PAN
POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.140792
2022, No. 53 (IV–VI): 158–163

# Soil moisture distribution pattern of surface drip irrigated mango

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RECEIVED 19.05.2021 ACCEPTED 23.09.2021 AVAILABLE ONLINE 29.06.2022

**Abstract:** At present, Pakistan has been facing acute shortage of irrigation water and farmers have been using conventional irrigation methods for orchards, such as flood and basin irrigation, thus wasting huge amount of fresh water. Therefore, it is necessary to find efficient irrigation methods to cope with this major burning issue. The micro drip irrigation method is considered efficient but in the case of mango orchards there is a problem of irrigation frequency, number of emitters, and duration of flow from emitters to meet water demand. Considering the above, an experiment was conducted in the experimental field of the Sindh Agriculture University, Tandojam, by installing the drip system with two circular peripheries of lateral lines in clay loam soil covering the entire canopy of a mature mango tree. The radius of the first and second periphery around the tree trunk was 100 cm and 150 cm, respectively. Four emitters with 4 $dm^3 \cdot h^{-1}$ discharge of individual dipper were fixed in each periphery. Emitters were tested for six different irrigation times, i.e. 1, 2, 3, 4, 5 and 6 h, to observe the moisture distribution pattern. Hydraulic characteristics, such as density, field capacity, porosity, infiltration rate, available water and permanent wilting point (PWP), were determined using standard methods (1.4 $g \cdot cm^{-3}$, 33%, 49%, 8 $mm \cdot h^{-1}$, 12.41% and 20% respectively). The texture class of the soil profile was determined as clay loam at the soil depth 0–120 cm. Fifty soil samples were collected at 0–10, 10–30, 30–60, 60–90, and 90–120 cm depths and at 0–20, 20–40, 40–60, 60–80 and 80–100 cm distances on two opposite sides of emitters. The emitters provided sufficient moisture up to field capacity in clay loam soil with flow duration of 4 h. The maximum moisture distribution efficiency was 77.89% with flow duration of 4 h at vertical depth of 0–120 cm and 0–100 cm distance horizontally among four emitters as compared to 1, 2, 3 h flow duration which under irrigated the canopy area and 5, 6 h flow duration which excessively irrigated the canopy area of the mango tree. The water demand of the mango tree was met by 4 h flow duration which provided adequate moisture to the entire canopy up to 120 cm depth in the root zone and water saving was calculated as 15.91% under the installed drip irrigation system as compared with the conventional (basin) irrigation method.

**Keywords:** double periphery, drip irrigation, mango orchard, moisture content, flow duration

## INTRODUCTION

Sustainability of agriculture depends upon availability of water at specific time. Proper selection of an irrigation method is vital for better management of orchards. Among traditional methods, basin flooding is the most common method that uses large quantities of water to irrigate orchards in Pakistan.

Drip irrigation represents one of the fastest expanding technologies in modern irrigated agriculture. It is widely believed that an increase in the agricultural water use efficiency is the key to mitigating water shortage and reducing environmental problems. Considerable potential for further improvement in agricultural water use efficiency in the region depends on effective conservation of moisture and efficient use of limited water resources.

The concept of real-time control and optimisation of irrigation is in its developmental stage but it has already demonstrated water saving potential [Koech, Langat 2018]. The agricultural management of orchards has been changing from flood irrigated to drip irrigated orchards [Hondebrink *et al.* 2017]. The main cost items in the drip system, particularly for orchards, are lateral lines and emitters. These high-cost components can possibly be reduced by manipulating in the planting pattern without significantly affecting the yield [Singh *et al.* 2017]. Ideally, a well-designed system applies nearly equal amount of water to each plant. Such a high uniformity coefficient is only possible through properly designed emitters that provide steady discharge to all emission points [CHAMBA *et al.* 2019].

Through a properly designed drip irrigation system, uniform distribution of water is ensured which results in better yields. Water saving is calculated at 50.27% for young mango plants and 15.91% for mature mango trees under the drip irrigation method as compared with the conventional (basin) irrigation method. Under the drip irrigation method, the crop water productivity of a mango plant with respect to growth parameters is 0.0017 cm·dm$^{-3}$. The coefficient of uniformity and distribution uniformity decrease substantially at sub-main slopes steeper than 30%. A system with a uniformity co-efficient of at least 85% is considered appropriate to meet standard design requirements [JAMREY, NIGAM 2018]. The fruit yield with full water demand met (100% potential crop evapotranspiration – *ETc*) averaged 24.1 kg·tree$^{-1}$, amounting to 21.2 kg·ha$^{-1}$·mm$^{-1}$ in terms of water-use efficiency [DURÁN ZUAZO *et al.* 2019]. In the drip irrigation method, water movement and its distribution in soil depend upon many parameters, e.g. soil texture, crop planting pattern, discharge of emitters, amount of water applied, climatic factors, etc. However, not much information is available on the influence of the combination of factors such as emitter discharge, amount of irrigation supply, crop planting pattern, and agro-environmental conditions of soil moisture distribution and its subsequent effect on yield.

Therefore, this experimental study was conducted by changing the orientation of emitters toward more efficient moisture distribution in a mango orchard. This study provides basic guidelines to the farming community on how to properly manage a drip irrigation system for better fruit quality and maximum production in a mango orchard.

## MATERIALS AND METHODS

### EXPERIMENTAL SETUP

The experiment was conducted in the experimental field of the Department of Horticulture, Sindh Agriculture University, Tandojam. The drip irrigation system was installed with two circular peripheries of lateral lines in clay loam soil. The radius of the first and second periphery around tree trunk was 60 and 150 cm, respectively (Fig. 1). The distance between first and second lateral lines was 90 cm. The diameters of the peripheries were settled as per shadow of the mature mango tree canopy. Eight emitters labelled $E_1$–$E_8$ (four emitters in first and four in second periphery). The discharge rate of each emitter was 4 dm$^3$·h$^{-1}$, while the moisture distribution data were collected after flow duration of 1, 2, 3, 4, 5 and 6 h. The internal diameter of the emitter nozzle was 0.3 cm and the flow velocity from the nozzle was 0.157 m·s$^{-1}$.

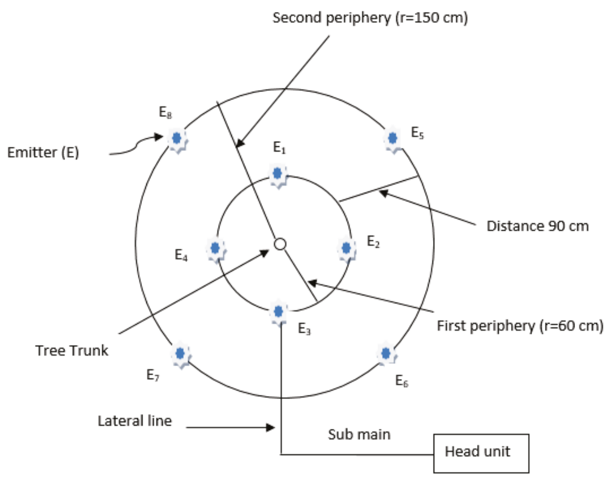



**Fig. 1.** Layout of drip irrigation system; source own elaboration

### HYDRAULIC CHARACTERISTICS OF SOIL

Soil hydraulic characteristics were determined before the experiment in the laboratory of the Department of Irrigation and Drainage, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam. Samples were collected from 0–10, 10–30, 30–60, 60–90, and 90–120 cm soil depths and at 0–20, 20–40, 30–60, 60–80 and 80–100 cm distances from the emission point. The samples collected from identical depths and distances were mixed thoroughly and analysed using standard procedures [RYAN *et al.* 2007]. Various hydraulic properties i.e. texture, bulk density, field capacity, porosity, infiltration rate, available water, and permanent wilting point were determined. They found as follows: soil texture – clay loam (sand 39%, clay 35% and silt 26%), average dry bulk density – 1.4 g·cm$^{-3}$, field capacity – 33%, porosity – 49 %, infiltration rate – 8·mm h$^{-1}$, available water – 12.41% and permanent wilting point – 20%.

### DISTRIBUTION UNIFORMITY

The graduated cylinders were placed under each emitter and volume of water in a given time was measures. This provided the discharge of each emitter. The distribution uniformity of eight emitters fixed around each mango periphery was then calculated using following formula given by JAMREY and NIGAM [2018]. The distribution uniformity was found 89%.

$$D_u = 100\frac{V_{LQ}}{V_{\text{avg}}} \tag{1}$$

where: $D_u$ = distribution uniformity (%), $V_{LQ}$ = average of the lowest 1/4 volume of water collected, $V_{\text{avg}}$ = average volume collected (dm$^3$).

### SOIL MOISTURE CONTENT (SMC)

To determine the soil moisture distribution pattern, soil samples were collected from predefined soil depths and distances from emitters, using a soil auger, before and after irrigation. Before irrigation application the soil moisture content was determined 2.6, 4.2, 3.4, 7.0 and 14.5% at 0–10, 10–30, 30–60, 60–90 and 90–120 cm soil depths respectively. The samples were collected after 24 h of emitter operation at both sides of emission point [PHOGAT *et al.* 2012]. The emitters were operated for various flow duration of 1, 2, 3, 4, 5, and 6 h. This resulted in a total of 25 samples in each direction of emitter around one mango tree for each flow duration. The moisture content was determined by standard gravimetric method.

### RADIUS OF WETTED ZONE AND WETTING CIRCUMFERENCE

On the surface of soil, the maximum radius of the wetted zone from each emission point was measured with a measuring tape and circumference of the moisture distribution pattern around each emitter was determined (Tab. 1) after the flow durations of 1, 2, 3, 4, 5 and 6 h in the first and second periphery.

**Table 1.** Average radius and circumference of wetting pattern with flow durations

| Flow duration (h) | Maximum radius (cm) | Circumference (cm) |
|---|---|---|
| 1 | 34 | 181.73 |
| 2 | 38 | 201.94 |
| 3 | 47 | 234.52 |
| 4 | 53 | 253.56 |
| 5 | 59 | 295.95 |
| 6 | 65 | 362.08 |

Source: own elaboration.

### MOISTURE DISTRIBUTION EFFICIENCY

The moisture distribution efficiency at each and every distance ($x$) and depth ($y$) was determined by averaging and subtracting absolute values of deviations from mean moisture content at each depth with every flow duration [Mirjat *et al*. 2010]. The following formula was used [Jamrey, Nigam 2018]:

$$\eta_d\% = 100\left(1 - \frac{y}{d}\right) \tag{2}$$

where: $\eta_d$ = distribution efficiency (%), $y$ = average of absolute values of deviations from mean, $d$ = mean depth of water stored in the root zone.

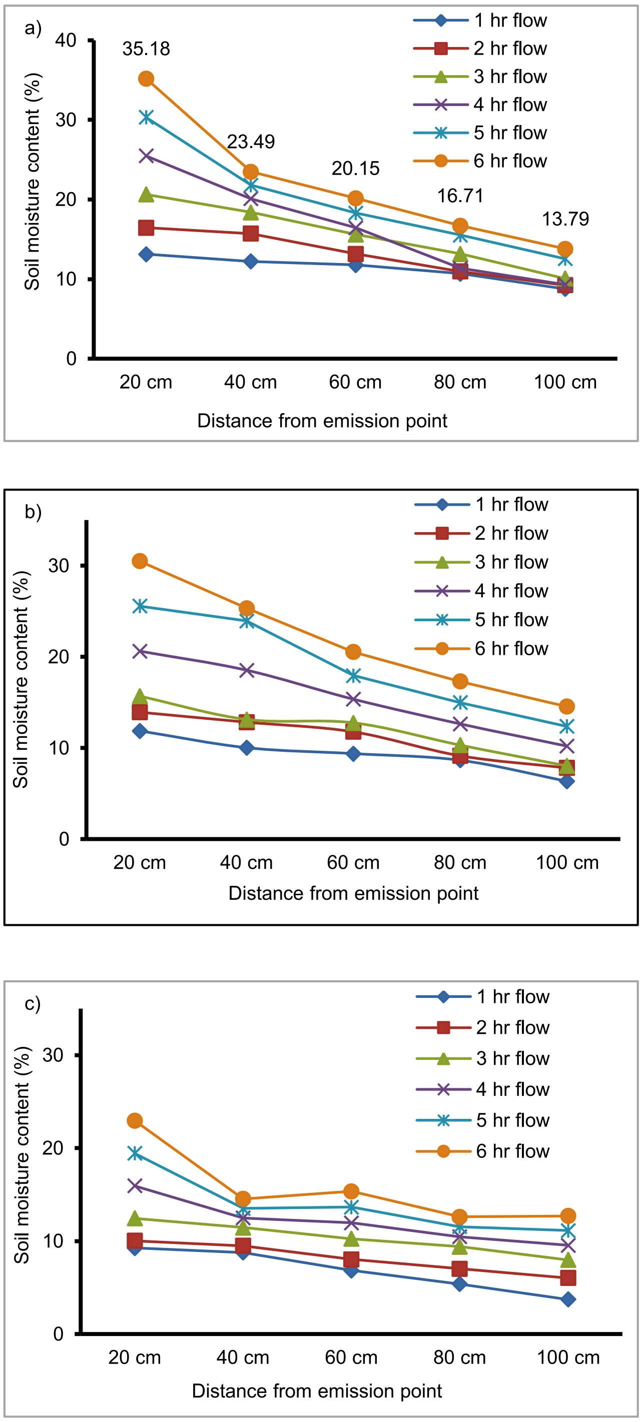
## RESULTS AND DISCUSSION

### SOIL MOISTURE CONTENT AND PATTERN OF WETTED ZONE WITH SINGLE EMISSION POINT

The soil moisture content (SMC at 0–10, 10–30, 30–60, 60–90 and 90–120 cm depths is shown in Fig. 2a–e. The moisture contents were determined at 0–20, 20–40, 40–60, 60–80 and 80–100 cm distances on two opposite sides from each emission point. Before starting the flow from the system, the soil moisture content was determined. To determine the moisture distribution pattern, each flow duration (i.e. 1, 2, 3, 4, 5 and 6 h) started at 8:00 am and samples were collected after 24 h from the completion of each flow duration.

Figure 2a shows SMC observed at 10 cm depth for various distances away from the emission point. The moisture content was higher at a distance of 20 cm from the emission point for all operating times as compared to other distances away from same point. Maximum moisture (35.2%) was observed if the system was operated for 6 h. It decreased to 30.33, 25.48, 20.63, 16.46, and 13.13% for identical distance if system operation reduced to 5, 4, 3, 2, and 1 h, respectively. Almost similar trends were observed at other distances, the soil moisture decreased with reduced operational times. The further we go, the SMC approaches the wilting range for the system operated for 1 and 2 h while it remains in the range near to the field capacity for flow durations of 4, 5 and 6 h. However, water movement seems to pronounce more in a vertical direction rather horizontal one. The radius of the wetting pattern of two laterals did not overlap when flow durations were kept as 1, 2 and 3 h, while it overlaid the wetted zone when 4, 5, and 6 h operation times were applied.

The SMC observed at 30 cm depth for various distances away from the emission point are shown in Figure 2b. Almost similar trends in the SMCs were observed at 30 cm depth. The soil moisture content was higher at a distance of 20 cm from the



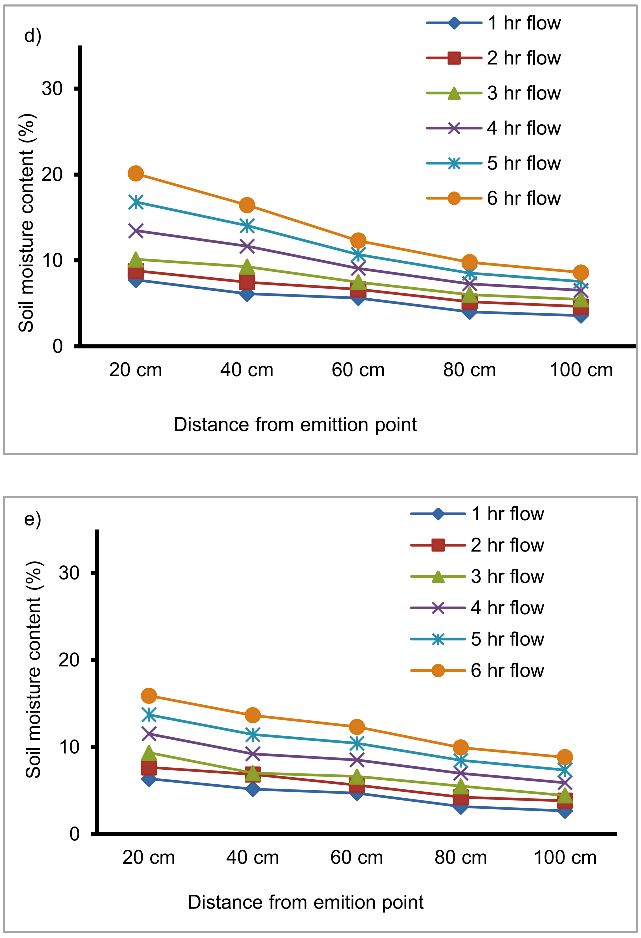



**Fig. 2.** Soil moisture content observed at different soil depths with single emission point: a) 10 cm, b) 30 cm, c) 60 cm, d) 90 cm, e) 120 cm; source: own study

emission point for all operating times as compared to other distances away from same point for 30 cm depth. Maximum moisture (30.5%) was observed if the system was operated for 6 h. It decreased to 25.6, 20.6, 15.7, 13.9, and 11.9% for 20, 40, 60, 80 and 100 cm distances if system operation reduced to 5, 4, 3, 2, and 1 h, respectively (Fig. 2b). Data further reveals that the SMC remained close within the range of the field capacity at 20 and 40 cm distance for flow duration of 6 h at the soil depth of 30 cm with a single emission point. But the percentage the SMC at same soil depth for flow duration of 1, 2, 3, 4 and 5 h along the horizontal distance was ominously low that warns for early irrigation.

The SMC at 60 cm depth for various distances away from the emission point are presented in Figure 2c. The SMCs observed at 60 cm depth and 20 cm lateral distance from a single emission point ranged between 10.0 and 22.9% for 1 to 6 h of operation. The further we move, the SMC significantly reduces for 1, 2, 3 and 4 h operation at 20, 40, 60, 80 and 100 cm distances from the emission point. This indicates the extended operational time to provide required moisture for plant's healthy growth.

The SMC at 90 cm depth ranged between 7.7 for 1 h and 20.1% observed at 20 cm distance from emission point. The maximum SMC was observed when the emitter was operated for 6 h (Fig. 2d), while it decreased with other operational times (i.e. 1, 2, 3, 4, and 5 h). Almost similar trends were observed in the SMC if it was observed at 40, 60, 80 and 100 cm distance from the emission point. The SMC was near to the PWP for 6 h flow duration while it was less than the PWP at the same soil depth for other operational times. It is anticipated that the emitter has limited water movement in a horizontal direction, whereas water movement is more pronounced in a vertical direction.

The SMC observed at 120 cm depth is less than the PWP with the flow duration of 1, 2, 3, 4, 5 and 6 h along all horizontal distances i.e. 20, 40, 60, 80 and 100 cm from the emission point (Fig. 2e). The maximum SMC (15.9%) was observed at 20 cm from the emission point for 6 h of operation. It reduced to 8.8% at the 100 cm distance from the emission point for identical operation time. The SMC was even lower if the emitter was operated for fewer hours. These results suggest that the SMC was not available at 90 cm depth for the root uptake under all flow durations with a single emitter. Almost similar trends were reported by KUMAR and SAHU [2013] and JOB *et al.* [2016]. They observed moisture distribution at various soil depths for a set of conditions with different flow durations of the emitters. Their findings revealed that the soil moisture content in the soil profile decreased gradually with increase in depth and radial distance with respect to the emitters flow duration. Vertical movement of water in the soil profile was higher than that of horizontal movement due to the soil intake rate as well as force of gravity (depth wise data of soil moisture content before irrigation is mentioned in "Materials and methods" chapter).

## SOIL MOISTURE CONTENT AND PATTERN OF WETTED ZONE WITH FOUR EMISSION POINTS

For mango orchards, it is desired that moisture is available up to 120 cm depth so that roots can extract required water. However, the rooting depth varies with plant age. It has been estimated that for a 20 to 35-year-old tree the rooting depth is about 200 cm [AZEVEDO *et al.* 2003]. In this study the SMC was monitored to vertical depths of 120 cm at different horizontal distances from 20 to 100 cm. The SMC was much higher and almost equivalent to that usually observed at the field capacity for 120 cm depth when the emitter was operated for 5 and 6 h (Fig. 3). The two lateral lines were laid around the periphery of the tree and were spaced 90 cm from each other. It was observed that wetted zone radius of emitters installed in the inner lateral overlapped the emitter

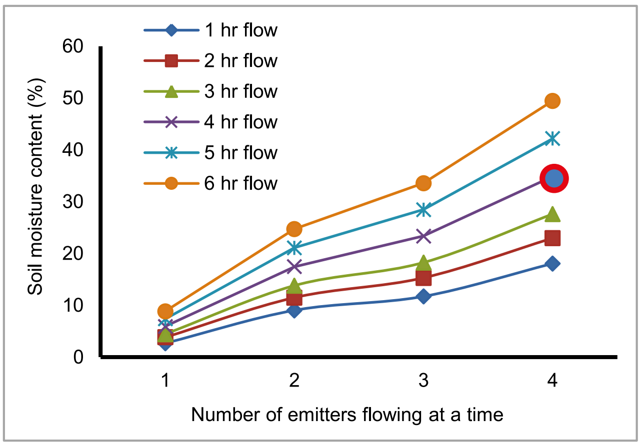



**Fig. 3.** Soil moisture content observed at 120 cm vertical depth and 100 cm horizontal distance from emission points; source: own study

installed at the outer lateral when all the emitters were continuously operated for 5 or 6 h. Flow through four emitters in the first periphery and four emitters in second periphery covered the wetted zone radius of about 48.5 and 58.0 cm, respectively, for inner and outer laterals. A larger SMC was observed due the overlapping wetted zone radius of emitters installed in inner and outer laterals.

The soil moisture between field capacity and wilting point is considered as available for plants. Enough moisture was available with the flow duration of 4 h at the depth of 120 (Fig. 3). However, the SMC was even higher than moisture at the field capacity for operation of 5 and 6 h. The SMC was in excess of moisture at the field capacity. The surplus moisture was easily drained to deeper depths below the root zone due to the overlapping of wetted zones. While the SMC remained below the field capacity when emitters were operated for 1, 2 and 3 h. The overlapping of wetted zones was observed at the horizontal distance of 40, 60, 80 and 100 cm. The SMC at 120 cm depth was equivalent to that at the field capacity with the flow duration of 4 h, while it was above the field capacity for 5 and 6 h flow duration at the distance of 100 cm from the emission point (Fig. 2e). As the flow duration increased, the maximum moisture moved to deeper depths but lesser in the horizontal direction. Almost, similar results have been reported by Bajpai and Kaushal [2020].

### SOIL MOISTURE DISTRIBUTION EFFICIENCY AT 0–120 CM SOIL DEPTH WITH 4 EMITTERS

Figure 4 shows the moisture distribution efficiency in the wetted zone covered by four emission points. The four emitters were allowed to operate for 1, 2, 3, 4, 5 and 6 h. After 24 h of flow, the samples were collected from the wetted zone inside four emitters. The uniform moisture distribution efficiency (in %) was observed with the flow duration of 4 h. The maximum moisture distribution efficiency was 79.12% at the vertical depth of 0–120 cm and 0–100 cm distance horizontally with 4-hour flow duration among four emission points. By increasing the flow duration, the maximum moisture distribution efficiency was observed at 60 cm horizontal distance from each emitter. Almost similar results were reported by Shekhar *et al.* [2017]. Due to

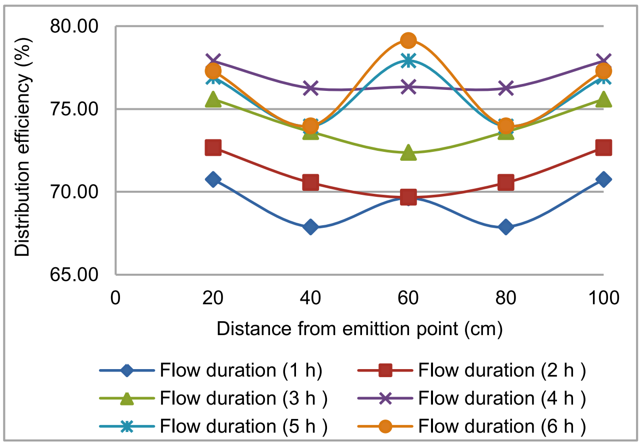



**Fig. 4.** Moisture distribution efficiency observed within the wetted zone at 0–120 cm vertical depth and 0–100 cm horizontal distance from four emission points; source: own study

overlapping of the moisture zones among four emitters fixed in first and second periphery of lateral lines, the moisture distribution efficiency was found fluctuating. This may be because of moisture flow diffusion restricted by other emitters in the soil profile vertically and horizontally.

## CONCLUSIONS

The soil moisture content in the soil profile decreased gradually with increased depth and radial distance with respect to the emitters flow duration. The flow duration of 4 h fulfilled the water requirement of the mango tree up to the 120 cm rooting depth when four emitters operated simultaneously. The maximum moisture distribution efficiency was 79.12% at the vertical depth of 0–120 cm and 0–100 cm distance horizontally with 4 h flow duration among four emission points. The flow duration of 1, 2, 3 h could not ensure the required moisture content (less than field capacity), while 5 and 6 h caused deep percolation from the root zone.

Two peripheries of lateral lines around the mango tree were able to provide sufficient moisture across its canopy. The comparison of different flow times suggests that 4 h duration provided a suitable moisture distribution in horizontal as well vertical direction. Hence, it could be adopted. The overlapping of flow radiuses of emitters installed in double peripheries of lateral lines with four emitters in each periphery were suitable to cover the tree canopy and uniformly distribute moisture up to the 120 cm depth as well as up to the 100 cm distance from the emission point. Water saving is possible with reduced overlap. This could be done by decreasing the discharge from emitters.

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