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Design of organic drip fertigation unit and effect of irrigation frequency & timing on tomato crop root growth under organic drip fertigation

Sonal Chourasia and Vinay K Tiwari

Abstract
Tomato is a fast-growing vegetable crop cultivated during both Kharif and Rabi seasons, with a growth period of 90 to 150 days. The ideal mean daily temperature for its growth ranges from 18 to 25 ºC, with night temperatures between 10 and 20 ºC. In Chhattisgarh, regions such as south Bastar, Kanker, Rajnandgaon, Datewada, Jashpur, Sarguja, and Durg district are prominent tomato-growing areas.

Approximately 42 million hectares of land in India have potential for drip and sprinkler irrigation, with around 30 million hectares suitable for sprinkler irrigation of crops like cereals, pulses, oilseeds, and fodder crops. Drip irrigation, on the other hand, can be applied to approximately 12 million hectares of land, benefiting cotton, sugarcane, fruits, vegetables, spices, and condiments, as well as some pulse crops like red gram.

The objectives of this research project are to investigate the correlation between irrigation frequency and root development, design a Fertigation unit for the Drip system, and compare the costs and efficiency of organic versus chemical fertilizers.

Fertigation, a method of applying fertilizers through the irrigation water via the drip system, enhances nutrient availability and efficiency, resulting in increased fertilizer use efficiency of 80 to 90 percent. For the root development study, an experiment using containers with clay loam soil mixed with organic fertilizer was conducted. The water requirement estimation utilized the evaporation pan method based on crop and canopy factors. Soil physical properties were measured using core cutter techniques. The design of the Organic Drip Fertigation system consists of several components, including a pump, fertilizer unit, filter, mains, sub-mains, emitters, and connectors. The root container experiment revealed that 60-70% of the roots' dry weight is concentrated in the 0-10cm layer for all irrigation frequencies, with the highest root dry weight observed in the 1-day irrigation frequency. The Fertigation system dimensions can cater to an 18 m^2 tomato crop field for approximately one week with regular drip line maintenance. In comparison, organic fertilizer offers an average profit of approximately Rs. 6406 per acre.

Keywords: Irrigation, drip fertigation, root, organic fertilizer

1. Introduction

Tomato requires temperatures between 18-24 ºC, with the optimal production occurring at 20 ºC and ceasing entirely at around 30 ºC. The crop has a growing period of 90 to 150 days and thrives with mean daily temperatures of 18 to 25 ºC and night temperatures between 10 and 20 ºC. Frost and temperatures above 25 ºC, combined with high humidity and strong winds, adversely affect yield. Tomato can be grown in a wide range of soils, but it prefers well-drained, light loam soil with a pH of 5 to 7.

Effective irrigation is crucial for tomato growth and yield. Proper timing of irrigation is essential to avoid water and nutrient deficiencies that can lead to reduced yield. Soil moisture should be adequate during germination and early growth to promote root development. Deep rooting is encouraged by providing water only when the soil's available water is 20% depleted. Frequent, shallow irrigations should be avoided to prevent shallow root systems and stress in the plants. Proper irrigation time, such as early morning or late evening, can improve water efficiency.

This project's objectives include studying the relationship between irrigation frequency and root development, designing a Fertigation unit for Drip system, and comparing the costs of organic versus chemical fertilizers. Drip irrigation minimizes water wastage by directly irrigating the root zone rather than the entire land surface. Fertigation, the application of plant nutrients dissolved in irrigation water, is an efficient way to meet the crop's water and nutrient requirements.

The study focuses on an economic and organic Fertigation unit, utilizing cow dung and urine mixed with water and fermented with Jaggery to form organic fertilizer supplied through drip pipelines.

To conduct the experiment, a farm in Dhanora village, Chhattisgarh, was selected during the 2015-16 period. The research aimed to determine the water requirement of the crop, study irrigation scheduling using drip irrigation, evaluate different components of the drip irrigation system, determine the capacity of the Organic Drip Fertigation System, and analyze the economics of this system.

2. Location details and Soil type

The study field belongs to Chhattisgarh Agricultural Engineering College located at Dhanora, Durg-Bhilai road. This site was selected due to favourable soil, climatic and socio-economic conditions. Government of Chhattisgarh is encouraging an intensive use of drip irrigation by farmer in this district through subsidies and extension methods. Selection of the site was done according to the facilities of easy access and availability of electric supply for experimental observation.

The site has Clay-loam soil with well drained clay sub soil Although, Tomato can be grown on a variety of soil. It grows satisfactorily at pH of 5.2 to 6.8. The Core cutter method for determining the Bulk density and Dry density of the soil. The value came out to be 1.934 g/cc. The soil type is determined using sieve analysis; which gives the percentage of various particles present. According to this the soil is classified. The field has Clay-Loam soil which is favorable for tomato.

3. Effect of irrigation interval on tomato root growth in root containers: Root containers experiment was conducted to study the relationship between irrigation frequency and root development. Clay loam soil with bulk density of 1.9344g/cc mixed with 100gm organic fertilizer (sample of cow dung and urine fermented mix) was packed in the containers to 30cm height. One tomato seedling was transplanted in the middle of each container on 21st September. Three irrigation frequencies 1, 3 and 5 days with four replicates were followed. Before the start of the treatments the containers were saturated with the water while they were kept at the field capacity during the growth period. The development of roots was observed from the transparent side of the containers. The plants were harvested after 3 weeks. The weight of the above ground Biomass was recorded after drying at 70 ºC. The roots for each 10cm depth were collected separately and washed and weighted after dried at 70 ºC to study the root mass over depth for each irrigation frequency.

4. Method of irrigation: The manner in which irrigation water is applied to land is the method of irrigation. The irrigation water may be applied to crops by flooding it on the field surface, by applying it beneath the ground surface, by spraying it under pressure or by applying it in drops. We selected the low-pressure drip irrigation because it is an advanced method which saves about 25-50% water as compared to other surface irrigation methods, saves labour and weeding. Irrigation scheduling can be very well done under this method of irrigation.

In the field, a 0.5 HP volute centrifugal pump is used for supplying the water-fertilizer mix from the main tank to the main line of the drip system. The discharge of the pump set is 1.8m^3/hr. The Organic Drip Fertigation system consist of components such as fertilizer tanks (nos.4), pressure gauge, manual handmade filter unit, main line, connector, end cap, coupler, laterals. The water is directly applied to the root zone of the crop in a calculated amount and in a uniform pattern all over the field. Proper management of water and fertilizer quantity can be done.

5. Components and design of organic drip fertigation

The design of the Drip Fertigation unit requires some general information like water source, type of crop, topographical conditions etc. The source of water is a Tank which is the Water cum fertilizer tank. The capacity of the tank is 0.665 m^3 or 662.5 l. Different crop require different plant spacing and irrigation requirements. In the field experiment for Tomato crop the spacing is 0.75m plant to plant and 0.5m row to row. It is necessary to know the general land slope to determine the size and location of main and sub main lines, by which the pressure is maintained all over the field. However, gentle to moderate slope has a negligible effect in the water distribution. The location of the field is so chosen that it is nearly level land.

The soils infiltration rate, water holding capacity, texture and structure and bulk density must be known when selecting emitter type determining spacing, and setting up irrigation scheduling. The selected design parameters are mentioned in Table 1.

Table 1: Design for Drip Irrigation in Tomato crop

Sr. No.	Design parameter	Content
1	Crop	Tomato
2	Crop command (sq. m.)	18
3	Spacing between plants(m)	0.75
4	Spacing between rows(m)	0.5
5	Total no of plants	40
6	No. of lateral	5
7	No of emitter per lateral	8
8	Emitter flow	4l
9	Emitter operating pressure	0.8 kg/cm^2
10	Type of emitter	Online
11	Type of lateral	LDPE
12	Diameter of lateral	16
13	Lateral length	
14	In one line	5.5
15	Overall	27.5
16	Diameter of main line	4cm
17	Length of main line (m)	3

Fig 1: Components of organic drip fertigation unit

The components of organic drip fertigation unit are explained as under:

5.1 Pump
Pump is the most important part of any irrigation technique. It supplies irrigation water from water source to the field. The pump is of 0.5 HP power rating, 0.372 kW, generating a discharge of about 1.8m^3/hr.

5.2 Main line
The water from the head unit is supplied to the sub mains or laterals via the main pipe line. Since here we have a small experimental field, therefore no sub-mains are used; direct connection of laterals is made to the mains.
In the field, 4cm diameter main line is used which is made up of PVC. Holes are made in the main line according to the inter-row distance, using a PVC drill. Small connectors are inserted made of rubber, to which the laterals are connected.

5.3 Fertilizer Unit
For doing fertilizer application along with irrigation i.e. for Fertigation a fertilizer unit is set up. Usually, a fertilizer injector working on the principle of Venturi is used. The venturi works on the concept of difference in pressure in pipelines. A lower pressure sucks the fertilizer from the tank. Here, we have used an organic fertilizer. Fresh Cow dung and urine are mixed in ratio of 1:1; which is fermented, filtered and pumped directly to the drip lines along with water. Hence, no need of venturi.

5.4 Filtration Unit
Filtration unit consist of different type of filter such as disc filter, gravel filter, screen filter, and hydro cyclone filter etc. Gravel filter used to filter algae, solid particle and dirt from the water, hydro cyclone filter is used to separate sand from irrigation water, and disc or screen filter is used for fine filtration.
Here, we have used series of nylon mesh, tied to the mouth of transfer pipe between the settling tank and fermentation tank and a combination of nylon mesh and cloth between the fermentation tank and water cum fertilizer tank.

5.5 Valve
Valves were used in distribution of the water in equal proportion to the plant. They are also useful in increasing or decreasing the pressure in the pipeline. The valves are useful in conveying water from one main line to many sub-main lines.
The valve is fixed between the pump and the pressure gauge so that it can be adjusted for a desired value of pressure.

5.6 Pressure Gauges
Pressure gauges are used for measuring the pressure in the head unit of system. It is also used in measurement of pressure in mainline, sub-main line and lateral. In the field we have to maintain a pressure of about 0.8 kg/sq.cm in main line. Head losses occur in mainline and sub main line. A pressure gauge ensures uniform pressure and hence, uniform distribution of water.

5.7 Laterals and Emitters
Point source drippers (emitters) are either on-line or in-line emitters. On-line emitters are installed in the wall of the irrigation lateral by punching suitable holes at locations specific to the crop being irrigated. In in-line drip line the drippers are factory installed within the lateral.
In the field, there is online drip line installed of 16 mm diameter, the spacing between emitter is 0.75 m. The lateral spacing is 0.5m.

5.8 End Plug
The end plugs are used to close the drip line at the end point. By this, adequate pressure is maintained in the system. The end plug must close every lateral line so that the pressure is not released and the water is not lost idly.

5.9 Jointers and connectors
The main line is connected to the pump through a PVC threaded jointer. Holes were drilled in the mains and rubber grommets were inserted, so as to connect laterals through a drip take-off. Leakage points in laterals are fixed using hole plugs.

6. Method of estimation of water requirement of crop
The evaporation pan method is used for estimation of water requirement. The estimation of Water requirement is based on crop factor, canopy factor and pan evaporation. The evaporation pan is also known as U.S. Weather Bureau class

A pan. It is made up of 22-gauge galvanized iron, 120cm in diameter and 25cm in depth and painted white and exposed on a wooden frame in order that the air may circulate beneath the pan. It was filled to a depth of about 20cm the water surface level is measured daily by means of a hook in a stilling well, and evaporation is computed as the difference between observed levels adjusted for any precipitation measured in standard rain gauge. Water was added each day to bring the fixed point in the stilling well.
The relationship between Evapotranspiration and evaporation is given by the crop factor:

ET = Eo x Kc

Where,
ET = Evaporation or consumptive use
Eo = pan evaporation
Kc = crop coefficient

On the basis of above formula irrigation scheduling for tomato crop is carried out. Estimation of water requirements of crop is calculated by considering canopy factor as wetted area.

Canopy factor= G.C. + 0.15 (1 - G.C)

Where,
G.C. = Ground cover

It is given by:
G.C. = Shadow area/plant area

Evapotranspiration or irrigation required or water requirement of crop were given by,
ET = Pan Evaporation x Crop factor x Canopy factor
The Crop Evapotranspiration under standard conditions, denoted as ET_c, is the Evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Table 2 shows the average ET_o for different agro climatic regions in mm/day.

Table 2: Average ET_o for different agro climatic regions in mm/day

Regions	Mean daily temperature (°C)		
	Cool 10 °C	Moderate 20 °C	Warm >30 °C
Tropics and sub-tropics	2-3	3-5	5-7
-Humid and sub-humid -Arid and semi-arid	2-4	4-6	6-8
Temperate region -humid and sub-humid	1-2	2-4	4-7
-Arid and semi-arid	1-3	4-7	6-9

Crop coefficient K_c is influenced mainly by the specific characteristics of the crop, including its stage of growth. To a limited extent K_c is also influenced by the climate. The value of K_c for a crop is determined experimentally and reflects the physiology of the crop, the degree of crop cover, the location from where data are obtained and the method used to compute ET_c.
K_c represents the integrated value of 4 major factors *viz*., (i) crop height, which influence aerodynamic resistance, (ii) albedo (reflectance) of crop soil surface, (iii) evaporation from the soil, especially exposed soil.

The fig. 2 depicts the crop stages of tomato, and the table 3 summarizes the main crop coefficients used for water management. The suggested value (by FAO) of K_c for tomato during mid-season stage is 0.8.

Water requirement (m^3/acre) of crop is given by

= ET_c x days in a week (7) x area of field in sq.m

Irrigation Rate is the ratio of application of the water applied by the dipper per unit area, it is calculated by:
Irrigation rate (mm/hr)
I = Dripper discharge (lph) / [Lateral spacing (m) x Dripper spacing m]

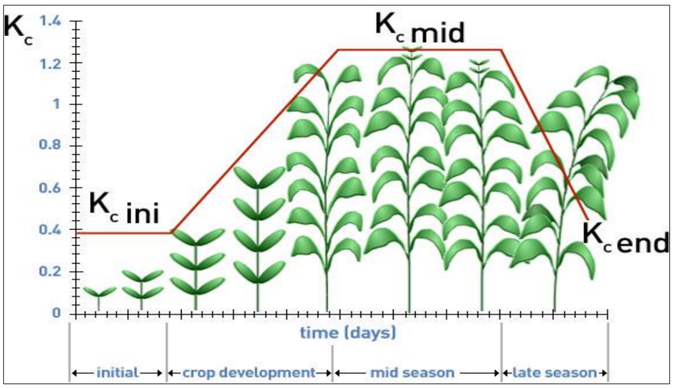

Fig 2: Variation of K_c with different crop stages

Table 3: Stages of development of tomato and K_c values

Stages of Development				
Crop characteristic	**Initial**	**Crop Development**	**Mid-season**	**Late**
Stage length, days	30	40	40	25
	35	40	50	30
	25	40	60	30
	35	45	70	30
	30	40	45	30
Root Depth, m	0.25	>>	>>	1.0
Crop Coefficient, Kc	0.6	>>	1.15	0.7-0.9
Yield Response Factor, Ky	0.4	1.1	0.8	0.4

Rate of discharge was given by rate of irrigation in the area to be irrigated, calculated by the following formula,
Q (lit/hr) = irrigation rate (mm/hr) x area to be irrigated (sq.m)

Irrigation time is the time required to complete the irrigation. It is dependent on irrigation water requirement mm/hr. It is calculated by,

$$\text{Irrigation time (hr)} = \frac{\text{water requirement per day } (\frac{mm}{day})}{\text{rate of discharge } (\frac{mm}{hr})}$$

7. Result and Conclusions

The result of average shoot and root dry weights, total water supply and root shoot ratio are presented in the table 4. The result indicate that the shoot and root dry weight is decreased by an increase in irrigation interval. The shoots and roots dry weight for 1-day irrigation frequency was higher than 3 and 5 days. The root-shoot ratio for 1- and 5-days irrigation frequencies were similar but were lower than that of 3-day frequency. Increasing irrigation intervals led to an increase in water use efficiency (amount of water used to produce 1g of dry weight). The 5- and 3-days irrigation frequencies saved 18% and 17% water respectively compared to 1-day irrigation frequency.

Table 4 shows the dry weight distribution of roots over 0-50cm soil depth. The results indicate that 60-70% of the roots dry weight is present in 0-10cm layer for all the irrigation frequencies. The roots dry weight was higher in 1-day than the remaining irrigation frequencies up to 40cm depth. On the contrary the roots dry weight from 40-50cm depth was increased by irrigation intervals. The roots reached the bottom of the containers lay down and then started branching and developed the lateral roots.

Table 4: Effect of irrigation interval on plant growth characteristics

Irrigation interval (day)	Total water supply (l/plant)	Root dry weight (g)	Shoot dry weight (g)	Root – Shoot ratio	Consumed Water (l/g)
1	1.468	0.281	3.06	0.09	0.44
3	1.278	0.271	2.28	0.10	0.41
5	1.066	0.241	2.76	0.09	0.36

8. Crop Evapo-transpiration

$ET_c = ET_o \times K_c$

The suggested value (by FAO) of K_c for tomato during mid-season stage is 0.8.

= 4 x 0.8

= 3.2 mm/day

9. Water requirement of crop

Water requirement (l/day) of crop is given by

= ET_c (m/day) x days in a week (7) x area of field in sq.m

= $3.2 \times 10^{-3} \times 7 \times 18$

= 403.2 l/day

10. Irrigation rate (mm/h)

= Dripper discharge (lph) / [Lateral spacing (m) x Dripper spacing m]

= 4 / (0.50 x 0.75)

= 10.67 mm/h

11. Rate of discharge

It is given by rate of irrigation in the area to be irrigated and is calculated by the following formula,

Q (l/h) = irrigation rate (mm/h) x area to be irrigated (Sq.m)

= 10.67 x 18

= 192.06 l/h

$$\text{Irrigation time (h/day)} = \frac{\text{water requirement per day (l/day)}}{\text{rate of discharge (l/h)}}$$

$$= \frac{403.2}{192.06} = 2.099 \text{ h/day}$$

12. Design parameter of organic fertigation unit

Nutrient Value of cow dung**:** N- 505ppm, P- 255ppm, K-360ppm**.** The composition in percentage is shown in table 5. The Composition of Cows Urine is Water - 95%, Urea - 2.5%, Minerals, Hormones, Salts & Enzymes - 2.5%. The Fertilizer unit comprises of a sequence of 4 tanks. They are as follows: -

Tank 1: Mixing tank: The cow dung + urine mixture and water are poured into the tank in the ratio of 1kg: 1l. They are properly mixed with a stirrer (a wooden stick), till a uniform consistency is reached. 10l of water for every 1l of urine/ 1kg of cow dung is mixed.

Tank 2: Settling tank: The mixture is poured to the settling tank where it is allowed to stand for 3-5 hours. The thick sludge gets accumulated at the bottom and the thin slurry is carried forward to the next tank.

Tank 3: Fermentation tank: Jaggery is powdered and mixed in the tank. The solution is left for 2-3 days for the fermentation reaction to occur. The fermented mix is shown in plate no. 4.

Tank 4: Water cum fertilizer Tank: The Fermented solution from tank 3 passes through a series of nylon mesh of mesh size 1x1 mm; so that the fertilizer gets free of all the suspended impurities which may clog the pores of drip lines.

After filtration, the solution is mixed with water in 1:10 ratio. The pump is directly fitted to the tank 4; and drip Fertigation is done.

The dimensions of fertilizer unit are illustrated in table 6. The organic solution is mixed with water in the ratio of 1:10. So, 240 l of fermented mix can form: 240 + 240 x 10 = 2640 l of Fertigation solution.

Water requirement per day is 403 l. Considering 5% runoff and other losses. Water needed per day: 403 + 403 x 0.05 = 423.15 l ~ 425 l.

Therefore, number of days the Fertigation unit can serve the field:

$$= \frac{2640}{425} = 6.21 \text{ days} \sim 6\text{days}$$

The Fertigation system of above dimension can serve a 18 m^2 field (the experimental plot) of tomato crop for Approx. one week with regular maintenance of the drip lines. The second round of solution can be simultaneously prepared in the tank 1 and 2.

Table 5: Composition of cow dung

Sr. No.	Component	Percentage
1.	Moisture	77
2.	Organic matter	20
3.	Nitrogen	0.32
4.	Phosphorous	0.14
5.	Potassium	0.30
6.	Calcium	0.40

Table 6: Dimensions of fertilizer unit

Sr. no.	Tank	Dimension (m)	Capacity of tank (l)
1.	Mixing tank	0.58 x 0.58 x 0.60	201.8 ~ 200
2.	Settling tank	0.58 x 0.58 x 0.83	279.2 ~ 280
3.	Fermentation tank	0.58 x 0.58 x 0.72	242.2 ~ 240
4.	Water cum fertilizer tank	0.91 x 0.91 x 0.80	662.5 ~ 660

13. Relative Cost Benefit of organic fertilizer over chemical

The cost has been updated as per year 2023. Approx requirement of Inorganic fertilizer in 18m^2 of Land

Urea (1kg) = 6 Rs. DAP (0.5 kg) = 25 Rs

Total Cost = 31 Rs

Requirement of Cow Urine in 18m^2 of Land

$$\text{Requirement for } 18m^2 = 0.5 \text{ lit } \frac{1 \text{ Lt Cost} = 5 \text{ Rs}}{\text{Total Cost} = 2.5 \text{ Rs}}$$

i.e., for 1 acre the relative cost benefit of organic fertilizer over chemical would be approximately = Rs.6406

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