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Research Paper :

Design of gravity-fed drip irrigation system for tree based farming system

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ABSTRACT

The gravity-fed drip irrigation was fabricated using local and market available materials. The test crops were bottle gourd, bitter gourd and cucumber, grown in specially dugout pits, filled with medium textured soil mixed with manures, fertilizers. The CROPWAT model was used to estimate the ET of various vegetables for scheduling irrigation. Systems hydraulic performance was evaluated by measuring discharge variation among the different emitters, estimating friction head losses in different components. The frictional head loss in the lateral was found to 0.2640 cm cumulatively. Whereas the frictional head loss of emitters was found to be 67.73 cm, the frictional head losses in the fitting were found out to be 6.995 cm. Total head requirement of the system included the head required at the farthest emitter for operation and the frictional losses in the bend, control valve and filter as 2.3 m. Among the vegetable, the bottle gourd resulted in significantly higher average yields as compared to other vegetables. Bottle gourd produced highest yield under drip irrigation (290.9 q ha^{-1}), closely followed by the yield under basin irrigation (229.2q ha^{-1}). In this way the locally fabricated micro drip irrigation system was found significantly superior as compared to the basin irrigation.

Key words : Gravity fed drip irrigation system, Frictional loss, Basin irrigation crop yield.

India has formidable proportion of wastelands being out of cultivation due to various problems *viz.*, water and wind erosion, water logging, salinity, alkalinity and gully formations etc. The country has 144.2 mi.ha area subjected to water and wind erosion, 8.53 Mha area suffering from water logging and 3.97 Mha area under ravines and gullies (SPWD, 2005). These wastelands are now necessary to be put under cultivation due to increased population pressure. In the state of Chhattisgarh also the situation is not different. These waste lands locally called as *Bhata lands* (red lateratic) are basically *Entisols* and are nutrient and water deficient with meagre soil depth. About 20 per cent of the total geographical area of the state is covered under these soils. These soils are deficient in organic matter content with poor water holding capacity. Therefore, utilization of waste lands, through judicious use of water for survival of plantations, is most important. Micro irrigation system is one of the best options for use of limited water and fertilizer under degraded *Bhata* land.

Micro-irrigation systems are advanced method of irrigation through which water is applied directly to root zone around the plant through a pipe network with the help of emitter. Drip irrigation records higher water use efficiency of 52.81 and 26.02 $kgha^{-1}mm^{-1}$ as compared to 10.96 and 11.94 $kgha^{-1}mm^{-1}$ under flood irrigation i.e on an average drip irrigation system had water saving of 41% over flood irrigation (Sharma and Kumar, 2007). Low cost micro-irrigation system, such as gravity-fed drip technique for growing winter vegetables, can save water up to 40 % (Sahu, 1984).

In Chhattisgarh also, gravity fed drip irrigation set was designed, developed and used for growing vegetables in farmer's field (Rao and Sahu, 2002 and Patel and Sahu, 2004) resulted in higher produce (25-30%), savings in water (45-48%), labour (45%) and fertilizer cost (50%). Looking to the success of this technique, the study is proposed to evaluate this technique along with basin irrigation methods for growing vegetables under tree plantation being developed in the *Bhata land.*

METHODOLOGY

The study area was situated at village Uparwara in Abhanpur block of district Raipur, Chhattisgarh. It was about 20 km away from university campus. The study area was located at 210.15' N latitude and 81^0.36' E longitude with an altitude of 300.6 m above the mean sea level. The average annual rainfall in the study area was found about 1422 mm with 64 annual numbers of rainy days. The soils of the study area characterized by a red lateratic soil termed as *Bhata land* (*Entisols*) with water holding capacity was very low (2.12 cm), infiltration rate of this soils was remarkably high (6.24 cm/hr). The field capacity ranged from 12-20 % with bulk density 1.78 kg cm^2. Permanent wilting point was in the range of 6-10 %.

Tree plantation model:

The study area comprised of four tree species *i.e.* *Gmelina arborea (Khamar), Dalbergia sissoo (Sissoo), Albizia lebbeck (Kalasiris), Emblica officinalis (Aomla)* etc. with different spacing to increase the biomass production and organic matter in the soil. Vegetable crops were grown in between the tree as an inter-crop with additional remuneration in dugout soil pits filled with medium textured soil mixed with farm yard manures and fertilizer. Gravity based drip irrigation, basin irrigation were applied for saving of young plantation especially during summer season.

Design of micro drip irrigation system:

The manifold and its lateral were designed and operated as a single manifold system, the micro drip irrigation system, which was controlled by a single valve and inline filter. The details of various design parameters were worked out as fallows.

Area : 28 x 26 = 672 m^2 (nearly flat)

Water source : Farm pond, Tank - HDPE 750 liters capacity, positioned on adjustable platform (height-1.5-2.5m)

Test crops : Bottle gourd, Cucumber and Bitter gourd

Climate : Semi -humid

Soil type : In general-Bhata land (waste land) – sandy loam

Pits – Clay loam

Infiltration rate: In General -Average 18 mm h^{-1} and in Pits - 10 mm h^{-1}

ET crop $_{peak}$: 8.3 mm day^{-1}

Ground water contribution: Nil

Effective root zone depth D : 0.50 m

Field capacity of soil FC : 19.4 per cent by weight

Permanent wilting point PWP: 8.48 per cent by weight

Bulk density of Soil, W : 1.78 g cm^{-3}

Critical point for MDIS, CP : 0.85 (allowable moisture depletion 15%)

Application efficiency, E_a : 90 per cent

Lateral spacing, S_1 : 4 m

Emitter spacing, S_E : 1 m

From the above mentioned field data, the various parameters of drip irrigation design were worked out. Stepwise procedure followed was as follows:

Step 1: Net depth of water to be applied in one irrigation

$$d_{net} = \frac{(FC - PWP)}{100} \times W \times (1 - CP) \times D \times 100 \quad (1)$$

$$= \frac{(19.4 - 8.48)}{100} \times 1.78 \times (1 - 0.85) \times 0.5 \times 100 \quad (2)$$

= 11.66 mm

Step 2: Gross depth of water to be applied in single irrigation

$$d_{gross} = \frac{d_{net}}{E_a} = 11.66/0.9 = 12.95mm = 0.01295m \quad (3)$$

Step 3: Irrigation interval, days.

$$\text{Irrigation interval} = \frac{d_{gross}}{ET_{crop}} \quad (4)$$

ET crop = Peak ET crop+ losses = 8.3 +3.2 = 11.5 mm day^{-1} while losses are 3.2 mm

$$\text{Irrigation interval} = \frac{12.95}{11.5} = 1 \text{ day}$$

Step 4: System capacities:

It was assumed that 672 m^2 area will be irrigated in 2 hours in one day and the fraction of the total area wetted = 0.1

Main:

Main pipe is immediately linked to the sub-main within 1.5 m distance.

Sub-main:

A = 672 x 0.16 = 107.52 m^2,

d_{gross} = 12.95 mm , t = 7200 s

Capacity (flow rate) q = (0.01295 x 107.52) / 7200 = 696.192 L h^{-1}

Lateral:

Length of each lateral: 26 m, Number of laterals: 7

Q_{lat}, capacity of each lateral = 696.192/7 = 99.45 L h^{-1}

Emitter discharge:

Capacity of the emitter is its discharge per plant

$$\text{Emitter discharge} = \frac{d_{gross} \times A_t}{t}$$

= 1.1655

Since one lateral cover two plant rows, each emitter was provided with two micro tube, hence discharge per micro tube is 0.58275 Lh^{-1}

Daily water requirement:

The daily water requirement of vegetable grown under drip irrigation method was estimated by using the formula

Volume of water required daily

$$= ET \times \frac{At}{T_p} \quad (5)$$

where T_p = total number of plants

Volume of water required per plant per day was 2.988 L per day

Step 5: Frictional head losses in different components

Main : Pressure drop due to Friction for main, 1.5 m length can be calculated by using the formula suggested by Williams and Hazans as given below

$$H_f = 15.27\, L\, Q^{.852}\, D^{-4.871} \quad (6)$$

where H_f = Friction losses, m

Q = Total pipe flow, 0.19338 lps

D = Inside diameter of the pipe, 5.74 cm

L = Length of pipe, 1.5 m

Total friction losses along the length of main was found 0.022 cm

Sub-main:

The main was attached to the sub-main which had total length of 28 m. There were 7 laterals attached to the sub-main. The frictional head losses in different sections of the sub-main were worked out and then these were summed up to get total head losses. Frictional head loss in the n^{th} section was worked out as follows:

$$F_n = \frac{f_n L V^2}{2gD} \quad (7)$$

where, F_n is the head loss due to friction in n^{th} section of the line, m

f_n is the friction factor in n^{th} section of line

L is the length of n^{th} section of line, m

g is the acceleration due to gravity, 9.81 m s^{-2}

D is the inside diameter of the sub-main, m

Friction factor depends upon the Reynold's number.

Total friction losses in the sub main section will double the cumulative friction of one part of sub main.

Laterals:

The flow passing through n^{th} section of lateral was worked out by equation based on the Reynolds number Where the Kinematics viscosity of water was considered as 10^{6} $m^2 s^{-1}$. The flow was considered to be laminar if Reynolds number was less than 2000 and turbulent if it was greater than 10000.

In case of laminar flow the friction factor was worked out by

$$f_n = \frac{64}{R_e} \quad (8)$$

In the case of turbulent flow the friction factor was worked out by

$$f_n = \frac{0.316}{R_n^{0.025}} \quad (9)$$

In the present study, the friction factor was calculated for each section of the line based upon the flow characteristics evaluated through R_n. The cumulative friction head loss in lateral line and sub main line with multiple outlets and for varied spacing of emitters and lateral line were obtained by using the above said procedure.

Emitters:

The frictional head loss in the emitters (in meter) was calculated by Darcy-Weisbach's formula rearranged as follows:

$$H_{fe} = (L_t \times f \times q^2) / (15.68 \times D^5) \quad (10)$$

where, L_t is length of micro tube in m, D is inner diameter of micro tube in mm , q is the discharge of emitters in L h^{-1} ,f is the friction factor calculated for laminar flow as 64 / Re

Fittings:

Friction head loss in fitting was calculated in terms of knowing equivalent length of main and by using standard tables. It was shown in Table 1 and after that by summing all these friction loss, total friction in fitting is 6.995 cm

Step 7: *Total head requirement of the system* : Total head requirement of the system included the head required at the farthest emitter for operation and the frictional losses in the bend, control valve and filter etc.

H_{sys} = Head required for operation + frictional losses (pipes + fittings + emitters)

Discharge - head relationship:

The flow rates of emitters for a constant head at each node were measured. This was done by collecting the amount of water in a measuring flask with a time

Table 1 : Frictional losses in different component used in fitting

Component	Equivalent length of main Le/d where d= 57.4mm	Equivalent length of component Le, mm	Friction losses in component cm
Control valve	3	172.2	0.34
Filter	40	2296	4.59
Tee connection	8	459.5	0.9184
Reducer T-T connection	10	574.0	1.148

interval of 5 minutes and then converting it to emitter flow rate in L h^{-1}. While taking measurement of emitters it was kept in minds that the head variation should not be much (< 10 cm). Water tank was positioned on adjustable platform; it facilitated the water tank to be positioned at 1.5 m height from the ground level. An attempt was made to study the effect of various heads of water on the discharge of emitters. The water heads were allowed to vary from 1.5-2.5 m.

RESULTS AND DISCUSSION

The judicious use of scarce water resources can be made by water efficient methods such as drip irrigation. The low cost versions of micro irrigation *viz*. gravity-fed drip irrigation system attempted to fabricate and evaluated at the study site for vegetable production.

Frictional head losses:

The frictional head losses in different components were worked out by using different formulae as given by equations 1.5 to 1.8. The frictional head loss in main was 0.022cm and that of sub-main the cumulative figure was0.039cm whereas in the lateral was found to 0.2640 cm cumulatively. Total frictional head loss in all seven laterals was found to be 1.848 cm. The frictional head loss of emitters was calculated by equation 1.9 and that was found to be 67.73 cm whereas the frictional head losses in the fitting were found out to be 6.995 cm. As the length of the pipe (sub main, lateral) increased, the cumulative frictional losses in that pipe also increased. Fig. 1 and 2 show the variation in frictional head loss in sub-main and laterals, respectively. The polynomial relationship existed between the cumulative frictional head losses in sub-main and linear relationship for laterals with high value of the coefficient of determination (sub-main: r=0.89, lateral: r=0.99). These figures indicated that with

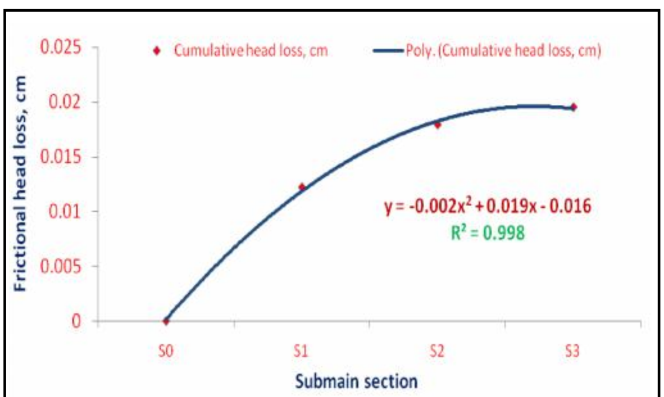

Fig. 1 : Frictional head loss in the different section of the sub-main

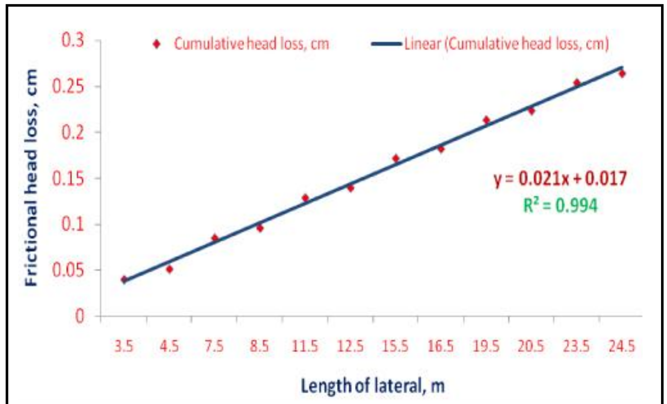

Fig. 2 : Frictional head loss in the different section of the lateral

the increase in the section length of the pipe, the cumulative friction head losses increased. Coefficient of uniformity (CU) of the system was determined. It varied from 98.67 to 99.69 per cent in laterals with an overall CU of the system as 99.2 per cent whereas the emission uniformity (EU) was found to vary from 97.93 to 99.22 per cent with an overall system's EU was worked out to be 98.93 per cent.

Total head requirement of the system:

The total designed head required for the system was worked out. It was found to be 2.3 meters, in which frictional head losses in various components accounted for 33.73 per cent. The remaining 66.26 per cent of the total head was required at the farthest emitter to work. Guled *et al*. (1997) reported that low-head drip systems operate under pressures of 0.5-2.0 m compared to the 10-15 m water head needed for standard drip irrigation.

Discharge – head relationship:

Head – discharge relationship of micro tubes showing the variation in average discharge values at different pressure heads are depicted in Fig. 3. This relationship was found to be represented by second order polynomial curve. It revealed that the discharge through micro tubes of 2 mm diameter increased with increased head. The same trend was observed at head, middle and tail end of the lateral of 26 m length. But it was noticed that the discharge decreased with increased length of lateral. The following correlation by polynomial function was established between average discharge of micro tubes (Q) in L h^{-1} and pressure head (H) in m.

$$Q = -0.002H^2 + 0.021H + 0.5149 \quad (1.10)$$

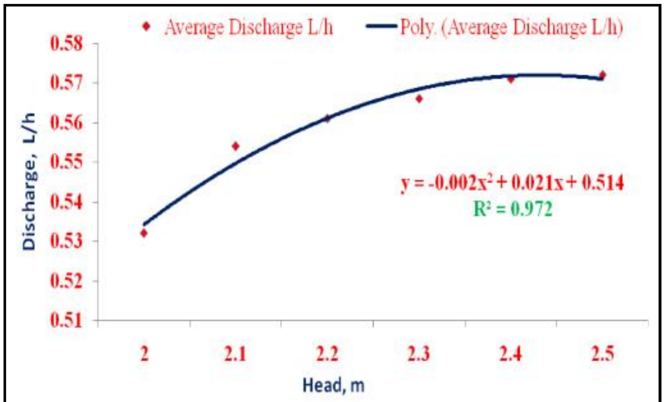

Fig. 3 : Head discharge relationship

Table 2 : Vegetable (Crop) yields in different irrigation (q/ha)

Vegetable	Replication	Drip irrigation (qt/ha)	Basin irrigation (qt/ha)
Bottle gourd	1	298.7	185.8
	2	310.5	273.0
	3	276.0	193.7
	4	273.0	221.0
	5	290.1	254.2
	6	317.0	198.0
	7	279.0	270.8
	8	283.0	237.1
Average		290.9	229.2
Bitter gourd	1	154.2	113.0
	2	158.2	121.5
	3	137.9	141.3
	4	119.0	131.0
	5	163.0	129.0
	6	140.3	97.2
	7	142.1	109.0
	8	138.3	113.0
Average		144.0	119.25
Cucumber	1	140.0	123.7
	2	142.1	129.2
	3	138.0	97.2
	4	153.0	118.7
	5	158.2	141.1
	6	139.0	87.5
	7	160.0	123.0
	8	154.2	137.0
Average		148.1	119.75
Overall average		194.4	156.1

Crop yields:

On an average the marketable vegetable yields under drip irrigation (194.4 q ha^{-1}) and were significantly higher by 25.73 as compared to those under basin method of irrigation (156.1 q ha^{-1}) shown in Table 2. Among crops, bottle gourd resulted in significantly higher yield by 26.9 per cent under gravity fed drip irrigation, respectively over that under basin irrigation (229.2 q ha^{-1})..

Conclusion:

Tree plantation in waste lands can be made economically attractive and socially acceptable by intercropping of vegetables. In order to promote vegetable production in waste land as well as water scarcity areas gravity-fed drip irrigation can best be used advantageously over basin irrigation.

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