DESIGN OF DRIP IRRIGATION SET FOR SMALL VEGETABLE GARDENS

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Abstract. The need for an affordable small scale irrigation system in most small gardens in Nigeria today is on increase and as a result an attempt has been made to design a drip irrigation set for small vegetable gardens. The drip irrigation set dimensionally consists of a main line diameter of 12.7 mm, three lateral lines of diameter 19.05 mm and emitters of diameter 1.5 mm spaced 60 cm along the lateral lines. The emitters discharge rate was found to be 2.12 litres / hour and this will hopefully complete one irrigation of the area (5 m x 10 m) designed for 4 hours at peak consumptive use periods, employing two shifts of the three laterals.

Key words: drip irrigation, drip irrigation set, main line, lateral line and emitters.

INTRODUCTION

Drip irrigation offers small holders a practical method of improving irrigation efficiency and of increasing the yields of most horticultural. Orchard and field crops by marching frequently low volume applications of water and dissolved fertilizer to the rate of uptake by the crop. Thus the soil is maintained continuously in a condition which is highly favourable to crop growth. As the application are localized close to the plant root zone, losses through drainage or by wetting inter-rows and ridges are minimized. Howell et al. (1981) reviewed over 50 research reports on crop response to drip irrigation. Drip irrigation generally compare favourably with other types of irrigation both in terms crop yield and water conservation.

Although highly efficient in water application, the existing drip irrigation equipment consist of a complex system with many secondary components is very expensive. This has been largely responsible for its lack of practice in this part of the world where the average farmer is living on subsistence level and thus too poor to meet up with the huge cost of drip irrigation installation. Affordable drip irrigation set for use in vegetable gardens is necessary if the benefits of drip irrigation enjoyed by a large percentage of Nigerians. In consideration of above limitations regarding drip irrigation practice the present paper had at main objective to design affordable drip irrigation set for use in vegetable gardens.

MATERIALS AND METHODS

Components of drip irrigation system consist essentially of main line, submains, laterals and emitters. The main line delivers water to the submains and the submains to the laterals. The emitters which are attached to the laterals distribute water for irrigation. The mains, submains and laterals are usually made of black polyvinyl Chloride (PVC) tubing. The

emitters are also usually made of PVC materials. PVC material is preferred for drip system because it can withstand saline irrigation water and is also not affected by chemical fertilizers.

The secondary components include fertilizer tank, pressure gauge, water meter, pressure regulator, filters flushing valves and pump.

In this design were used the following specifications:

Length of ridge (lateral) = 1 m

Width of a ridge = 50 cm = 0.5 m

Area of a ridge =10 x 0.5 = 5 m^2

Depth of a ridge = 0.5 m

Centre to centre of a ridge =1 m

Operating pressure H =10 m

Slope of lateral line =1 %

No. of emitter = 10 = 17 spaced at 60 cm equally along the lateral line 0.6.

Determination of Consumptive Use of Vegetables

B$_1$. Net irrigation requirement: This is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. The net depth of irrigation can be determined from readily available moisture (RAW).

RAW = (MAD) AW

Where: RAW = Readily available water (mm), MAD = Maximum allowable deficiency, and AW = Available water.

RAW = (MAD)(Drz)(Fc – Pwp)(P)/100

MAD for tomatoes = 0.5 with effective rooting depth of 90 cm (Drz); P = area wetted as a percent of the total area = 40%.

RAW = 0.5 x 0.9 x (11.7-3.7) x 40/100 = 14.4 mm

B$_2$. Gross irrigation Requirement: The gross irrigation requirement is the total amount of water applied throughout irrigation.

Gross irrigation requirement = Net irrigation requirement/Field efficiency of the system

= 14.4 mm x 100/80 = 18 mm (For drip irrigation system, application efficiency = 80%)

B$_3$. Irrigation interval/frequency. This is the number of days between irrigations during periods without rainfall.

The design irrigation frequency = Net depth of irrigation/Transpiration rate of tomatoes

T = Et x Ps/85

where, T = average transpiration rate of the tomato (mm/day), Ps = area shaded by the crop as a percentage of the total area (%), ET = conventionally accepted consumptive use rate of the crop (mm/day).

Taking Ps = 40 % and ET (tomato) = 7.5 mm, T = 7.5 x 40/85 = 3.53 (mm/day)

Therefore, Irrigation interval (I$_t$) = 14.4 mm/3.53 mm x day = 4 days, which is the maximum irrigation interval that would not stress the tomato crop excessively.

B$_4$. Irrigation period (Ip): Irrigation period is the number of days that can be allowed for applying one irrigation to a given designed area during the peak consumptive use period of the crop being irrigated.

Ip = (Mb-Ml) x bd x dz /(100 x Cu) (Isrealson et al., 1962)

where: Ip = irrigation period (day), Cu = consumptive use (mm/day); Mb = moisture content at the start of irrigation (%), and Ml = moisture content in the root zone at the lower limit of moisture depletion (%).

Mb-Ml = 0.75FC - 0.625FC = 0.125FC (Isrealson et. al. 1962)

For FC = 11.7%, dz = 900 mm, Cu =7.5 mm/day, bd = 1.70g/cm^3

Ip = (0.125 x 11.7 x 900 x 1.70) x day /(100 x 7.5) = 2.96 days

Area = Length x Width = 10 m x 0.5 m = 5 m^2

Taken 40% of the entire ridge area to be wetted by the emitters, then the effective wetted area per ridge = 0.4 x 5 m^2 = 2 m^2

For 6 ridges, volume of water required = 6 x 2 x 0.018 = 0.216 m^3

Volume = Gross application depth x area = 216 liters

Various actual irrigation periods of 24 hrs, 12 hrs and 6 hrs were tried after which 6 hrs was chosen for the design since it gave maximum discharge per lateral line.

Q = volume/time = 0.216 (m^3)/24 (hrs) = 0.009 m^3/hrs = 9 l/hr

q = 0.216 (m^3)/12 (hrs) = 0.018 m^3/hrs = 1 l/hr

q = 0.216 (m^3)/6 (hrs) = 0.036 m^3/hrs = 36 l/hr

For each ridge the discharge q = 0.01 l/sec.

The 17 emitters were spaced 60 cm along the lateral line. For 17 emitters, the discharge rate, q = 36 l/hr

Therefore, for 1 emitter = 36/17 = 2.12 l/h

Each lateral line contains 17 emitters with a total flow rate of 36 l/hr

Main line discharge rate = 36 l/hr x 3 = 108 l/hr

B$_5$. Drip set capacity: In this design, the area of the garden to be irrigated is 50 m^3 (5 m x 10 m). Therefore, amount of water required per irrigation = area of the garden x gross irrigation depth = 5m x 10m x 1.8cm = 500cm x 1000cm x 1.8cm = 0.90 x 10^{7}cm^3 = 9.0 x 10^3 litres.

The layout of the drip irrigation system is as shown in Figure 1.
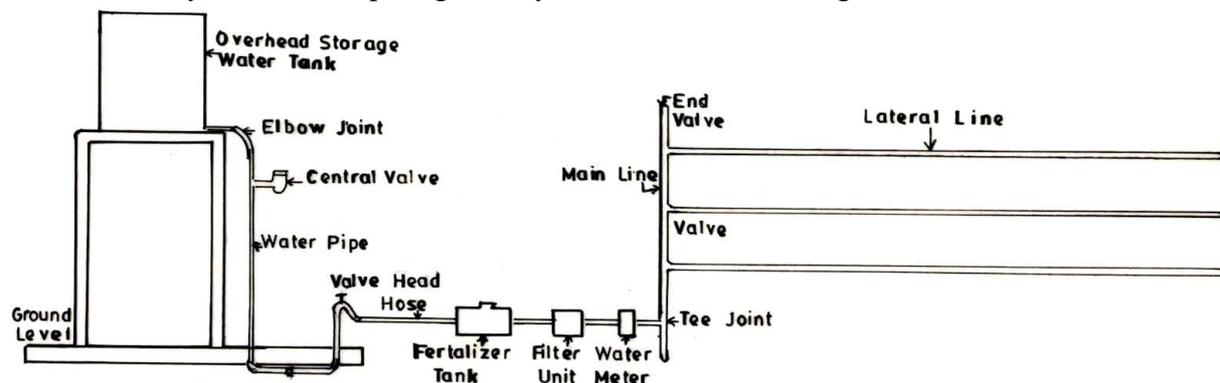

Figure 1. Assemble diagram of the set up system

B$_6$. Filter design: A filter consisting of the fine gravel and sand of selected sizes is installed in between 200 size mesh located in a pipe supply the main line from the fertilizer.

B$_7$. Emission uniformity design

The emission uniformity of water application is computed by the equation:

EU = 100 (1.0-1.27 x Cv) x qm/qa (Agricultural Engineers Year book, 1981)

where: EU = the design emission uniformity in percent

n = space between plants divided by the same unit length of lateral line.

n = 1 (Agricultural Engineers Year book, 1981)

Cv = the manufacturer's coefficient of variation for line source emitter.

Cv = 0.09 (Agricultural Engineers Year book, 1981)

qm = the minimum emitter discharge rate for the minimum pressure in the system in l/hr.

qm = 2.18 l/hr (From Table 1)

qa = the average or design emitter discharge rate in l/hr.

qa = 2.12 l/hr

EU = 100 (1.0-1.27 x 0.09) x 2.18/2.12 = 91.23 % = 91%.

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Table 1

The results of the flow rate of the drip irrigation system tested

Lateral line	1		2		3	
Emitter	Vol. (litres)	Time (Mins)	Vol. (litres)	Time (Mins)	Vol. (litres)	Time (Mins)
1	0.18	4.0	0.18	4.4	0.18	4.3
2	0.18	4.0	0.18	4.4	0.18	4.4
3	0.18	4.0	0.18	4.5	0.18	4.4
4	0.18	4.1	0.18	4.5	0.18	4.4
5	0.18	4.5	0.18	4.6	0.18	4.58
6	0.18	4.5	0.18	4.6	0.18	4.6
7	0.18	4.7	0.18	4.7	0.18	4.7
8	0.18	4.32	0.18	4.7	0.18	5.28
9	0.18	4.54	0.18	4.8	0.18	4.5
10	0.18	4.55	0.18	5.0	0.18	5.20
11	0.18	4.44	0.18	5.11	0.18	5.21
12	0.18	4.05	0.18	5.3	0.18	5.25
13	0.18	5.20	0.18	5.4	0.18	5.30
14	0.18	4.25	0.18	5.6	0.18	5.22
15	0.18	4.42	0.18	5.5	0.18	5.32
16	0.18	5.46	0.18	5.4	0.18	5.7
17	0.18	4.45	0.18	4.9	0.18	5.50
Sum		75.48		83.41		83.84
Average time to fill a can per emitter	4.44 mins		4.91 mins		4.93 mins	
Rate of discharge per emitter		2.43l/hr		2.20l/hr		2.19l/hr
Average discharge rate	2.43 x 17 = 41.31l/hr		2.20 x 17 = 37.40		2.19 x 17 = 37.23l/hr	
Main line discharge = 115.94l/hr						

Pressure variation

The total energy drop by friction for lateral can be expressed as:

$$H = 5.35 \times (Q^{1.852}/D^{4.871}) \times L$$

where: H = Total energy drop by friction at the end of lateral (m), Q = Total discharge at the inlet of lateral (l/sec), D = Inside diameter of lateral (cm), Q = 0.036 l/sec (lateral line discharge), D = 1.9 cm, L = 10 m.

$$H = 5.35 \times (0.036^{1.852}/1.9^{4.871}) \times 10 = 0.00497 = 0.005 \text{ (m)}$$

Operating head/pressure is calculated by: Required emitter head, He, for the required discharge (2.12 l/hr).

The discharge equation for the emitter is: $Q = 1.41 \times P^{0.5}$ (Larry James, 1988)

where: Q = emitter discharge (l/hr)

P = Operating pressure (m)

$$Q = 2.12 \text{ l/hr}$$
$$P^{0.5} = 2.12/1.41$$
$$P = (1.5)^2 = 2.25 \text{ (m)}$$
$$He = 2.25 \text{ m}$$

The various head losses by friction of this set are calculated as follows:

Using Williams and Hazen's equation (Taking C = 150)

$$Hm = 15.27 \times (Q^{1.852}/D^{1.871}) \times L \text{ (Michael, 1978)}$$

where: Hm = energy drop by friction at the main

Q = total discharge in the main line pipe (litre/sec)

L = length of the pipe (m)

D = diameter of the main line (cm) = 1.27 cm

$$Hm = 15.27 \times (0.03^{1.852}/1.27^{4.871}) \times 6 = 0.043 \text{ m}$$

$H_L = 5.35 \times (Q^{1.852}/D^{4.871}) \times L$

where H_L = energy drop by friction at the lateral

$Q = 0.01$ l/sec

$D = 1.9$ cm

$H_L = 5.35 \times (0.01^{1.852}/1.9^{4.871}) \times L = 0.0005$ m

$\Delta Z_L = hl$

$hl = FH_L + Mi$

Mi = minor losses at the fittings = 0

From the Table F = 0.33 (Larry James, 1988)

$Hl = 0.33 \times 0.0005$ (m) = 0.000165 (m) = 0.00017 (m)

$\Delta Zm = 0.33 \times 0.043$ (m) = 0.014 m

Pressure head at the filter

$Q = 1.41 \times P^{0.5} \rightarrow 1.4 = 1.41P^{05} \rightarrow 1.4/1.41 = P^{0.5} \rightarrow P = 1$ (m)

Average lateral pressure, Ha is:

$Ha \quad = He + 1/4hf + \Delta Z/2$

$\quad = 2.25 + 0.00125 + 0.00085$

$\quad = 2.2521$ (m)

Lateral inlet pressure, H_L

$H_L \quad = Ha + 3/4hf + \Delta Z/2$

$\quad = 2.2521 + 3(0.00125) + 0.00085$

$\quad = 2.26$ (m)

Main line or manifold pressure Hm is:

$Hm \quad = H_L + hfm + \Delta Z/2$

$\quad = 2.26 + 0.043 + 0.014/2$

$\quad = 2.31$ (m)

Pressure head at the fertilizer tank, H_F

$Q = 1.41P^{0.5} = 2.08$l/hr $\rightarrow 2.08 = 1.41P^{0.5} \rightarrow 2.08/1.41 = P^{0.5} \rightarrow P = (1.48)^2$

$H_T = 2.19$ (m)

The **operating pressure**, Ho is:

$H_O = Hm + H_T + H_F + H_L + He$

$H_O = 2.31 + 2.19 + 1 + 2.26 + 2.25 = 10.01$ (m)

Pressure head variation, Hvar is

Hvar = (Hmax - Hmin) / Hmax

The discharge variation, qvar is:

qvar = (qmax - qmin)/qmin

From Table 1 qmax = 2.43 l/hr and qmin = 2.18 l/hr

qvar = (2.43 - 2.18)/2.43 = 0.10288 = 10.3%

From qvar, Hvar can be calculated as thus:

qvar = 1 - (1 - Hvar) → 0.10288 = 1 - (1 - Hvar) → 0.10288 = 1 - 1 + Hvar →

0.10288 = 0 + Hvar → 0.10288 = Hvar → Hvar = (Hmax – Hmin)/ Hmax

0.10288 = (10 - Hmin)/10 → 0.10288 × 10 = 10 - Hmin → 1.0288 = 10 - Hmin

Hmin = 10 - 1.0288 = 8.9712 (m)

Discharge in the emitter can also be given as:

qa = av, where qa = discharge per emitter, a = area of the emitter, and v = velocity of flow per emitter

$q = \Pi d^2/4 \, v$ (d = 1.5mm)

$9.0 \times 10^3/3600$ sec $\quad m^3 = \Pi(0.0015)^2 \times v$

$v = 4 \times 9.0 \times 10^{-3}/ \Pi (0.0015)^2 \times 3600 = 1.41$m/sec

RESULTS AND DISCUSSIONS

The constructed drip irrigation set was tested and the result is shown on Table 1. Lateral 1 has the emitter discharge rate of 2.43 l/hr which is the maximum emitter discharge of the drip set. Lateral 2 has emitter discharge rate of 2.20 l/hr and lateral 3 has the least with the emitter discharge rate of 2.18 l/hr. The discharge values are close to the designed emitter discharge rate of 2.12 l/hr. The variation in emitter discharge is least (8.4%) in lateral 3 but maximum in lateral 1 (10%). The pressure variation is 10% with minimum pressure head of 9 m.

The designed water requirement for 6 ridges is 0.36 m^3 (36 litres), at the discharge rate of 36.0 litres per lateral, it will take: 360/108 = 3.3 hrs = 3 hrs to complete one irrigation of the designed area. Therefore the number of shift for the 3 hrs:

No. of ridges/No. of lateral = 6/3 = 2 the allowable period of application is 3 days.

Since 360 litres of water will complete one irrigation of the designed area, a 2000 litres water tank can complete three irrigations which invariably will last for 12 days during peak consumptive use periods.

CONCLUSION

The availability of drip irrigation set using durable local materials will help greatly to minimize the problem of high cost of initial investment which discourages the average farmer from taking drip irrigation technique despite its numerous advantages. The system designed and constructed in this study may be used in large or small farms. It is within the technical competence and financial reach of the farmers.

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REZUMAT

PROIECTAREA SISTEMULUI DE IRIGARE PRIN PICURARE PENTRU GRĂDINILE MICI DE LEGUME

În momentul de față, în Nigeria, sunt de actualitate sistemele de irigație la scară mică, convenabile pentru grădinile mici. În lucrarea de față se prezintă un proiect pentru un sistem de irigație prin picurare, destinat unor grădini mici de legume. Din punct de vedere al dimensiunilor, acest sistem constă dintr-o conductă principală cu diametrul de 12,7 mm, trei conducte laterale cu diametrul de 19,05 mm și emițătoare cu diametrul de 1,5 mm, la distanța de 60 cm în lungul conductelor laterale. Rata de descărcare a emițătoarelor s-a calculat a fi de 2,12 l/oră, valoare care se speră că va asigura o irigare completă a suprafeței de 5 m x 10 m, proiectată pentru 4 ore în perioadele de folosire maximă, necesitând două schimbări ale celor trei conducte laterale.