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Analysis Of Wetted Soil For Determination Optimal Irrigation Duration, Discharge Rate And Design Of Drippers Around The Trunk Under 'Tommy Atkins' Mango In Zabid Valley, Tihamah – Yemen

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Abstract

Mango is a major fruit crop in Tihamah plain, the most irrigation practices are basin irrigating with low efficiency, 1% only of croups area used modern methods (bubbler, and drib irrigation). Effective of drip irrigation depend several vectors such as determination of crop requirement water, duration irrigation, dripper discharge and system of distribution of drippers around the trunk, wetted volume at the root zone. This work aims to determination the best of irrigation duration, discharge rate and distribution of drippers around the trunk under 'Tommy Atkins' mango. The experiment was carried out during October 2016 in a farm, heigh above sea level 127m, located at zabid valley in the southern part of Tihama plain in the west of Yemen. properties of climatical and physical of soil were studies and salinity of water irrigation, three treatments were done, 2d, 4d- 20 cm and 4d- 40 cm, water applied was 80 l for tree treatment and for discharge were used 8, 16 and 32 lph for each treatment, tree irrigation duration were evaluated with each discharge 10 h for 8lph , 5h for 16 lph , 2.5 h for 32 lph. ETC/ day was estimated, hydraulic and physic properties of soil were studded. Several parameters were evaluated, volume water content, coefficient of uniformity, wetted volume of effective root area and percentage wetted. Results shows, the treatment of 4d- 40 cm with discharge 8 plh and irrigation duration 10h was the best treatment which percentage wetted reached to 100%, witch wetted volume of effective root zone recorded 6m3, average water content reached 26% and coefficient of uniformity are reached to 87%. also the discharge of 16 lph with duration irrigation 5h can be used for drip irrigation to mango tree, percentage wetted reached 83%. Saved water reached to 68% compared traditional irrigation. Iso- volumetric water content line in the soil profile was done.

Keywords: *drip irrigation; wetted volume; duration irrigation; discharge rate; iso-water content volumetric line*

1. Introduction

water resources are limited and scares in Yemen. In Yemen 90% of the total water are consumed by irrigation, 99% of agriculture crops are irrigated by traditional irrigation with very high-water loss 40-50% . In contrast, drip irrigation may have field level application efficiency of 70-95%, losses are minimized (Postel, 1999; Postel et al., 2001). In Yemen, Mango crop in Yemen has spread widely as a result their adaptation to the current environmental condition in Yemen, economic profit and food, it has 38% of the total area of fruit cultivation in Yemen, in Tihima plain where was conducted our experimentation, an area of the mango crop occupies 11% of the total irrigated area in the plain (MAI, 2013). surface irrigation system is main practice at the mango farms, amount of water is estimated of applied to one hectare is 25563m3/hac/ season by improving irrigation under Tihama condition (MIA, 2008). Bithell et al. (2011) estimated the total water use mango of applied to mango crop to be 204 mm (2044m3). characteristics of the drip irrigation system were analyzed by many researchers (Dagedlen, et al., 2009; -Galvez, 2006; Phene, 1991; Phene et al., 1992) they reported that the drip irrigation offers a great potential to improve water management by improving crop yield and quality using less water and localizing fertilizer chemical. Matter. (2007) observed that the average yield of mango under surface drip irrigation and sub-drip irrigation increased to 15 and 26% respectively in compared to surface irrigation (farrow). Total water consumed under drip irrigation was 54.22% less than of farrow irrigation method (Soomro et al., 2015).. The wetted volume under drip irrigation system was subject of discussion of many studies (keller and Karmeli, 1974; Kaller and Blienser, 1990; Al- Qinna et al,.2001; Al- Hafedh et al,.2001; Hamammi et al,. 2002; Alizadeh, 2003; Moshe, 2007; Hoori and Alizadeh, 2007; Azevedo et al,. 2011; Neshat and Nazziri, 2012; Molavi et al. 2012; Harby, 2014; Shashi et al.,20 17; Shoukat et al., 2022) these studies showed that, the volume of the wetted area is influenced by many factors, include soil physical properties, soil initial humidity, as well as dripper discharge rate, duration irrigation, crop root characteristics and evapotranspiration. Skagge et al. (2004) reported that, irrigation management of drip irrigation depends on some parameters such frequency, irrigation duration, dripper's discharge rate and the spacing and placement of drip tubing. The wetted soil volume under emitter (dripper) is an important field characteristic in drip irrigation system design (Revol et al,. 1991). There are number of configurations designed to increase the percentage wetted area, double lateral, pigtail, zig- zag, looping and spaghetti tubes (Merkley and Allen, 2004). For the wetted area, most engineers agree on a minimum 33% and a maximum 67% (FAO, 2002). Tager et al. (2012) according to the report, the drip irrigation method saved 56.4% and resulted in 22% increases in yield compared to farrow irrigation method. Zu. (1996) reported that, the volume of the wetted soil presents the amount of soil water stored in the root zoon. The distribution of roots of 'Tommy Atkins' mango was evaluated by Marcelo et al. (2014) who have seen that the root

system is most dense at 0.5-1.5m from trunk and 0.2 to 0.9 m depth in the soil for trees an 11- 12 years age. Also, Choudhury et al. (1992) discovered that the largest number of roots were located at a distance between 0.3m to 1.6m from the trunk and at a between depth 0.3- 0.9m.

At Tihama in Yemen, an advantage and desventages of drip irrigation in the level field has not been studied and there not more research's concentration for drip irrigation system.

2. Material and methods

2.1 Site of experiment

Our experiment was carried out during October 2016 in a mango farm (Al-Ghazali's farm) located at Zabid valley,heigh above see level 127m, in the southern part of Tihama plain in the west of Yemen (fig 1). an annual average rainfall less of 100 mm, in winter average minimum and maximum temperature are 20 and 29.8 ◦C respectively, while in the summer, an average minimum and maximum are 38 and 45 ◦C respectively. The soil particle size distribution was 75% sand, 7.2 salt and 17.8 clay, the bulk density and porosity were 1.5g/m3 and 43% respectively, field capacity and permanent wilting point were 21 % and 9% respectively.

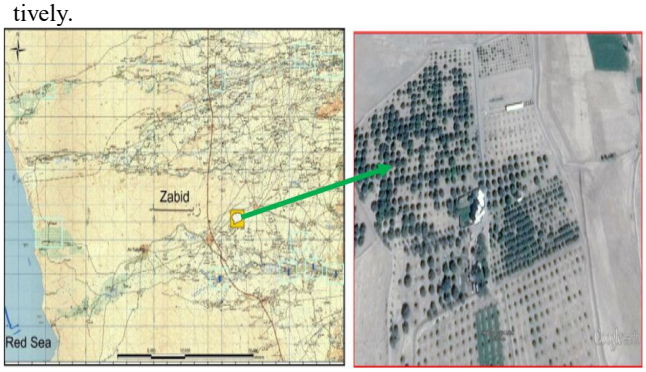

Fig. 1. The farm of mango which our experiment's site ' in zabid valley (from google earth program)

2.2 Crop water requirement (ETC)

a portion of the soil is wetted by the drip irrigation only. the evaporation component of evapotranspiration can be reduced accordingly and prolactin is negligent. Using the appropriate ground cover reduction factor Kr, ETC is calculated as fallow:

ETC= ET0 x KC x Kr (1)

In Tihama plain, the KC (crop coefficient) was estimated for mango tree (table 1).

Table. 1. The values of K_c per month for mango tree

Month	Kc
Jan	0.90
Feb	0.9
Mar	0.85
Apr	0,85
May	0,85
Jun	0,85
Jul	0.85
Aug	0,85
Sep	0.85
Oct	0.85
Nov	0.85
Dec	0.85

ET0 was calculated by CROP WAT program (table 2)

Table 2. Agro- climatic data used in Zabid valley and ET0

Month	Min temp	Max tamp	Humidity	Wind	Sun	Red	ET_0
	˚C	˚C	%	m/s	hour	Mj /m^2/ day	Mm/ month
Jan	16.8	34.0	71	1.7	7.4	17.4	127.46
Feb	17.9	35.5	69	1.6	6.9	18.1	123.91
Mar	19.7	38.7	68	2.0	7.2	19.9	168.43
Apr	21.2	41.3	66	2.0	8.5	22.6	190.32
May	23.9	41.7	65	2.0	9.2	23.5	206.43
Jun	25.1	41.8	64	1.9	8.2	21.7	190.77
Jul	25.0	41.3	64	2.2	6.2	18.8	186.48
Aug	25.2	40.9	64	2.0	6.2	18.9	181.47
Sep	24.0	40.3	66	1.6	7.3	20.2	169.77
Oct	20.8	38.8	67	1.3	8.5	20.7	162.22
Nov	17.8	36.6	68	1.3	8.2	18.7	143.60
Dec	17.0	34.5	69	1.3	8.4	18.1	129.80

The daily water supplied for the tree is an average calculated by Eq. (1), with ET0= 4.9, Kc= 0.85, Kr= 0.54. tree spacing 6 x6. a value of 80 l/ day/ tree are used in our experiment.

2.3 Layout of drip irrigation system at the field

A drip irrigation system was designed and installed in the field (fig 1) for tree treatment with tree trial for each treatment were done and tree discharge was used 8, 16, 32 l/h for each trial as fallow:

1- tow dripper on both sides of the trunk tree (2d).

2- four dripper around the trunk with a circular spacing of 20 cm from the trunk (4d- 20 cm).

3- four dripper around the trunk with a circular spacing of 40 cm from the trunk (4d-40 cm).

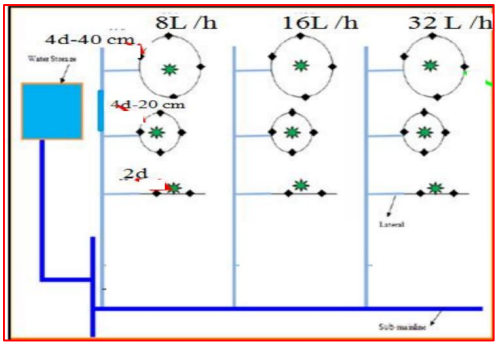

Fig. 2. Layout of experiment at the field

Four irrigation duration were done as fallow:

- 10 h for the discharge 8 l/h.
- 5h for the discharge 16 l/h.
- 2.5 h for the discharge 32 l/h.
- Supplied water was 80 l for each irrigation duration (table 3)

Table 3. amount of water, irrigation duration, discharge and treatments wtith discharge per dripper at each treatment

amount of water (L)	Irrigation duration (h)	Discharge (lph)	Treatment		
			2d	4d-20 cm	4d- 40 cm
			Discharge per dripper		
80	10	8	4l/h	2 l/h	2 l/h
	5	16	8l/h	4 l/h	4 l/h
	2.5	32	16l/h	8 l/h	8 l/h

2.4 System of soil sampling

Soil sampling were taken from four successive layers (0-25, 25-50, 50- 75, 75-100) and distance from dripper (0, 25, 50, 75 and 100 cm (fig 2).

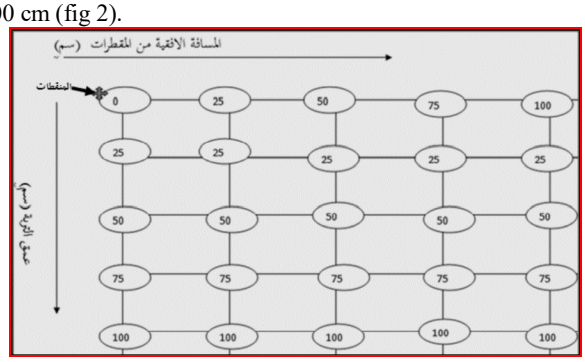

Fig. 3. Layout of soil samples at the field

2.5 Parameters of study

Many parameters were taken in this study; average volumetric water content (θV), coefficient of uniformity (CU%), wetted front vertically and horizontal cm, the percentage wetted (PW), volume of effective root area (Vw) and water saving (WS).

2.5.1 Average volumetric water content $\bar{\theta}$

$$\bar{\theta} = \frac{\sum_{i=a}^{n} \theta_i}{n \times 4} \quad (2)$$

Where θ_i= volumetric water content measured, n= the number of the samples for each layer.
iso- moisture curves in the soil profile were done by surfer program 13.

2.5.2 Coefficient of uniformity (CU%)

Coefficient of uniformity is an important goal for drip irrigation for an evaluated of uniformity of water redistribution within the soil profile, the equation is the most widely and accepted criteria used to define uniformity (Christiansen, 1941; Ould Mohamed El- Hafedh et al, 2001; Zoldoske et al, 1994).

$$CU = 100 \times \left[1 - \frac{\sum_{i=a}^{n} |\theta_i - \bar{\theta}|}{n \times \theta} \right] \quad (3)$$

2.5.3 Percentage wetted (P_W) volume of effective root zone (V_r)

For the aim evaluate the irrigation efficiency, the wetted volume of effective root zone must be calculation. Normally, the wet area is circular at the level of the soil surface around dripper and assuming that the wetted volume under a point source (dripper) is a cylindrical shape (Peries et al, 2007; Thabet and Zayani, 2008; Neshat and Nasiri, 2012). The wetted volume was estimated as follow:

$$V_W = A_W \times Z \quad (4)$$

Where Aw = the surface wetted area at a level zero, it is calculated by following a formula:

$$AW = \pi \times \frac{D^2}{4} \quad (5)$$

Where D = diameter of the wetted area on the surface level, Z= an average depth of the wetted front in the root zone measured at points 0, 25, 50, 75 and 100 cm from the dripper and 0- 25, 25-50, 50-75 and 75- 100 cm at the depth for each point.

Most of the effective root zone volume (Vr) for mango is calculated according to the following:

$$Vr = Ar \times d \quad (6)$$

Where Ar = effective root zone, d= effective root depth.
For percentage wetted of the effective root volume (Pw) is can be estimated as follows:

$$PW = 100 \times \frac{V_W}{V_r} \quad (7)$$

2.5.4 Water saving (WS)

Water saving was determined by dividing applicate water with drip irrigation over basin irrigation method, this procedure has been adopted by Tiger et al (2012):

$$WS = \frac{W_f - W_t}{W_f} \times 100 \quad (8)$$

Where Wf = total water used in basin irrigation, Wt = total water used in drip irrigation (m3/tree/day).

3. Results and discussion

In order to more explanation about the results, before beginning of irrigation an average volumetric water content and coefficient of uniformity were taken, they were 17% and 94% respectively. A volume of water supplied 80 l/tree by three duration a short, moderate and long duration 2.5, 5 and 10 h. The wetted volume (bulb) was characterized by the depth and width wetted front (Acer et al, 2009; Thabet, 2013; Neshat and Nasiri, 2012). In the drip irrigation, the volume of the soil wetted presents water stored in the root zoon (effective area root). An age of tree 10 years and effective root depth 0.9 m this correspondent horizontal 1.5 m, effective root area and 7m2 and effective root volume were estimated 7m2 and 6m3 respectively.

3.1 Volumetric water content ($\bar{\theta}$) and coefficient of uniformity (CU)

Soil moisture content (W) was estimated and the bulk density (ρь) soil. Volumetric water content was calculated according to the following:

$$\theta = W \times \rho_b \quad (9)$$

in the root area, the average volumetric water content varied from 22 to 26% and all value were near the field capacity (21%), soil water content in the bulb must be close to field capacity. the high values observed at discharge 8 lph with all treatment 2d, 4d-20 cm and 4d-40 cm (table 3). The coefficient of uniformity was varied between 84 and 88%, the high values were with treatment of 4d- 40 cm ranged between 87-88% this values are near to value initial of coefficient uniformity 94%, coefficient uniformity in the profile soil must be close near to value initial. The high value was observed under the discharge 8l/h at 4d-20 cm and discharge 32 lph with 4d-40 cm 87 and 88% respectively. the values of volumetric water content were increased near the dripper and decreased when moving away dropper this was observed, Changes of volumetric water content in the profile soil wer done by exsel program (fig 4-6). Iso- moisture curve in the soil profile was done by Surfer program (fig 6-8).

Table. 3. changes of volumetric water content in the profile soil

Treatment	discharge	$\bar{\theta}$ %	CU%
2d	8 lph	26	85
	16 lph	24	84
	32 lph	23	85
4d- 20 cm	8 lph	25	85
	16 lph	25	85
	32 lph	24	84
4d- 40 cm	8 lph	26	87
	16 lph	24	87
	32 lph	22	88

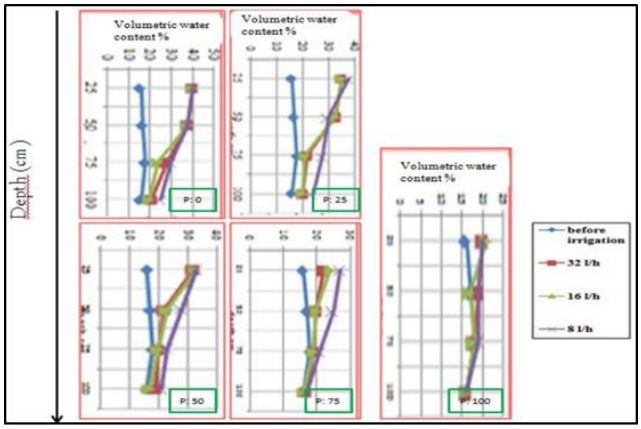

Fig. 4. Varied of volumetric water content in the soil profile at treatment 2d

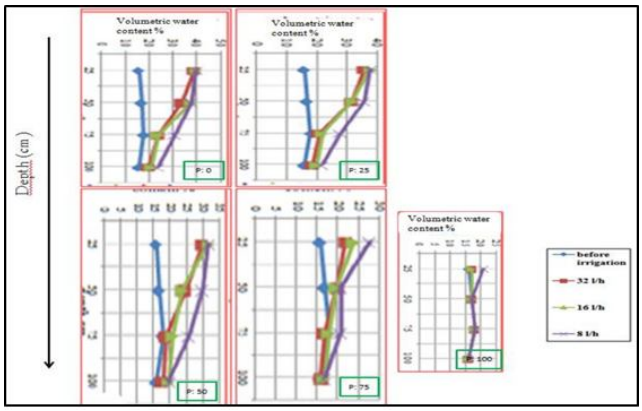

Fig. 5. Varied of volumetric water content in the soil profile at treatment 4d- 20 cm

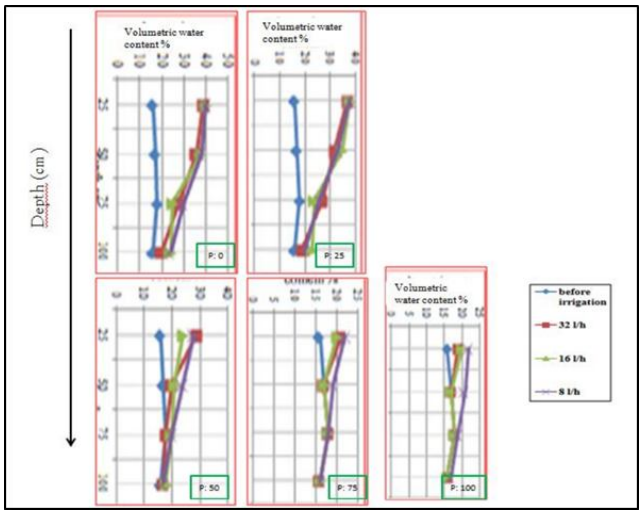

Fig. 6. Varied of volumetric water content in the soil profile at treatment 4d- 40 cm

3.2 Width of surface wetted area (W) and average depth of wetted front(Z)

The width and depth wetted front were measured of the surface wetted area is ranged from 75 to 140 cm (table 4). The width of the surface wetted area must be close 150 cm, the high value was observed at treatment 4d- 4o cm with discharge 8, 16 lph, it reached to 140 cm. For the wetted font depth, the values are ranged from 70 to 90 cm (table 4). The value of wetted front depth must be close to 90 cm, the maximum value of wetted font depth was 90 cm at discharge 8 lph with treatment 4d- 40 cm. It is clear that wetted front depth was increased near the drippers and decreased when moving away drippers (fig 4-6).

3.3 Percentage wetted

The results reveal that the percentage wetted were estimated at all treatment with long irrigation duration 10 h for the discharge 8 lph, moderate irrigation duration 5 h for the discharge 16 lph, short irrigation duration 2.5 h for the discharge 32 lph. wetted volume and percentage wetted were estimated by Eq (4) and Eq (7).

Table. 4. Wetted volume (V_W) and percentage wetted ($P_{w)}$ for three treatment d2, 4d- 20 cm and 4d-40 cm

Discharge (lph)	Irrigation duration (h)	Treatment					
		d2		4d- 20 cm		4d- 40 cm	
		V_W	P_W	V_W	P_W	V_W	P_W %
8	10	2.5	42	4	67	6	100
16	5	1	17	3	60	5	83
18	2.5	1	17	3	50	3	50

The volume wetted must be close 6m3. (Table 3) showed that the values of volume wetted varied between 1to 6m3 and percentage between 17 to 100%, the treatment 4d- 40 cm with discharge 8 lph and long irrigation duration 10 h was superior, the values of volume wetted reached to 6m3 and percentage wetted 100%, this case can be used for trees irrigation. Also, a case of treatment 4d- 40 cm with discharge 16 lph and moderate irrigation duration 5 h was suitability for used trees irrigation because the values of volume wetted and percentage wetted recorded 5m3 and 83 % respectively.

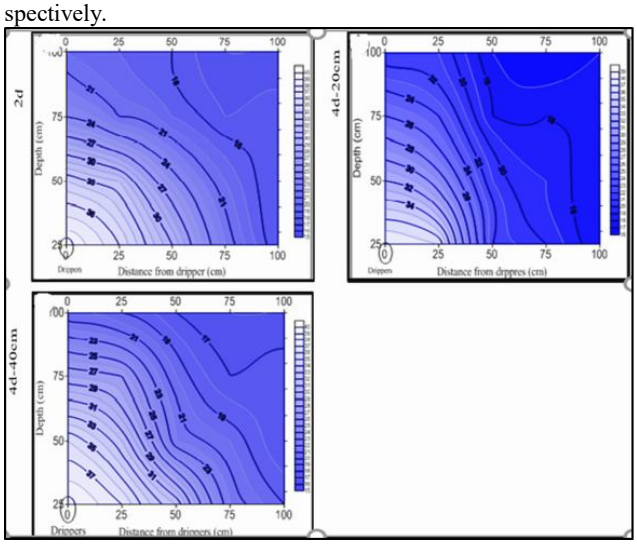

Fig. 7. Iso- volumetric water content line into the soil at discharge rate 32 lph with treatments, 2d, 4d- 20 cm and 4d- 40 cm.

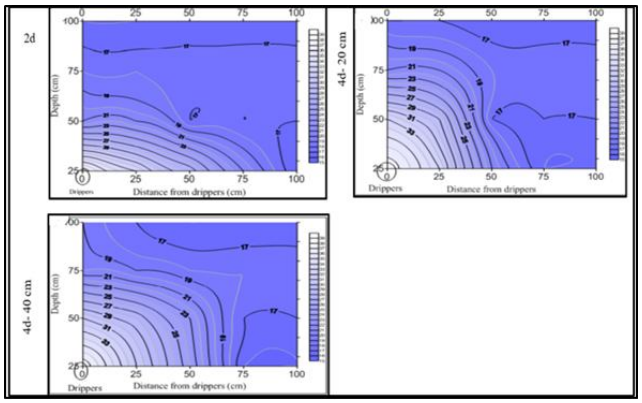

Fig.8. Iso-volume water content lines at discharge rate 16 lph with treatments, 2d, 4d- 20cm and 4d- 40 cm.

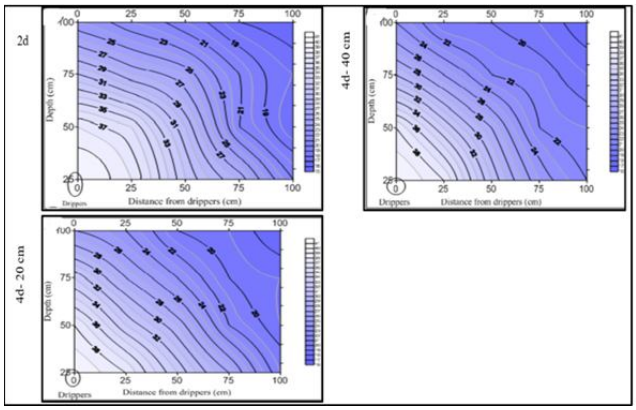

Fig. 9. Iso- volume water content lines at discharge rate 8 lph with treatments, 2d, 4d- 20 cm and 4d-40 cm.

3.4 Saved water

Saved water was compered improving irrigation (moving water by plastic pipes to near tree at the field). Irrigation Scheduling was done in our experiment to estimating of Water requirement/season/ha (m3) (table 5).

Table. 5. Scheduling water under drip irrigation with Appling water 80 l/day/ tree

Month	Day's month	Applied water/ day/ tree (L)	Water requirement/ month (L)	Water requirement/ season/ha (m^3).
Jan	31	80	2840	8I39m^3
Feb	29	80	2320	
Mar	31	80	2480	
Apr	30	80	2400	
May	31	80	2480	
Jun	30	80	2400	
Jul	31	80	2480	
Aug	31	80	2480	
Sep	30	80	2400	
Oct	31	80	2400	
Nov	30	80	2400	
Dec	31	80	2480	

The traditional irrigation is used practice in the mango farms, amount of water is estimated of applied to hectare is about 25563m3/ha/season under Tihama condition, in our experiment water requirement/season/ha (m3) was 8139m3 (table 5). The water saved is calculated by Eq (8) as follow:

$$WS = \frac{W_f - W_t}{W_f} \quad WS = \frac{25563 - 8139}{25563} \times 100 = 68\%$$

This result showed that, efficiency of drip irrigation compared traditional irrigation. Saved water reached to 68%, thus, drip irrigation very suitable to management of water uses of irrigation to agriculture crops as well as fruit trees of mango at Tihama plain and general Yemen.

4. Conclusion and recommendations

For designing of drip irrigation there are several stages must be taken into account as irrigation duration, discharge rate of drippers lateral designing and sub- letteral with drippers around trunk of tree. Successful of drip irrigation system in the field must be wetted volume in the effective root area and percentage wetted that indicated volume of water storage in sub- surface of soil at root zoon. In our experiment many parameters were analysis water content water, coefficient of uniformity, wetted front of horizontal from trunk and depth in the root zoon with four treatment 2d, 4d- 20 cm and 4d- 40 cm were measured. results showed that treatment of 4d- 40 cm with discharge rate 8lph and long duration irrigation 10 h was superior for that we are advancing use this case to supplied water for mango trees in farm's mango, which the wetted volume recorded 6 m3 and wetted percentage 100%, and average water content and coefficient of uniformity were reached to 26% and 87% respectively, also with 16 lph at the same treatment, percentage wetted was reached 83%, and average water content and coefficient of uniformity were reached to 24% and 87% respectively, this case, can be used to drip irrigation for mango trees. Saved water reached to 68% compared traditional irrigation. Iso- volumetric water content line in the soil profile was done and surfer program was used.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conficts of interest.

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