Operating a drip irrigation system in different types of soil

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Abstract

The drip irrigation method is the best method that has been used in the world among the other irrigation methods because of its good and high uniformity. To achieve the goals of using a drip irrigation system, it must be designed and operated properly so that rates and location of delivery of water in the root zone is matched to crop requirements. Generally, the criteria for a drip irrigation system operation are based on soil texture classes. Soil wetting is one of the most important parameters to determine the deep percolation rate and efficiency of the system. Knowledge of soil wetting pattern and its movement plays a large role in deciding depth and space of pipes, the design of irrigation scheduling and improving the efficiency of the drip irrigation system.

The objective of this study is to develop an approach to operating the drip irrigation system in sandy and clay soils by improving the preparation of a computerized method of operating of high workability regarding the type of crops, its consumptive use, type of soil, frequency of irrigation and water distribution in the network .The study adopts two approaches as follows: field work approach and theoretical approach. In field work approach, soil analysis to physical conditions and chemical properties that affect a soil quality as well as suitability for growing plants. To observe the performance of this system, a study was conducted in an engineering laboratory of soil tests. For the theoretical approach a well known piece of software called CROPWAT was used for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. Measurements of the conceptive use, discharge, velocity, wetted soil width, wetted soil depth, frequency of irrigation for the two types of soil with silt content were calculated.

Keywords: drip irrigation, CROPWAT software, wetting depth, wetting width.

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1 Introduction

Drip, or trickle irrigation, is a type of irrigation that slowly applies small amounts of water to part of the plant root zone. Water is applied frequently, often daily, to maintain a favorable soil moisture condition and prevents moisture stress in the plant. In an effective irrigation system, water is distributed as close as possible to the plant's root system. When compared with the other irrigation systems, drip irrigation accomplishes this process more efficiently. Furthermore, it requires less water and less labor than other forms of irrigation (Broner [5]). This system is suitable for most soils if it is used in the right way. On clay soils water must be applied slowly to avoid surface water ponding and runoff. On sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil. The wetting patterns which develop from dripping water onto the soil depend on discharge and soil type. Soil analysis can provide important information about physical conditions and chemical properties that affect a soils quality as well as suitability for growing plants. Modern drip irrigation has arguably become the world's most valued innovation in agriculture since the invention of the impact sprinkler in the 1930s, which offered the first practical alternative to surface irrigation. Careful study of all the relevant factors like land topography, soil, water, crop and agro-climatic conditions are needed to determine the most suitable drip irrigation system and components to be used in a specific installation (Broner [5]).

2 The aims of the study

The present study aims to prepare a computerized method for operating a high workability drip irrigation system regarding the type of crops, its consumptive use, type of soil, field dimensions and water salinity. Also the paper aims to evaluate the effect of soil type on the performance of a drip irrigation system and an application of a field study for the design of the drip irrigation system for different types of soil is stated.

3 Study area

The study area is located in Al-Kut Palms station of Kut Province, 185 km south of Baghdad. It located between longitude 43°42′and latitude 31°15′. On the road Kut-Baghdad from the north side; its area is about 323,760 m^2.

4 Effectiveness of soil types on selection of a drip irrigation system

For drip irrigation systems to deliver improved water, distance between emitters and emitter flow rates must be matched to the soil's wetting characteristics and the amount and timing of water to be supplied to the crop. Broad soil texture ranges (e.g. sand, loam, clay) are usually the only information related to soil wetting used in drip system designs. Wetting pattern for different types of soil can be summarized as:

1. Clay soil: It has densely packed particles that have little space for water or air. Water is absorbed very slowly and runoff can occur if water is applied to quickly. At situation, water tends to move outward away from the drip emitter, clay soil will hold water very well and can stay wet for several days.
2. Sandy soil: It is very loose and has plenty of space for water or air. Water is absorbed very quickly and runoff usually doesn't occur. When wet, water tends to move straight down through the soil. Sandy soil does not hold water very well and can dry out very quickly.
3. Loam soil: Drip irrigation system has an ideal state in-between mix of clay and sandy soil. Its absorption rate is greater than that of clay soil but not as fast as sandy soil. At situation of wet water will move outward and down more evenly. Loam soil will hold water well and dry out at a medium rate.

5 Field investigations

Soil analysis can provide important information about physical conditions and chemical properties that affect a soils quality as well as suitability for growing plants. Soil samples were collected from ten points at the depths of 0 to 30 cm using auger and core sampler. The augured samples were air dried and ground to pass through a 2 mm sieve for analysis of the physical and chemical parameters.
Soil of the study area was tested in the engineering Andrea laboratory of Kut Province.

5.1 Physical soil testing

Physical soil testing is the process of analyzing the gravel, sands, and amendments, used in green construction to determine many factors such as soil texture, moisture content, bulk density, particle density, porosity and hydraulic conductivity. Results of physical characteristics are illustrated in table 1.

5.2 Chemical soil testing

Chemical analysis is the most common method used to assess the nutrient content (and nutrient needs) of soil. An accurate determination of nutrient need is possible if two conditions are satisfied: first, that the soil sample is truly representative of the field to be analyzed; and, second, that the chemical testing method has been calibrated through enough research to the crops and soils in the area (Manachini *et al.* [7]). Chemical analyses were performed for 10 samples taken from the study area and the results of the parameter were stated in table 2.

Table 1: Physical characteristics of the soil samples.

Sample	Soil Classification (%)			Type	Moisture content (%)	Bulk density gm/cm^3	Particle density $(gm/cm^3$	Porosity (%)	Saturated hydraulic conductivity Ks(cm/min)
	Clay	Loam	Sand						
A1	43	43	13	Silty clay	7.11	1.60	2.58	36.82	0.0005
A2	44	39	18	Clay	3.17	1.68	2.56	39.37	0.002
A3	46	16	48	Sandy clay	2.58	1.48	2.55	40.39	0.0002
A4	50	35	24	Clay	5.14	1.64	2.53	35.59	0.002
A5	44	41	25	Clay	3.21	1.54	2.60	40.76	0.0015
A6	52	39	23	Clay	2.26	1.66	2.54	33.07	0.003
A7	45	33	25	Clay	3.31	1.61	2.70	37.77	0.002
A8	50	22	42	Sandy clay	6.68	1.58	2.57	35.40	0.001
A9	51	39	28	Clay	3.16	1.56	2.64	40.90	0.001
A10	49	18	36	Clay	10.29	1.67	2.54	33.46	0.001

Table 2: Chemical characteristics of the soil samples.

Sample	EC Ds/m	CEC mol/kg	Na mmol/l	HCO_3 mmol/l	Ca mmol/l	Mg mmol/l	Cl mmol/l	PH	SAR
A1	5.41	4.28	9.5	2.2	58.4	30.8	27.6	7.42	2.01
A2	4.88	4.28	12	1.4	49.6	24	24.8	7.48	2.80
A2	4.76	2.67	10.6	2	48.8	25.2	22.6	7.40	2.46
A4	5.81	3.74	10.5	2	58.4	36.8	29.9	7.36	2.27
A5	4.78	4.81	9.8	2.4	50.8	25.2	23.1	7.51	2.25
A6	4.60	4.28	11	1.8	49.6	18.4	21.7	7.38	2.91
A7	5.10	5.35	15	2.2	50.4	21.6	23.4	7.47	3.53
A8	4.79	4.81	11.9	1.2	50.4	21.6	23.1	7.75	2.80
A9	5.11	5.35	13.1	2.2	52.4	23.6	23.4	7.18	3.08
A10	4.72	4.28	9.2	2	54	22	19.5	7.26	2.11

6 Conceptive use determination

Two types of soil were tested; clay and sand each with different levels of silt, the most common parameter which importance to estimate is the percentage permanent wilting point (PWP) which can be found as (Basak [3]):

$$PWP = FC/f \tag{1}$$

where: FC is the field capacity, f is a factor varying from 2 to 2.4 depending upon the amount of silt content, while the available moisture content (AMC), is equal to:

$$AMC = FC - PWP \tag{2}$$

The depth of water stored in root zone (Dw) (cm), then written as:

$$Dw = (\gamma * d/w)\ (FC - \text{optimum moisture}) \tag{3}$$

where: γ is the bulk density (F/L^3), d is the root zone depth (L), w is the specific weight of water.

$$\text{Optimum moisture} = FC - RAMC$$

In which RAMC is the readily available moisture content and it is always assumed to 75% of AMC.

Field capacity of the study area is found by the soil tests as 7.5% for sand soil and 36% for clay soil. While the bulk densities of the two types of soils (sand and clay) considered in the present study are found as 1.55 gm/cm^3 and 1.45 gm/cm^3, respectively.

Root zone depth varies depending on the type of plant, for the study area 12 crops of plants are proposed with root zone depths ranging between 50 and 200 m.

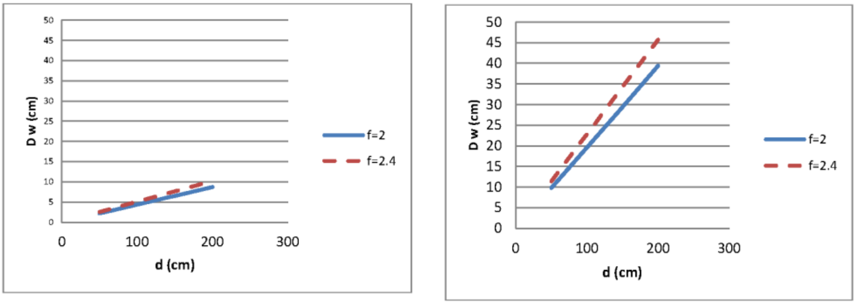
The depth of water stored in root zone (Dw) was found to be higher in clay soil than sand soil because it is saving the water for long time by little area as it is little porous. Increasing silt rate for each type of soil, increases the amount of irrigation water to disposal of silt and paid it out of the plant root zone. Figure 1 shows the relationship between stored water (Dw) and the root zone depth of the proposed croups of crops for both sand and clay soils. Consumptive irrigation use can be determined using the Blaney–Criddle formula (Blaney and Criddle [4]) as:

$$Cu = 0.75\ K * P\ (t + 17.8) \tag{4}$$

where Cu is the monthly consumptive use(cm), K is the crop factor of plant, P is the number of sunny hours and t is the highest temperature during the month (°C).

7 CROPWAT software

CROPWAT is a decision support tool developed by the Land and Water Development Division of Food and Agriculture Organization (FAO [6]). It is a computer program for the calculation of crop water requirements and irrigation



(a) sandy soil (b) clay soil

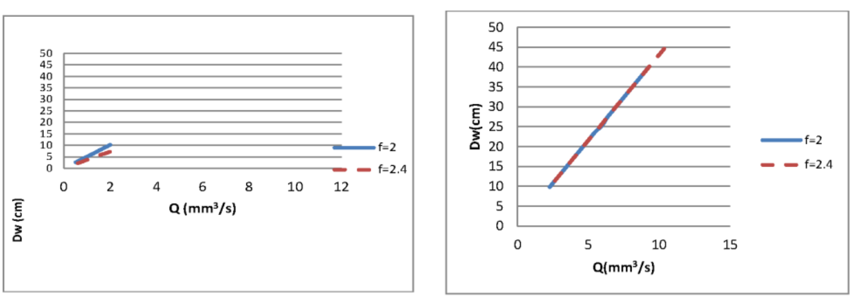
Figure 1: Relationship between water stored in root zone (D_w) and root zone depth (d)

requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

8 Drip irrigation system parameters

8.1 System discharge (Q)

The daily dripper discharge expressed as the volume of water wetted specified area of soil, it is for clay soil higher than sand soil as it ability to save the water for long time (as shown in figures 2(a) and (b)) for sandy and clay soils, respectively. The values are found to be range between 2.27 and 9.12 mm^3/s for clay soil with low silty (f=2) and 2.64–10.6 mm^3/s with high silty (f=2.4), while for the sand soil values of Q range between 0.5and 2 mm^3/s with low salinity (f=2) and 0.6–2.36 mm^3/s with high salinity (f=2.4). Tables 3 and 4 show the values of dripper discharge for clay and sandy soils, respectively. The present



(a) sandy soil (b) clay soil.

Figure 2: Relationship between dripper discharges (Q) and depth of water stored in root zoon (Dw).

drip irrigation system is located in an area of 323760m^2. This area is divided into 8 strips each with 40,470 m^2 (100*250)m contains a drip irrigation system consisting of a pump, filter, main pipe of 2.5 inch diameter, lateral pipe of 1 inch diameter and dripper pipe of 16 mm diameter (figure 3) (Al_Kut Palms station [2]). The system is recharged from the Tigris river to a basin with (10*10*2.5) m. Distribution of discharge values in the system can be taken as:

$$Q_L = Q_d * N_d \quad (5)$$

$$Q_m = Q_L * N_L \quad (6)$$

$$Q_h = Q_m * N_m \quad (7)$$

where: Q_d the dripper discharge, (V/T), Q_L the lateral pipe discharge, (V/T), Q_m the main pipe discharge, (V/T). Q_h the head discharge, (V/T), N_d number of drippers, (100 drippers), N_L number of lateral pipe, (20 pipes) and N_m number of main pipe, (8 pipes).

Table 3: Estimated flow velocity with discharge of the drip irrigation system in clay.

Crop No.	**Q_L (mm^3/s)**		**V_L(mm/s)**		**Q_m (mm^3/s)**		**V_m (mm/s)**		**Q_h (mm^3/s)**		**V_h (mm/s)**	
	f=2	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**
1	227	264	113.5	132	4540	5280	9.1	10.56	36320	42240	2.54	2.96
2	272	317	136	158.5	5440	6340	11	12.68	43520	50720	3.05	3.55
3	318	370	159	185	6360	7400	12.7	14.8	50880	59200	3.56	4.14
4	363	424	181.5	212	7260	8480	14.5	16.96	58080	67840	4.1	4.75
5	408	477	204	238.5	8160	9540	16.3	19.1	65280	76320	4.6	5.34
6	454	528	227	264	9080	10560	18.2	21.12	72640	84480	5.1	5.91
7	500	580	250	290	10000	11600	20	23.2	80000	92800	5.6	6.5
8	544	634	272	317	10880	12680	22	25.36	87040	101440	6.1	7.1
9	600	687	300	343.5	12000	13740	24	27.48	96000	109920	6.72	7.7
10	635	741	317.5	370.5	12700	14820	25.4	29.64	101600	118560	7.1	8.3
11	681	794	340.5	397	13620	15880	27.2	127040	108960	127080	7.63	9
12	912	1060	456	530	18240	21200	36.5	169600	145920	169600	10.21	12

Table 4: Estimated flow velocity with discharge of the drip irrigation system in sandy soil.

Crop No.	**Q_L(mm^3/s)**		**V_L(mm/s)**		**Q_m (mm^3/s)**		**V_m (mm/s)**		**Q_h (mm^3/s)**		**V_h (mm/s)**	
	f=2	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**	**f=2**	**f=2.4**
1	50	60	25	30	1000	1200	2	2.4	8000	9600	0.56	0.7
2	60	71	30	35.5	1200	1420	2.4	2.84	9600	11360	0.67	0.8
3	70	83	35	41.5	1400	1660	2.8	3.32	11200	13280	0.8	0.93
4	80	49	40	47	1600	1880	3.2	3.76	12800	15040	1	1.1
5	91	106	45.5	53	1820	2120	3.64	4.24	14560	16960	1.02	1.2
6	101	118	50.5	59	2020	2360	4.04	4.72	16160	18880	1.13	1.32
7	111	130	55.5	65	2220	2600	4.44	5.2	17760	20800	1.243	1.46
8	121	142	60.5	71	2420	2840	4.84	5.68	19360	22720	1.355	1.6
9	131	153	65.5	76.5	2620	3060	5.24	6.12	20960	24480	1.47	1.71
10	141	165	70.5	82.5	2820	3300	5.64	6.6	22560	26400	1.6	1.85
11	150	180	75	90	3000	3600	6	7.2	24000	28800	1.7	2
12	200	236	100	118	4000	4720	8	9.44	32000	37760	2.24	2.64

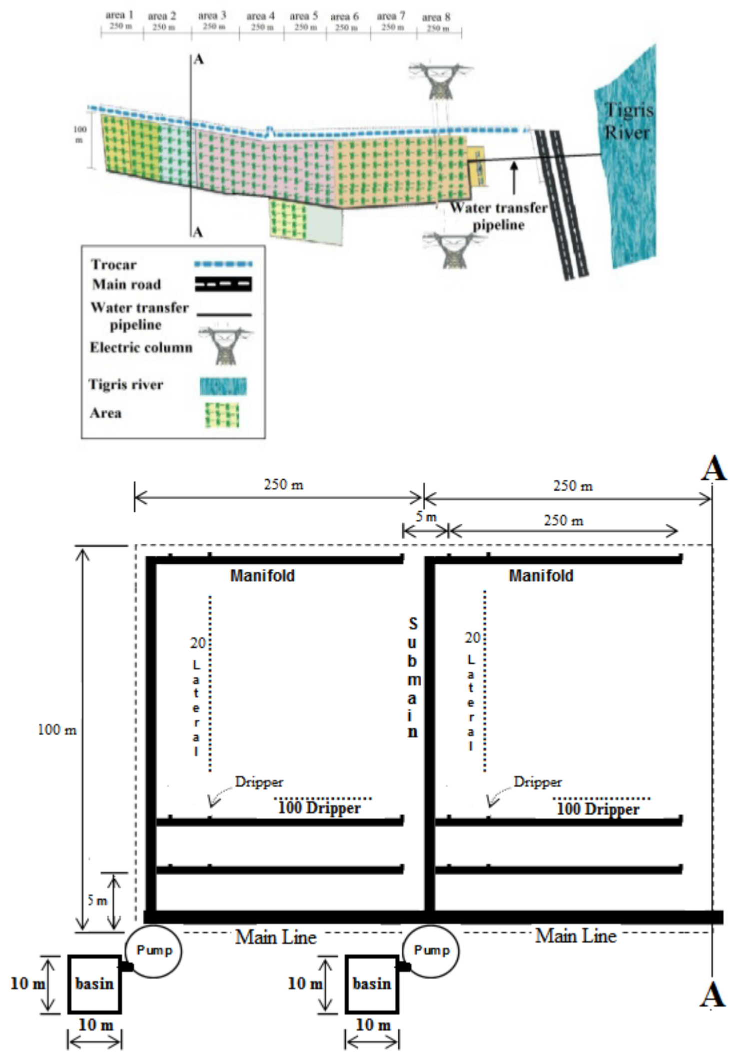


Figure 3: Outline of the drip irrigation system in Kut Province (Al_Kut Palms station, 2004).

From the equation of continuity, the flow velocity of the pipe is:

$$V = \frac{4\, Q_{L,m,h}}{\pi\, d^2} \tag{8}$$

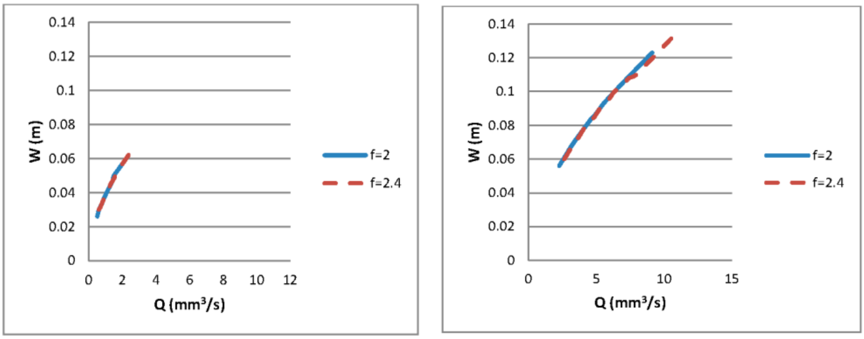
where: V is the flow velocity of the pipe, (L/T), d is the diameter of the pipe (L).

8.2 Wetted width (W)

The wetted soil width at the root zone of plants can be determined as (Phull and Babar [8]):

$$W= 3.245\ [q_w^{0.5} * d^{0.065} * t^{0.435}/ks^{0.065}] \qquad (9)$$

where: W is wetted soil width, (m), q_w water application rate or discharge rate per unit length of pipe, (m^2/s), ks saturated hydraulic conductivity of the soil, (m/s), d Depth of root zone, (m) and t time of crop irrigation, (s). Figure 4 shows wetted soil width of both soils.



(a) sandy soil (b) clay soil

Figure 4: Relationship between wetted soil width (W) and dripper discharge (Q).

8.3 Wetted depth (D)

The wetted soil depth needs to be applied to an irrigated system when soil water is reduced to the specified depletion level. The wetted soil depth at the root zone of plants can be determined as (Phull and Babar [8]):

$$D= 3.572[q_w^{0.5} * d^{0.177} * t^{0.323} / ks^{0.177}] \qquad (10)$$

where: D is wetted soil depth below porous pipe, (m), other parameters are defined previously. The relationship between wetted soil depth (D) and wetted soil width (W) was drawn for both clay and sand soil with (f=2) and (f=2.4) in figure 5.

8.4 Frequency of irrigation (Fw)

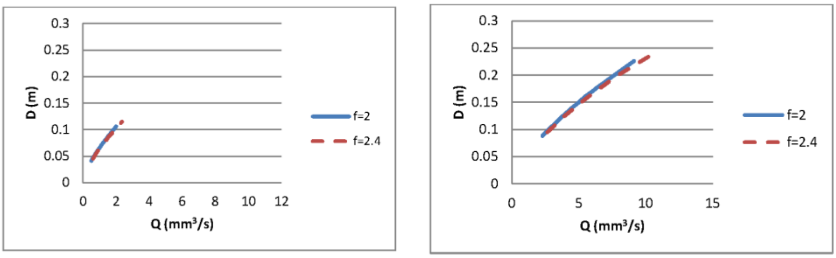
It refers to the number of days between two irrigated periods without rainfall. A moisture use ratio varies with the kind of crop and climate conditions and increases as the crop grows larger. Frequency of irrigation (Fw) can be found as (Basak [3]):

$$Fw = Dw/Cu \qquad (11)$$

where: Fw is frequency of irrigation (day), Dw the depth of water stored in root zone (cm).

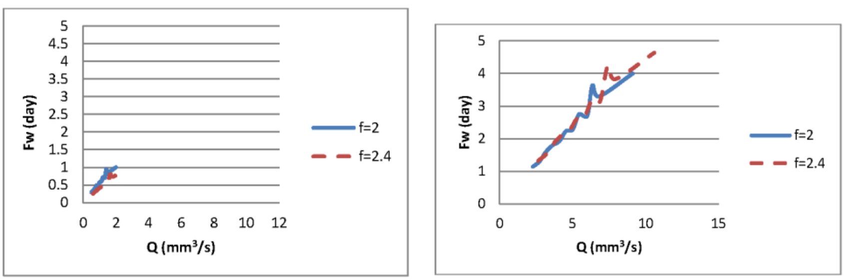
The frequency of irrigation is higher in clay and silty soil as in figure 6(a) and (b)

Summary of the irrigation system parameters are listed in tables 5 and 6 for both soils.



(a) sandy soil (b) clay soil

Figure 5: Relationship between wetted soil depth (D) and dripper discharge (Q).



(a) sandy soil (b) clay soil

Figure 6: Relationship between frequency of irrigation (fw) and dripper discharge (Q).

Table 5: Results of drip irrigation system parameters for clay soil.

Crop No.	Dw (cm)		Q_d (mm^3/s)		W (m)		D (m)		Fw (day)		Cu (cm/month)
	f=2	f=2.4	f=2	f=2.4	f=2	f=2.4	f=2	f=2.4	f=2	f=2.4	
1	9.8	11.4	2.27	2.64	0.056	0.06	0.088	0.095	1.14	1.32	258.78
2	11.76	13.7	2.72	3.17	0.062	0.067	0.1	0.107	1.3	1.52	271.11
3	13.72	16	3.18	3.7	0.068	0.073	0.11	0.12	1.6	1.85	258.78
4	15.68	18.3	3.63	4.24	0.073	0.08	0.121	0.131	1.8	2.1	261.25
5	17.64	20.6	4.08	4.77	0.078	0.084	0.131	0.142	1.92	2.24	276.04
6	19.6	22.8	4.54	5.28	0.083	0.09	0.141	0.152	2.23	2.6	263.71
7	21.56	25	5	5.8	0.087	0.094	0.15	0.162	2.28	2.65	283.43
8	23.52	27.4	5.44	6.34	0.092	0.1	0.16	0.172	2.75	3.21	256.32
9	25.48	29.7	6	6.87	0.097	0.103	0.17	0.181	2.7	3.14	283.43
10	27.44	32	6.35	7.41	0.1	0.108	0.177	0.191	3.63	4.23	226.74
11	29.4	34.3	6.81	7.94	0.104	0.11	0.185	0.2	3.3	3.83	268.64
12	39.4	45.7	9.12	10.6	0.123	0.132	0.226	0.24	4	4.64	295.75

Table 6: Results of drip irrigation system parameters for sandy soil.

Crop No.	Dw (cm)		Q_d (mm^3/s)		W (m)		D (m)		Fw (day)	
	f=2	f=2.4	f=2	f=2.4	f=2	f=2.4	f=2	f=2.4	f=2	f=2.4
1	2.55	2.175	0.5	0.6	0.026	0.03	0.041	0.045	0.29	0.25
2	3.06	2.61	0.6	0.71	0.03	0.032	0.047	0.051	0.34	0.3
3	3.57	3.04	0.7	0.83	0.032	0.035	0.052	0.057	0.4	0.35
4	4.08	3.48	0.8	0.94	0.034	0.037	0.057	0.062	0.48	0.4
5	4.59	3.92	0.91	1.06	0.037	0.04	0.062	0.067	0.5	0.43
6	5.1	4.35	1.01	1.18	0.039	0.042	0.066	0.072	0.58	0.5
7	5.61	4.8	1.11	1.3	0.041	0.045	0.071	0.077	0.6	0.51
8	6.12	5.22	1.21	1.42	0.043	0.047	0.075	0.081	0.72	0.61
9	6.63	5.65	1.31	1.53	0.045	0.049	0.079	0.086	0.7	0.6
10	7.14	6.1	1.41	1.65	0.047	0.051	0.083	0.09	0.94	0.8
11	7.65	6.5	1.5	1.8	0.05	0.054	0.087	0.095	0.85	0.73
12	10.2	8.7	2	2.36	0.057	0.062	0.106	0.115	1	0.88

9 Conclusions

From the information collected during this study, the following conclusions are drawn:

1. Rate of filtration from the drip irrigation system is dependent on soil type. This system of irrigation is able to localize the amount of water that need for specific soil. Clay soil needs less frequent wetting than sandy soil.
2. CROPWAT is an easier computer program to carry out standard calculations of crop water requirements and irrigation requirements based on soil, climate and crop data.
3. The designed discharge of the drip irrigation was found to be higher in clay soil than sand soil because it is saving the water for long time by little area as it is little porous. Increasing silt rate for each type of soil increases the amount of irrigation water requirement.
4. Flow velocity should be kept low, whenever the pipe diameter of irrigation system increase, this is to avoid water hammer problems in pipelines.
5. The wetted soil width depends on emitter discharge and soil type, it will be increase with soils in high silty clay compared with the low silt and bigger as compared to sandy soils. The wetted soil depth for clay soil is higher than sand soil as it ability to save the water for long time.
6. The frequency of irrigation is higher in high silty clay soil than sandy soil, the latter paid of water more quickly, so the irrigation needs convergent periods.

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