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A Computational Design of Drip Irrigation System through Optimizations for Savings of Water and Energy for Cultivation of Commercial Horticultural Crops in Indian Agro-Climatic Environment

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Abstract—*A drip irrigation system has been designed and optimized to utilize water and energy judiciously to meet the plant requirement and also to have maximum yield at minimum consumption of energy and time. Computational analysis have been made for the multi-loop system (closed end type) and land of new alluvial agro-climatic zone with sandy loam type soil and areas of 1 ha (10000 m^2). Hazen-William's formula has been used for finding out the pressure loss. Fruit crop like Mango (Mangiferaindica) have been considered for cultivation and its analysis. With the various size of key components, like main and sub main (DN) [Extruded HDPE/ rigid PVC; main 63 mm / sub main 50 mm], manifold [Extruded LDPE 40 mm], lateral [LLDPE; 25/20 mm], drippers (short orifice ; 9 lph capacity each and 3 emitters per plant), nos. of plants: 120, all relevant performance parameters have be evaluated through computational simulations and validated with the recognized standards and with the following observations:*

i). Savings of water and energy at very high level can be achieved. Energy losses have been minimized through proper selections of the pipes, fittings, centrifugal pump, isolation and throttling valves, safety-relief valves, drippers, strainers, filters and accessories as per relevant Standards.
ii) Emission Uniformities in the range of 98% and higher pressure balancing have been achieved since the flow of water takes place in both directions in such type of closed loop network.
iii). Total pressure head required in the pipe in the ground level near the well (Source of water) as computed is 21MWC(gauge).
iv). Considering the depth of well as a standard value of 22 ft(6.71m) in the locality, water layer is available through the further depth of another 2m in the well, the gross pumping head and rated capacity as computed are 30 MWC(gauge) and 3500 lph respectively.

The specified system has been designed to deliver a pre-defined amount of water at the root zones of the plant at regular intervals so that the plants do not suffer from stress or strain of less and over watering.

Keywords*: Drip irrigation, Emission uniformity, Meter Water Column, Extruded High Density Poly Ethylene, Linear Low Density Poly Ethylene.*

1. INTRODUCTION

Evapo-transpiration (ET) describes the transport of water into the atmosphere from surfaces, including soil(soil evaporation), and from vegetation(transpiration).

Drip irrigation is an efficient method of irrigation in which water is applied at the plant bottom at a rate nearly equal to consumptive use and there by avoid the conventional losses like evaporation, percolation, and runoff.

It is a slow process of application of water above and beneath the soil surface in the form of drops tiny stream or miniature spray. Water is applied at a point source from where water is sprayed onward in all direction and wet the root zone area. In principle it is a slow flow rate, low rate, frequent and long duration method of application of water. There other name of drip irrigation–drop irrigation, trickle irrigation, sip irrigation, dilution irrigation, daily flow irrigation, micro irrigation.

Advantage: Easier management, saving of labour, saving of water(30-70% water is saved), better growth and yield of crop, efficient use of fertilizer, less effect of insect and paste attack, low quality water or saline water can be used by the impact of drop application of water, salt will be displaced towards outer corner, problem soil(high infiltration rate of soil) is suitable in drip irrigation, this is an erosion and runoff free system.

Disadvantage: Initial cost is high, technical knowledge for installation and design is needed, clogging of emitters, services are not available in remote area.

Mango is one of the most important commercial fruits in India. Uttar Pradesh has the largest area and production followed by Bihar, Andhra Pradesh, West Bengal, Tamil Nadu and Orissa. The energy value per 100g of the common mango is about 250 KJ. Nutritional value of mango per 100gm are, carbohydrates-15gm, sugars-13.7gm, dietary fiber-1.6gm, fat-

0.38gm, protein-0.82gm, Vitamin A equivalent-54µg, beta-carotene-640µg, lutein zeaxanthin-23µg, thiamine(B_1)-0.028mg, riboflavin(B_2)-0.038mg, niacin(B_3)-0.669mg, pantothenic acid(B_5)-0.197mg, Vitamin B_6-0.119mg, folate(B_9)-43µg, choline-7.6mg, Vitamin C-36.4mg, Vitamin E-0.9mg, Vitamin K-4.2µg. There are some traces metals like, calcium-11mg, iron-0.16mg, magnesium-10mg, manganese-0.063mg, phosphorus-14mg, potassium-168mg, sodium-1mg, zinc-0.09mg.

In addition to mango's food value, it has also been used for its medicinal value. In Samoa, a bark infusion has been a traditional remedy for mouth infections in children (pala gutu), and in Tonga, infusions of leaves of mango, the orange (*Citrus sinensis*), and other species are used to make a portion to treat relapse sickness (kita). In India, a drink made from unripe mangofruit is used as a remedy for exhaustion and heat stroke. Half-ripe fruit eaten with salt and honey is used for a treatment of gastro-intestinal disorders, bilious disorders, blood disorders, and scurvy. Diabetes has been treated with a drink made from the infusion of fresh mango leaves. Diarrhea and throat disorders are treated by gargling bark extracts mixed with water.

Objectives are,(i)to design efficient type of piping system to discharge the water at a predefined rate at the root zones of the plant(Mango);(ii) to find out the sizes like diameter and thickness, length of different sizes of pipes to be connected in different parts of the network. Viz. main, sub main, manifold and lateral;(iii) maximum number of plants to be accommodated in the specified land areas;(iv) to find total pressure head of water required at entry of the crop field at actual; duration of irrigation required per day;(v) to calculate the pressure head, energy and power consumption required at the entry to the crop field;(vi) to find out the emission uniformities of the irrigation system; the requirement of pressure regulation/throttling if any between sub main and manifold; (vii)to estimate the bill of quantities of the piping systems with detail specifications, fittings and other components; (viii) selection of the pump, its type, pressure head, capacity, design points and operating points.

2. MATERIALS AND METHODS

Efforts have been exercised to develop the efficient piping network with minimum pipe diameter and length for **high values horticultural crops like mango** to have the higher emission uniformities , minimum wastage of water, minimum consumption of power , higher pressure balancing , minimum time of irrigation and pressure head , optimum water supply at the root zone and other associated parameters and to achieve the efficient drip irrigation systems with maximum savings of these precious consumables. While designing the drip irrigation system, highest water required for the plant throughout its lifecycle and peak rate of evapo-transpiration are considered for calculation of water requirement. Selection of drippers should be based on water requirement, soil type, water availability, electricity availability etc to emit enough water to fulfill water requirement within predefined time. Totally optimized, efficient and long-life system ensures saving in water, early maturity and a bountiful harvest, season after season, years after years. Apart from all these, savings in labour and fertilizer costs can also be achieved.

The land of new alluvial agro-climatic zone with sandy loam type soil and crop field area of 1 hectare and fruit crops like mango have been considered for development of the efficient type of drip irrigation systems through computational analysis.

.Multi loop type piping network where both ends of the lateral are connected to the manifold and a closed network has been formed through sub main and main pipes.

Table 2.1: Various design parameters considered for piping network for drip irrigation systems for crop field (Mango) of land area of 1 hectare.

Sl. No.	Parameters	Value / Data
1.	Total nos of plants	120
2.	Nos of rows of plants	20
3.	Nos of plant in each row and covered by each lateral	6
4.	Spacing of plant (m x m)	10 x 10
5.	Nos of laterals	20
6.	Nos of row covered	20
7.	Length of main (m)	51
8.	Length of each lateral (m)	50
9.	DN (main/submain/lateral)	63/50/25
10.	Pressure rating of main/submain (kg/cm^2g)	4-6
11.	Thickness of lateral (mm)	1-3
12.	Peak water requirement by each plant (lit/day/plant)	94
13.	Total areas (L x W) of the crop field (m x m)=(sq-m)	10000 [192m X 52m]
14.	Distance between two adjacent lateral (m)	10
15.	No's of plant covered by each lateral	06
16.	Distance between two adjacent plants along each row (m)	10
17.	Total length of sub main (m) in each plant (lit/day)	197 x 2
18.	Effective root zone; Radius(m); Area(sq-m)	4m ; 50.24 sq-m
19.	Nos of emitters/plant	03
20.	Types of emitters and tiny flow areas	Short orifice type, 0.2-0.4 mm^2
21.	Recommended discharge (lph)	09
22.	Recommended pipe flow velocity	1-1.5 m/s

Schematic diagram showing the plot of lands with the piping layout and plants, location of main, sub main, manifold and laterals have been furnished in Fig:3.2.

3. RESULTS AND DISCUSSIONS

Computational analysis and simulation have been made for the piping network within the crop field areas. Hazen-William's formula has been used for finding out the pressure loss against the flow through the piping network. Pressure head, water supply rate(capacity), power requirement and other performance parameters have been computed and furnished in table 3.1

Table 3.1: Drip irrigation system performance parameters

Sl. No	Parameters	Unit	Value(s)
1.	Total nos. of plants	Number	120
2.	Total flow rate of water in the main pipe at the entry to the crop-field	Litres/hour	3304.424
3.	Duration of irrigation required per day	Hours	3hours 26 minutes
4.	Minimum discharge through each dripper	litres/hour	9.123
		litres/day	31.33
5.	Minimum discharge per plant	litres/day	31.33 x 3 = 93.996
6.	Maximum discharge through each dripper	litres/hour	9.257
		litres/day	31.79
7.	Maximum discharge per plant	litres/day	31.79 x 3 = 95.37
8.	Minimum requirement of water for all plants per day	litres/day	94 x 120 = 11280
9.	Total actual amount of water to be applied at the root zones of all the plant	litres/day	11349
10.	Pressure head required at the entry to the crop field	MWC(g)	20.377
11.	Pressure required in the pipe in the ground level near the well	MWC(g)	20.522
12.	Minimum capacity of pump	litres/hour	3304.424
13.	Minimum standard capacity of pump [Rated Capacity]	litres/hour	3500.0
14.	Power required at the entry to the crop field	Watt	185.97
15.	Gross pumping head required for normal operation of the system considering the depth of water level inside the well from ground of crop field and head losses	MWC(g)	(21+7+2)= 30
16.	Power requirement at the electric-motor for normal operation of the system(Considering centrifugal pump efficiency:65% and motor efficiency:80%)	Watt	357.63
17.	Energy Consumption at the entry to the crop field	KJ/day	5445.79
18.	Emission Uniformities	(%)	98
19.	NPSH available at 32^{o}C water temperature	m	3.065
20.	NPSH available at 27^{o}C water temperature	M	3.17

Savings of power and energy at very high level can be achieved within the requirement of the relevant standard. Savings of water consumption per day and labour also appeared in appreciable amount and bill of quantities of the required materials have been optimized. Emission Uniformities in the range of 98% and higher pressure balancing have been achieved through the provisions of suitable pipes, pump, fittings, accessories since the flow of water takes place in both directions in such type of closed loop type network. Pressure variation along the sub main and also along the individual lateral are appeared in much lower range in closed loop type piping network resulting the achievement of better pressure balancing throughout the network within the crop field.

Table 3.2: Bill of quantities for the specified drip irrigation systems

Sl. Nos	Item	Size	Specification	Quantities	Standard
1.	**Pipes**				
i)	Main	DN-63 ID-59.4 mm	HDPE pipes, PN 6.0 kg/cm^2 Thickness-3.6mm	26m x 1	ISI-4984 standard
ii)	Sub main	DN-50 ID-47.1 mm	HDPE pipes, PN 6.0 kg/cm^2 Thickness-2.9mm	197m x 2	ISI-4984 standard
iii)	Manifold	DN-40 ID-37.7 mm	HDPE pipes, PN 6.0 kg/cm^2 Thickness-2.3mm	40m x 8	ISI-4984 standard
iv)	Lateral	DN-25 ID-22.7 mm	LDPE pipes, PN 4.0 kg/cm^2 Thickness-2.3mm	20m x 20	BS-6572:1985 standard
2.	**Valves**				
i)	Isolation valve (Ball Valves) (Full Port)	Valve orifice 0.032”	Made of brass. PN 10 bars	8 sets (Optional)	BS 5154,threaded to BS 21
ii)	Air relief Valve	DN 25 (¾'') valve for 3500lph, length 122mm	Working pressure 85 psi or 6kg/cm^2	1 set	ISI-4984 standard
iii)	Safety relief Valve (Spring-loaded type)	DN 63	Working pressure 85 psi or 6 kg/cm^2	1 set	ISI-4984 standard
3.	**Pump**	3500 litres/hour DN 25mm	Centrifugal Pump Speed N-	1 set	ISI-4984 standard

		to DN 80 mm	1450/2900 rpm at 50 Hz		
4.	**Strainer**	120 mesh/130 microns	epoxy coated metal body, PN 10bar,wash-out drain valve	1 set	BS 5154,threaded to BS 21
5.	**Fittings**				
i)	Reducing Tee	DN 40x40x25	made of PVC	24 sets	ISI-4984 standard
ii)	Equal Tee	DN 50x50x40	made of PVC	8 sets	ISI-4984 standard
iii)	Equal Elbow	DN 40X40	made of PVC	8 sets	ISI-4984 standard
iv)	Reducing Elbow	DN 40X25	made of PVC	16 sets	BS-6572:1985 standard
6.	Dripper	0.2-0.35 mm^2	Orifice type, made of PVC or PE	360 piece	ISI-4984 standard
7.	Pressure Gauge	DN 63, Bourdon SS-316	Dial type digital, Ranges 0-21 kg/cm^2	1 set	ISO-9001 standard
8.	Flow meter	DN 40 for 600-6000 lph	Operating pressure 10 kg/cm^2	1 set	ANSI-9001 standard

4. CONCLUSIONS

With the specified design of drip irrigation systems with multi loop (closed end) type piping network, better performances in terms of power consumptions, emission uniformities, savings of power and water, lower ranges in pressure regulations, higher pressure balancing, better yield, higher water use efficiency, minimum sizes of pipe, valves and fittings and other associated parameters can be achieved. As the crop field area increases, savings of energy and water becomes more significant.

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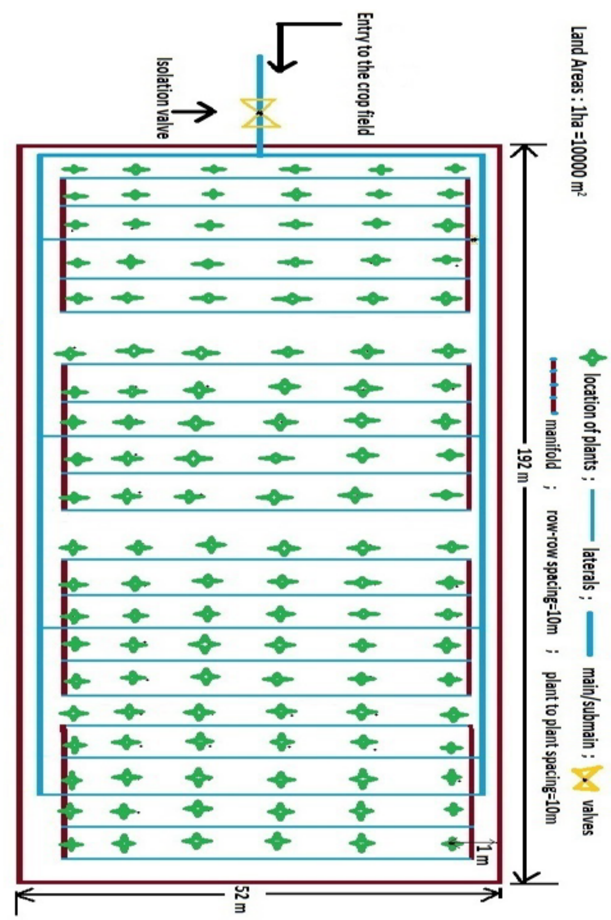

Fig: 3.2 Plot of lands showing the piping layout and plants