 m

Table 1. Initial physical and chemical properties of soil

Soil characteristics	Particulars	Composition
Physical characters	Bulk Density	1.4 g cm^{-3}
	Particle Density	2.4 g cm^{-3}
	Porosity	42 per cent
	Macropores	24%
	Micropores	18%
Chemical properties	Available N	185.6 kg ha^{-1}
	Available P	9.0 kg ha^{-1}
	Available K	356.7 kg ha^{-1}
	pH	8.07
	EC	0.78 S m^{-1}

Table 2. Treatment details

Treatments	Mulching sheet
T_1 M_1	Black Plastic mulch of 25 micron thickness with 80 per cent RDF
T_2 M_1	Black Plastic mulch of 25 micron thickness with 100 per cent RDF
T_3 M_1	Black Plastic mulch of 25 micron thickness with 120 per cent RDF
T_3 M_2	Black Plastic mulch of 50 micron thickness with 80 per cent RDF
T_5 M_2	Black Plastic mulch of 50 micron thickness with 100 per cent RDF
T_6 M_2	Black Plastic mulch of 50 micron thickness with 120 per cent RDF
T_7 M_3	No mulch with 80 per cent RDF
T_8 M_3	No mulch with 100 per cent RDF
T_9 M_3	No mulch with 120 per cent RDF

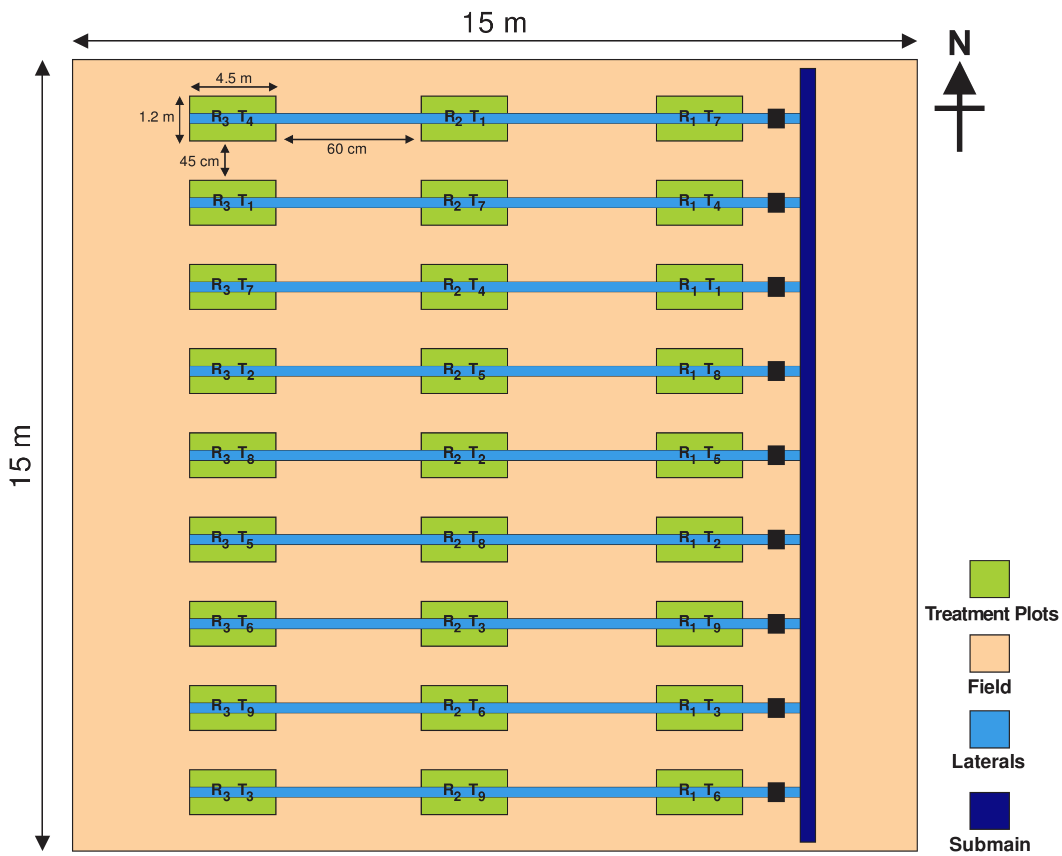

Fig. 1. Field layout of experiment plot

according to the treatments. The treatment details are given in Table 1. The experiment was designed under Factorial Randomized Block Design (FRBD) with the treatments mulching thickness and fertilizer levels. Each treatment combination is replicated thrice. Two types of plastic mulching films of different thickness and one control without mulch were selected for the study M1: Black plastic mulch of 25 - micron thickness, M2: Black plastic mulch of 50 micron thickness and M3: No mulch (Control) (Table 2). Threelevels of fertigation were adopted, namely 80 per cent, 100 per cent and 120 per cent of Recommended Dose of N, P and K and are denoted as F_1, F_2 and F_3.

2.2 Irrigation Scheduling

Irrigations were scheduled on the basis of climatological approach on mulch and control plots. Life saving irrigation was given immediately after transplanting and the field was regularly irrigated continuously for ten days. After the tenth day, subsequent irrigations were scheduled once in three days based on the following formula and applied each time as per the treatment schedule. The K_c values for chilli (COCH1) for different stages are given in the Table 3.

$$WR_c = CPE \times K_p \times K_c \times W_p \times A \quad (1)$$

Where,

WR_c - Computed water requirement (litre plant^{-1})
CPE - Cumulative pan evaporation for three days (mm)
K_p - Pan factor (0.8)
K_c - Crop factor
W_p - Wetted fraction (0.8)
A - Area per plant, m^2

Time of operation = (Volume of water required x irrigation interval) / Emitter discharge (2)

Table 3. Crop factor (K_c) values for chilli (COCH1)

Crop	Days	K_c
Initial stage	15-30	0.6
Flowering stage	30 - 60	0.7
Fruiting stage	60 - 90	0.8
Late season stage	90 -120	1.0

2.3 Coefficient of Variation (CV)

Coefficient of manufacturing variation was determined for the drip irrigation system from flow rate measurements of several identical emission devices and was computed with the following equation given [8]

$$Cv = \frac{\left[q_1^{\ 2} + q_2^{\ 2} + q_3^{\ 2} + ... + q_n^{\ 2} - n\overline{q}^{\ 2}\right]^{1/2}}{\overline{q}\left[n-1\right]^{1/2}} \quad (3)$$

Where,

q_1, q_2, q_3 &q_n - Discharges from different segments
q - Average discharge for the total segments
n - No. of segments

2.4 Statistical Uniformity

The statistical uniformity is obtained as (ASAE, 1993b)

$$SU = 100\ (1 - Cv) \quad (4)$$

Where,

SU - Statistical Uniformity
Cv - Coefficient of variation

2.5 Coefficient of Uniformity

The discharge rate of drippers was recorded at randomly selected emitter points on 1St, 5th, 10th and 15th and last one on each lateral to work out the uniformity of drip system as per the procedure given by [8]. The uniformity co-efficient was computed by the following formula

$$E_u = 100\left[1 - \frac{1.27}{\sqrt{Ne}}Cv\right]\frac{Q_{\min}}{Q_{avg}} \quad (5)$$

Where,

Eu - Emission uniformity in percent,
Ne - Number of point source segments
Cv - The manufacture's coefficient rate in the system, lph
Q_{min} - The minimum discharge rate, lph
Q_{avg} - The average rate of discharge, lph

2.6 Soil Moisture Distribution Pattern

The wetting pattern of soil under different mulches was analyzed by taking moisture content at different horizontal distances and depths. In order to study the soil moisture distribution in soil, samples were collected at a distance at 0, 15, 30, and 45 cm from emitter along the horizontal direction at surface and at a depth of 0, 10, 20, and 30 cm. The samples were collected before irrigation, immediately after irrigation, one day after irrigation and two day after irrigation. Using gravimetric method, the soil moisture measurements were calculated. The soil moisture content is expressed as per cent by weight on dry basis. Soil moisture contour maps were plotted by using the computer software package 'Surfer' of windows version.

2.7 Wetted Zone Diameter

Field observations were taken to measure the horizontal movement of wetting front over the surface of the field. The diameter of the wetting front was measured over different periods of time during emission and the wetting front advance equation was developed.

3. RESULTS AND DISCUSSION

The results of the experimental findings obtained have been discussed in following heads.

3.1 Irrigation Scheduling

The quantity of water applied per plant for chilli is given in Table 4.

3.2 Discharge Uniformity Assessment

The efficiency of drip irrigation depends on the uniformity of distribution of water throughout the field area. The discharge from the drippers at different points of emission was measured for a particular period at 50.66 kPa pressure and parameters such as Coefficient of Variation (CV), Statistical Uniformity (SU) and Coefficient of Uniformity (CU) were evaluated from the observed discharge. Volumetric method was used to calculate the Coefficient of uniformity of drip irrigation system.

3.3 Coefficient of Variation and Statistical Uniformity

The Coefficient of manufacturing Variation (CV) for drip irrigation system is calculated for the pressure of 50.66 kPa as 0.0207 per cent and Statistical Uniformity of the system was calculated as 97 per cent.

3.4 Coefficient of Uniformity

The Uniformity Coefficient of the drip irrigation system was found to be 0.9518. The high value of Uniformity Coefficient indicated the excellent performance of drip irrigation system in supplying water uniformly throughout the laterals.

Table 4. Quantity of water applied per plant for chilli

Crop Date	Quantity applied per plant (lpd)	Duration of irrigation (min) each day	Total quantity (l) applied per plant per stage
Initial Stage (Sep 25 to Oct 14) 1-20 days	0.427	20	1.281
Vegetative stage (Oct 15 to Nov 09) 21 - 45 days	0.223	10	0.669
Fruit setting stage (Nov 10 to Dec 24) 46 - 90 days	0.583	27	6.996
Final stage (Dec 25 to Jan 23) 91 - 120 days	1.078	48	10.78

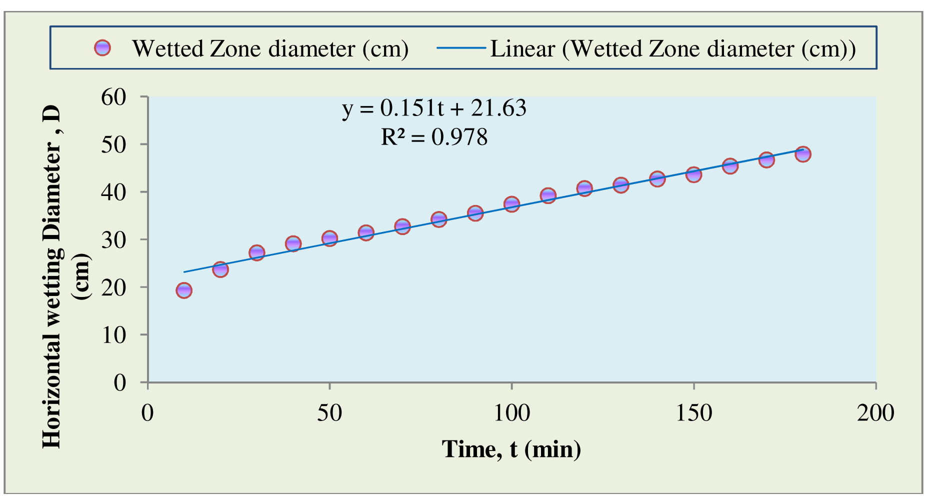

Fig. 2. Diameter of horizontal wetted zone

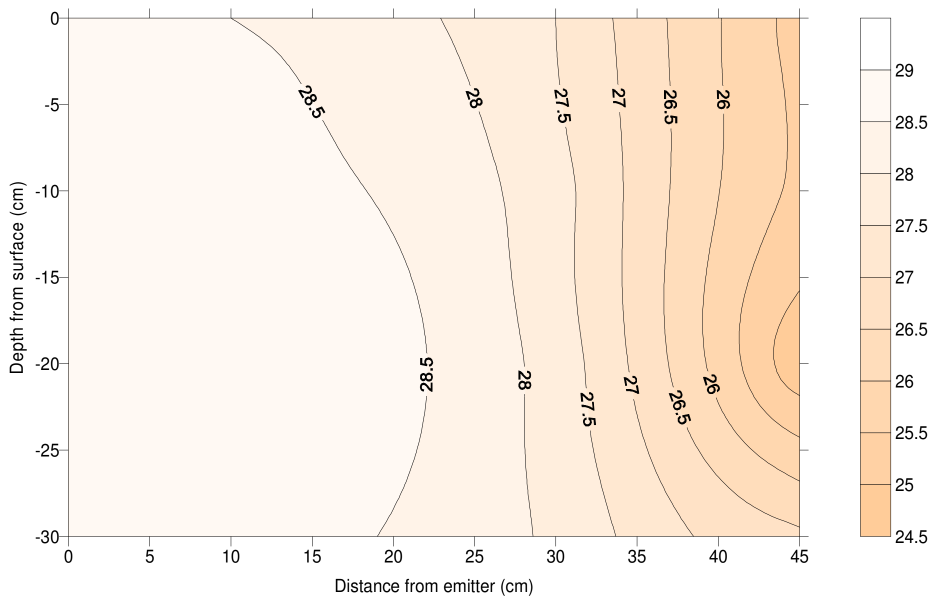

Fig. 3. Moisture content before Irrigation

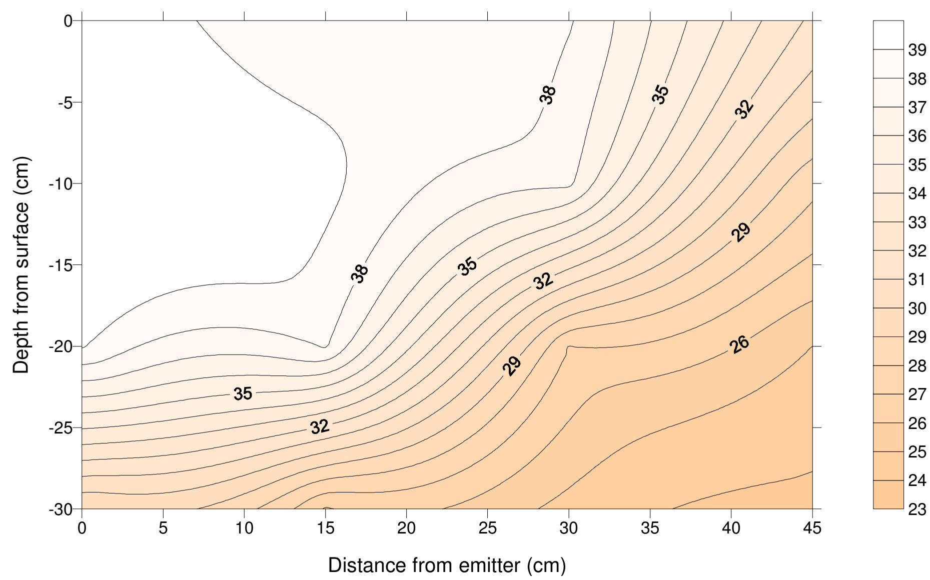

Fig. 4. Moisture content after irrigation

3.5 Wetted Zone Diameter

The diameter of the horizontal wetted zone during different durations of emission is graphically represented in Fig. 2. As the elapsed time increased, the rate of increase of wetted zone diameter decreased. This was due to the increased area for downward movement of water as the lateral wetting increased. A regression equation of type Y= AX+B was fitted to the horizontal advancement for 4 lph emitter in sandy clay loam soil. A high R^2 value of 0.97 shows the goodness of fit for the horizontal movement. The equation fitted was D = 0.151t + 21.63.

3.6 Soil Moisture Distribution Pattern

The soil moisture content at different depths, ie, surface, 0 to10, 10 to 20 and 20 to 30 cm at different distance from the emitter were estimated just before irrigation, immediately after irrigation, one day after irrigation, and two days after irrigation. The mean maximum soil moisture content 39.2% was

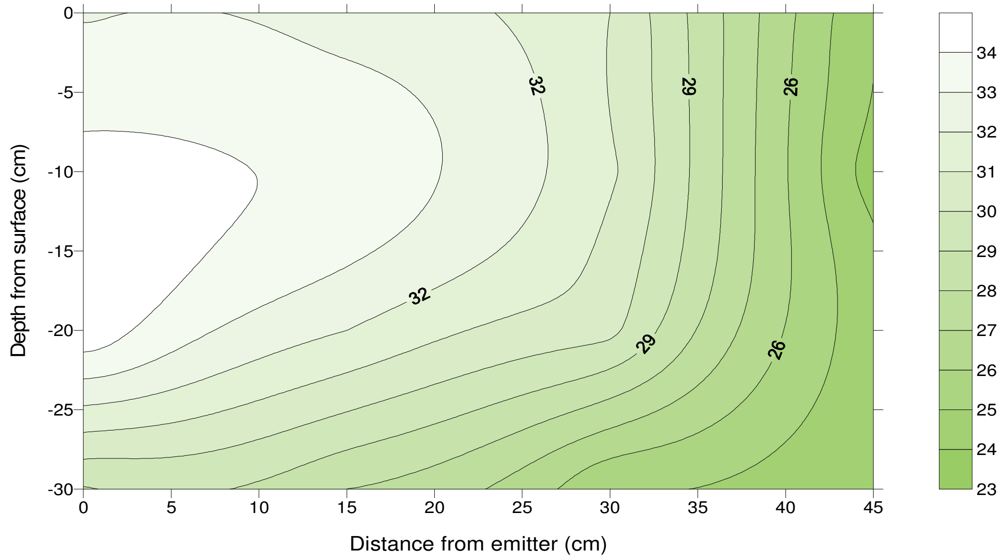

Fig. 5. Moisture content one day after irrigation

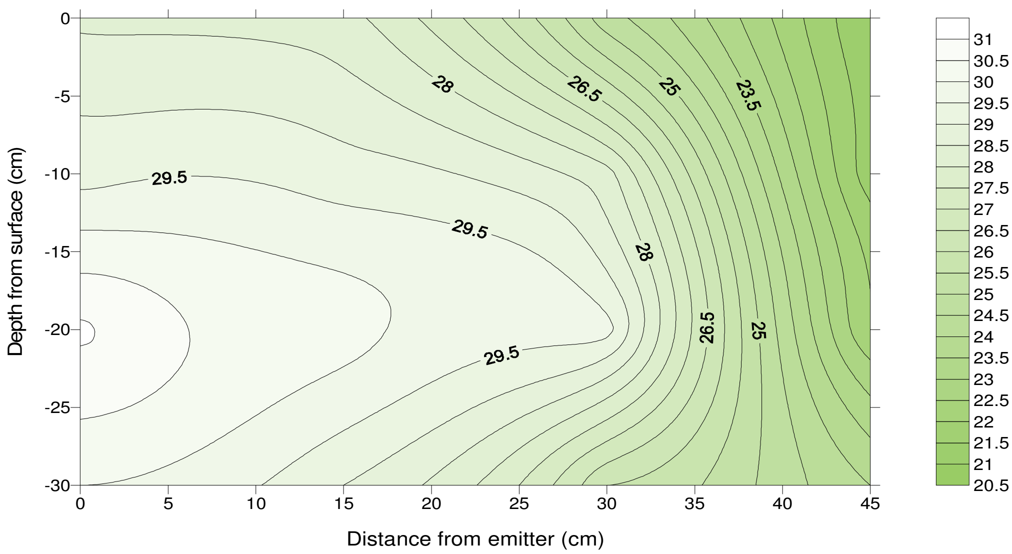

Fig. 6. Moisture content two day after irrigation

observed below the emitter at the depth of 10 cm immediately after irrigation.

The soil moisture contents estimated at different depths and distances from emitter were plotted by using the computer software package *"surfer"* of windows version and are shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6.

The reason for higher moisture content in the lower horizons might be due to water stored in soil pores with minimum evaporation loss. Soil moisture content was lesser in the surface layer than in depths at different locations from emitter. This might be due to more evaporation from the soil surface compared to lower layers [9,10,11]. Soil water content was relatively higher by volume near the emitter and it was decreasing as the distance from the emitting point increased [12-19].

4. CONCLUSION

The Coefficient of variation (Cv) was obtained as 0.0207 per cent kept at a constant pressure of 50.66 kPa, Statistical Uniformity (SU) as 97 per cent and Coefficient of Uniformity (CU) as 0.9518. As the elapsed time increased, the rate of increase of wetted zone diameter decreased. This was due to the increased area for downward movement of water as the lateral wetting increased. A regression equation of type Y= AX+B was fitted to the horizontal advancement for 4 lph emitter in sandy clay loam soil. A high R^2 value of 0.97 shows the goodness of fit for the horizontal movement. The equation fitted was D = 0.151t + 21.63. The mean maximum soil moisture content 39.2 per cent was observed below the emitter at the depth of 10 cm immediately after irrigation. The soil moisture contents estimated at different depths and distances from emitter were plotted by using the computer software package *"surfer"* of windows version.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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