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Precision farming of different horticultural crops by the application of drip irrigation for the Hi-tech horticulture unit at Pusa

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Abstract
Precision farming methods help us ensure judicious use of the available resources. One of the methods being the drip irrigation method for the precise application of water to the plant roots. Already existing 18 poly/net houses were selected for the study and was designed for the drip irrigation system, which consisted of 12 different crops. The design was based on the friction loss method and was calculated using the Hazen-Williams formula. The 2 lph drippers could be used for all of the crops, except tomato and mango crop, where 4 lph and 14 lph drippers were recommended, respectively. The diameter of the laterals used for all of the crops was calculated and was found to be 12 mm, except for the tomato crop, where 16 mm diameter laterals was recommended. The diameter of all the submain lines was calculated and was found to be 50 mm. The mains diameter recommended was 50, 75 and 90 mm. The total dynamic head and total discharge of the drip irrigation system was found to be 48 m and 88.72 m^3/hr, respectively. Finally, the size of the pump required to irrigate all the 18 poly/net houses simultaneously was found to be 22.5 hp.

Keywords: Precision farming, drip irrigation, Polyhouse cultivation, head loss, Hazen Williams

1. Introduction

Energy is the driving force of this world. Therefore it is our duty to make optimum use of energy to save it for our nearby future. For humans, it is the food which provides us with the required energy. Further, a lot of energy is used to produce food via agriculture. Therefore, the precise use of the resources is of utmost importance, possible through the precision agriculture methods such as drip irrigation. A study by the International Water Management Institute (IWMI) has shown that around 50 per cent of the increase in demand for water by the year 2025 can be met by increasing the effectiveness of irrigation (Seckler *et al*., 1998) [1].

Drip irrigation is still not that popular despite of yield and quality improvements by the use of technology at some locations (Wierenga and Hendrickx 1985) [2]. A significant amount of water is saved using the drip irrigation system but on the other hand, it required a properly designed system with various components such as pumps, filters, mains, sub-mains, etc. The use of pumps, filters, etc. consumed energy in the form of electricity, fuel, etc. Therefore, there arises a need for the design of such systems which would make optimum utilization of the scarce water resources.

Drip irrigation is done to provide water most efficiently at the right rate and practically near the root zone of the crop with the help of drippers (Dasberg and Or 1999) [3]. In this system, only a fraction of the soil surface is wetted. Drip irrigation is one of the latest innovative methods of irrigation which improves irrigation efficiency, reduces evaporation and enables the slow and precise application of water and nutrients to the precise locations, avoiding soil erosion and wastage of water by deep percolation (Schwankl 1997) [4]. Also, tillage operations are reduced by half by the use of drip as compared to the surface irrigation (Johnson 200) [5].

The study was undertaken to design the drip irrigation system for the Hi-Tech horticulture section of Dr. RPCAU, Pusa campus with specific objectives as follows:

1. To design a hydraulically efficient pipeline system for the Hi-Tech horticulture section with possibly minimum head losses.
2. To determine the proper size of the filter and pump to minimize the power consumption.

2. Materials and Method

This chapter deals with the various materials and method used in the design of the drip irrigation system for the already existing Hi-Tech horticulture unit at Dr. Rajendra Prasad Central Agricultural University, Pusa (Bihar).

This chapter describes the location of the experimental site, plan of work and the formulas used for the design of the drip irrigation system.

2.1 Description of the experimental area

The study was carried out at the Hi-Tech horticulture unit at Pusa. The co-ordinates of the Hi-Tech horticulture unit is at 25°59.124′ N latitude and 85°40.630′ E longitude which is located in Samastipur district of north Bihar, on the southern and western bank of the river Budhi Gandak with an altitude of 52.92 m above the mean sea level (MSL). The main climate characteristics of the study area were hot dry summers followed by cold winters. Average annual rainfall was 1270 mm, out of which about 1026 mm was received during the monsoon season from June to October. The study area consisted of 14 poly houses and 4 net houses, which had different types of flower crops namely rose, carnation, mariegold, guldabari, Anthurium, orchid, gerbera and Lilium. The fruit and vegetable crops present were mango, tomato, capsicum and cucumber. The purpose of the design was to mainly supply irrigation to the 18 polyhouses/Net houses with the help of drip irrigation system. Part of the study area consisting of the polyhouses and the net houses are shown in figure 1.

Fig 1: Partial glimpse of the study area

a. Design steps for the drip irrigation system

The following are to be found out for the design of the drip irrigation system.

1. Water requirement of the selected crops
2. Spacing requirements of the selected crops
3. Area of the poly/net houses under study
4. Length of laterals for each poly/net house
5. No of drippers required for each poly/net house
6. Selection of the drippers for each crop
7. Irrigation duration for each of the houses
8. Frictional loss measurement
9. Estimation of the diameter of the laterals, sub-mains and mains.
10. Calculation of the total dynamic head (TDH).
11. Calculation of size of the filters.
12. Calculation of size of the pump.

2.2.1 Water requirement of the selected crops

The crop water requirement can be defined as the depth of water required to meet the consumptive use of the crop. The crop water requirement mainly depends on the climate, soil type, the crop type and the growth stage of the crop. Water requirement of the different crops under study was referred from the Horticulture department of Dr. RPCAU, Pusa for further calculations.

2.2.2 Spacing requirements of the selected crops

Spacing requirements of the crops under study were referred from the Horticulture department of Dr. RPCAU, Pusa and was used for the design of the drip irrigation system.

2.2.3 Area of the poly/net houses under study

Area of the different polyhouses and net houses was measured using a metric tape of 50 m length having a least count of 1 mm. Length and breadth was measured and the area was calculated by calculating the product of length and breadth for each of the houses.

2.2.4 Length of laterals for each poly/net house

One of the dimensions of the houses, i.e. either length or breadth was selected for the lateral pipeline orientation according to the feasibility for inter-cultivation practices and considering other factors. Plantations were carried out on raised beds. Walking distance was provided between two beds for different operations to be carried out. Further on, according to the row to row spacing of the particular crop, no of laterals on each bed was calculated. Then, the total no of laterals in the house was calculated. The total length of the laterals in the particular house was calculated by obtaining the product of the length of one lateral and the no of laterals in the particular house.

2.2.5 No of drippers required for each poly/net house

Plant to plant spacing for the particular crop under study was referred. No of drippers on each lateral was obtained by dividing the length of each lateral by the plant to plant spacing for the particular crop. Further, total no of drippers in the particular house was obtained by multiplying the no of drippers on each lateral and the total no of laterals in the particular house.

2.2.6 Selection of the drippers for each crop

The emitters must supply enough water to the root zone to meet the plant water requirements. Drippers were selected based on the discharge capacity. The water requirement of the particular crop per day per plant was referred and according to the volume of water required by a plant per day, drippers with the appropriate discharge was selected for each of the crops.

2.2.7 Irrigation duration for each of the poly/net houses

Total water requirement for one plant in terms of volume of water per day was referred and was divided with the discharge capacity of the dripper selected to obtain the irrigation duration for each house.

2.2.8 Head loss determination

The Hazen-Williams equation is an empirical relationship which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction. The major head loss in pipes was calculated by the Hazen-Williams equation. The main advantage of this equation is that the roughness constant used in the equation is not a function of Reynolds number and is dependent only on the roughness of the material. In this method, all the frictional losses and pressure drops were determined by using various formulae or equations and the size of lateral, submain and main lines was computed. The Hazen-Williams equation can be expressed by the following relationship given below.

$$H = 1.526 \times 10^4 \times \left(\frac{Q}{C}\right)^{1.852} \times D^{-4.87} \times (L + Le) \times F$$

Where
H = Head loss in m
Q = Discharge in m^3/hr
C = Roughness co-efficient of the pipe
D = Diameter of the pipe in cm
L = Length of the pipe in m
L_e = Equivalent length of the pipe in m
F = Outlet factor (depends on the no of outlets on a pipeline)

2.2.9 Estimation of the diameter of the laterals
Drip irrigation lateral lines are the hydraulic links between the submain lines and the drippers. The laterals are small diameter flexible pipe or tubes made up of low-density polyethylene (LDPE) or linear low-density polyethylene (LLDPE) of standard sizes generally available of 12 mm, 16 mm and 20 mm diameters. Hydraulically, the laterals are a mouth outlet pipe with emitters acting as outlets.
The design of drip irrigation lateral involves designing the pipe diameter for a given length of run or designing length of the pipe for the selected diameter of pipe with minimum pressure or discharge variation which can deliver the required amount of water to the plants.
The size of lateral tubing can be determined using the Hazen-William equation. The variation in pressure head is kept within 0 to 20% of operating pressure. It has been suggested that C equal to 130 be used when working with small diameter pipes. (Howell and Hiller, 1974; Keller, 1986) because with the Reynolds number range occurring in drip irrigation (25000), the Hazen-William equation with C=150 seriously underestimates pipe friction losses.
Using the Hazen-Williams equation, head loss (in m) was calculated by substituting the values for the different factors involved in the head loss calculation. For a particular house's lateral design, discharge for one lateral was calculated in m^3/hr. Roughness coefficient of the laterals was taken as 130. The diameter of the lateral was selected initially on the basis of the smallest available size (in cm) in the market and was evaluated. The length of one lateral (in m) in the particular house was taken for the calculation. Further, the equivalent length (in m) of the pipe was calculated by the product of no of drippers on each lateral and the corresponding outlet factor. These values were substituted in the Hazen-Williams formula and head loss calculated was used in further steps of the drip irrigation system design process.
Operating head for the drippers was taken as 10 m and lateral head loss permissible was taken as 20 % of the dripper head i.e. 2 m. If the head loss calculated was lesser than the permissible lateral head loss, the lateral was selected. But if the head loss calculated was found to be greater than the permissible lateral head loss, the next lateral size available in the market was selected and the process was repeated until and unless head loss for the lateral selected was under permissible limits.

2.2.10 Estimation of the diameter of the sub mains
The head loss was calculated using a similar method as for the laterals. Here, Q is the sub-main discharge and is given below.

Discharge of submain (Q) = number of laterals × average discharge of one lateral

The roughness coefficient was taken as 140 for the sub mains and smallest size of sub main available was taken as 50 mm. Then finally, the head or pressure variation in the sub mains was calculated in percentage by the formula given below.

$$\text{Percentage pressure variation in the sub mains} = \frac{(\text{Head at the inlet} - \text{Head at the outlet})}{\textit{Head at the inlet}} \times 100\%$$

If the variation in pressure was less than 20 %, the sub-main size was selected, else the particular sub main size was rejected and next available sub main size was selected until the pressure variation was under 20 percent.

2.2.11 Estimation of the diameter of the mains
Mainline hydraulics is also same as that of laterals with sub mains acting as outlets instead of drippers. i.e. submains acted in the same way as the drippers acted in case of lateral design. The roughness coefficient for the mains was taken as 150. The smallest size of the mains selected was of 75 mm and further higher sizes were taken as per design requirements.

2.2.12 Total dynamic head calculation
The total dynamic head was calculated by the integration of all the pressure heads required to run the drip irrigation system such as head at the final main line, static head, filter losses, safety factor, fittings losses, etc as listed below.
The total dynamic head can be obtained by sum of the following heads
1. Pressure head at the emitter
2. Head loss in lateral
3. Head loss in submain
4. Head loss in mainline
5. Static head
6. Head losses due to filters
7. Head loss due to fittings @ 10% of above all as a safety factor

2.2.13 Filter size calculation
Filters are required to purify the irrigation water so that the dirt particles do not clog the emitters or corrode the pipes. It also provides the plant with clean water helping in its proper growth. Size of the filter is computed as follows:
Filter capacity (m^3/hr) = flow in the final main line in lps×3.6
Size of the filter was determined by the total discharge required by all the poly/net houses simultaneously. The next available size of the filter after the calculated total discharge was recommended for installation.

2.2.14 Power requirement of the pump
Size of the pump refers to the power rating of the pump used. Size of the pump depends on the total calculated discharge, total dynamic head (TDH) and efficiency of the pump to be used and was calculated by the formula given below.

$$WHP = \frac{Q \times TDH}{\eta \times 75}$$

Where
WHP= Water horsepower of the pump (HP)
Q= Discharge (LPS)
TDH= Total dynamic head (m)
η= Overall efficiency of the pump (decimal)

3. Results and Discussion
3.1 Crops under study
The 12 different crops used in the study were Rose, Mango, Carnation, Mariegold, Guldabari, Tomato, Capsicum, Anthurium, Orchid, Cucumber, Gerbera and Lilium. Mango, Anthurium and Orchid were planted in the net houses. The different crops were sown in the different poly/net houses indicated by a suitable poly/net house number as shown in Table 1 given below.

Table 1: Crops and their respective poly/net houses

Poly House number	Crop in the Poly house
1	Rose
2*	Mango
3	Carnation
4	Rose
5	Rose
6	Mariegold
7	Guldabari
8	Tomato
9	Capsicum
10	Tomato
11*	Anthurium
12*	Orchid
13*	Mango
14	Cucumber
15	Gerbera
16	Tomato
17	Lilium
18	Gerbera

Here * mark indicates that the concerned house is a net house.

3.2 Layout of the poly/net houses
The 18 houses had 12 different crops as shown in table 1. The layout of the laterals, sub mains and mains pipeline is shown in figure 2. Each of the houses had a submain, which was designated by the house number itself. i.e. submain connecting house number 1 would have its designation as sub main 1 and so on as shown in figure 2. Each of the mains was connected to a no of sub mains. Finally, all the mains pipelines were connected to the final main line i.e. mains no 8 as shown in figure 2.

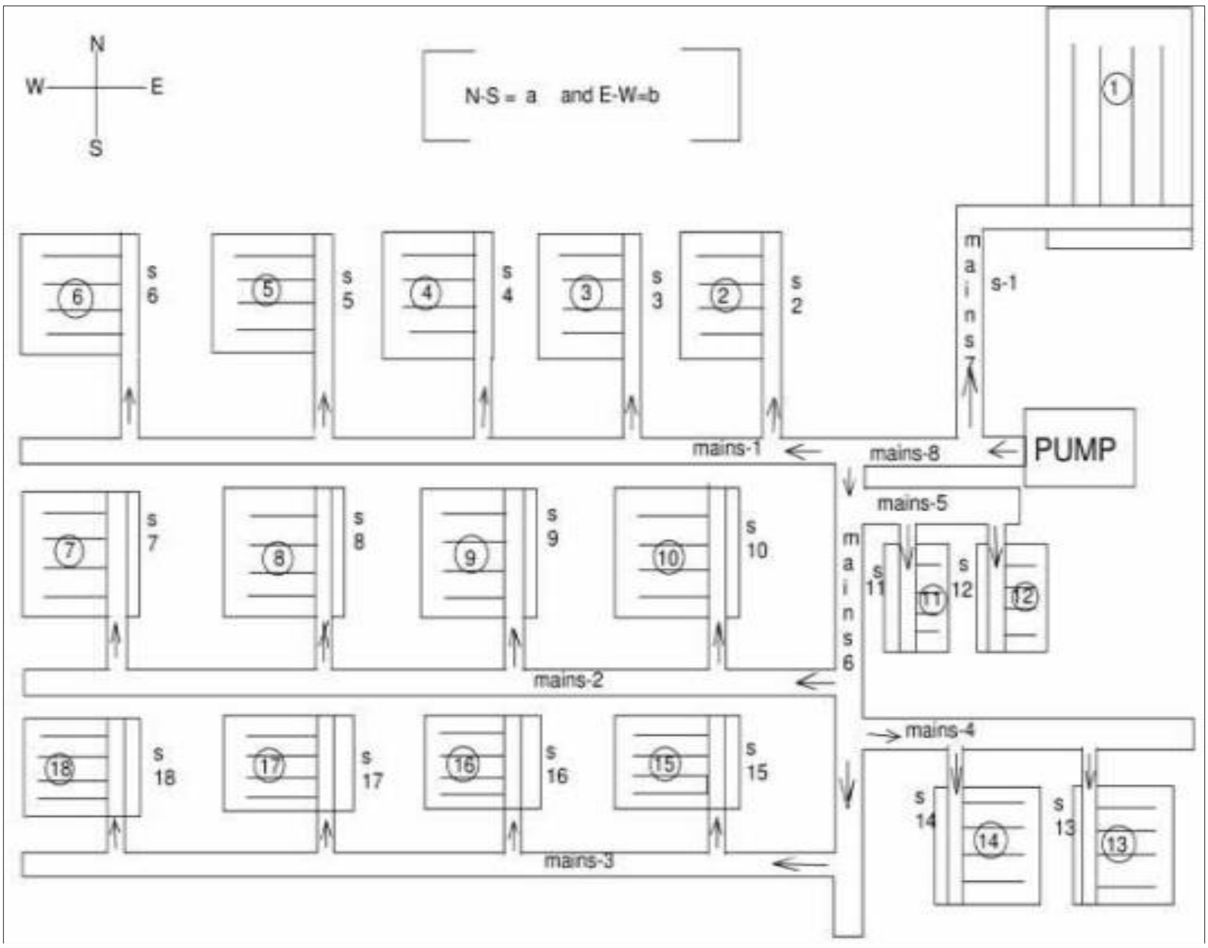

Fig 2: Layout of the experimental plot showing 18 poly/net houses under study

3.3 Water requirement of different plants

Water requirement for each of the plants was found out by consulting the horticulture department of Dr. RPCAU, Pusa. It was found that highest water requirement was for the mango plants (16.6 lpd/plant) followed by the tomato crop and the lowest for the carnations (0.42 lpd/plant) as shown in figure 3.

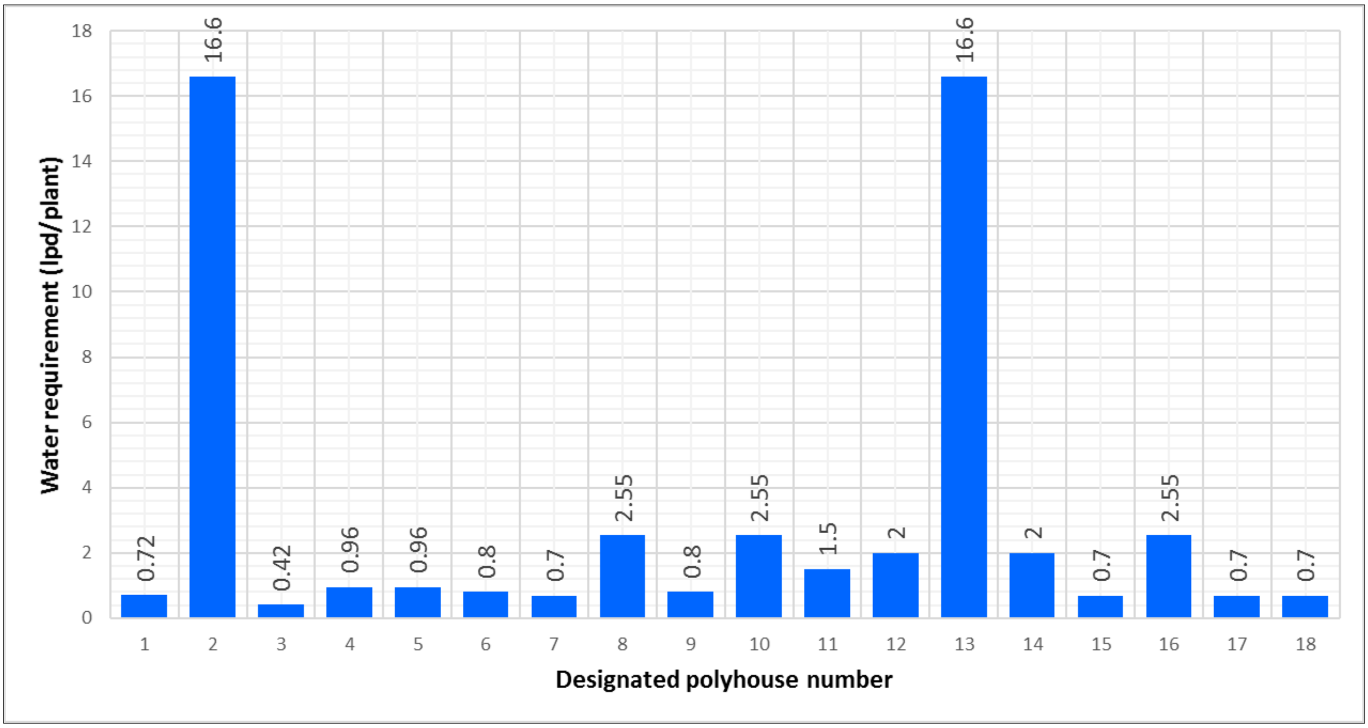

Fig 3: Water requirement of various crops used in the study

3.4 Area requirement for each of the plants

The row to row spacing and plant to plant spacing was multiplied together to get the area for one plant. The highest area per plant was occupied by the mango plants (1 m^2) and the lowest by the carnations (0.06 m^2) as shown in figure 4. The crop having the highest space requirements after mango was cucumber crop.

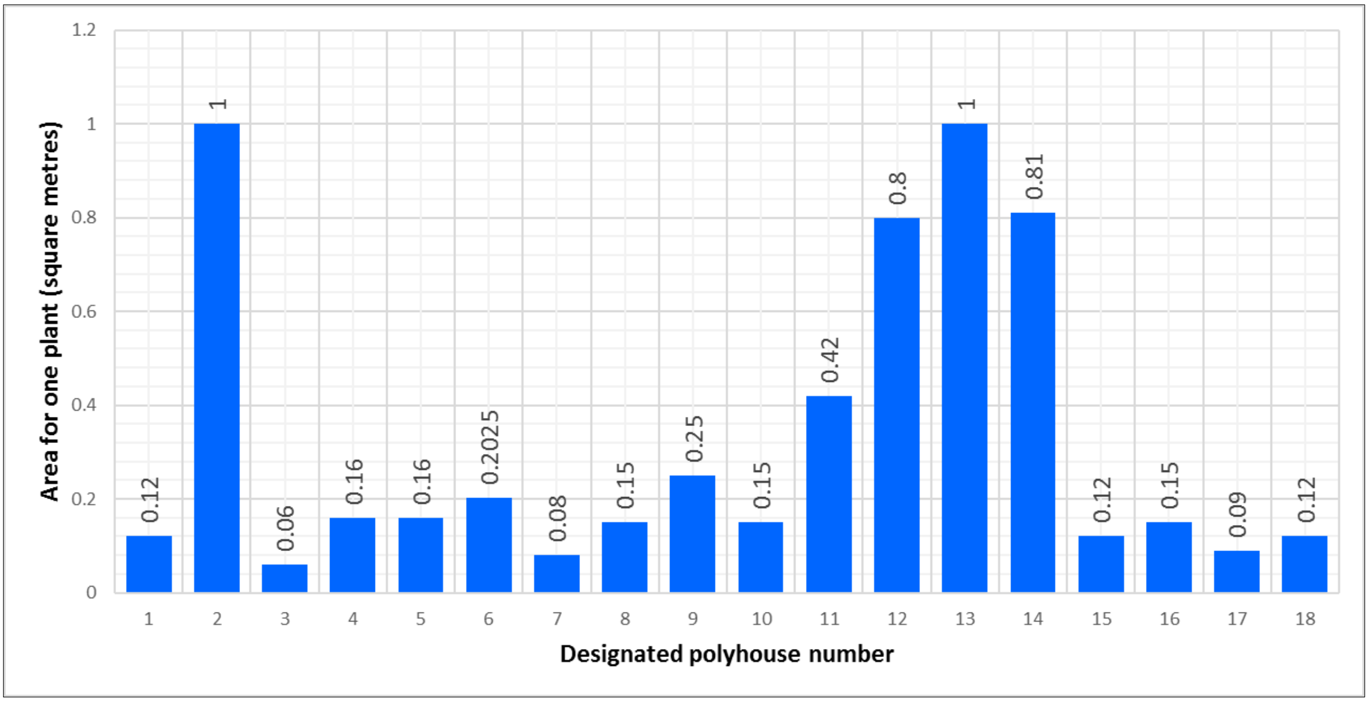

Fig 4: Area required by each of the plants under study

3.5 Measurement of area of the existing poly/net houses

There were 18 already existing pol/net houses of different dimensions. The house with the highest area was house no 1 and with the lowest area was house no 13 as shown in figure 5. Poly houses numbered 4, 5, 6, 7, 8, 9, 10 and 14 had the same area of 570.2 square metres. Also, poly houses designated with numbers 15, 16, 17 and 18 had equal area of 381.9 square metres.

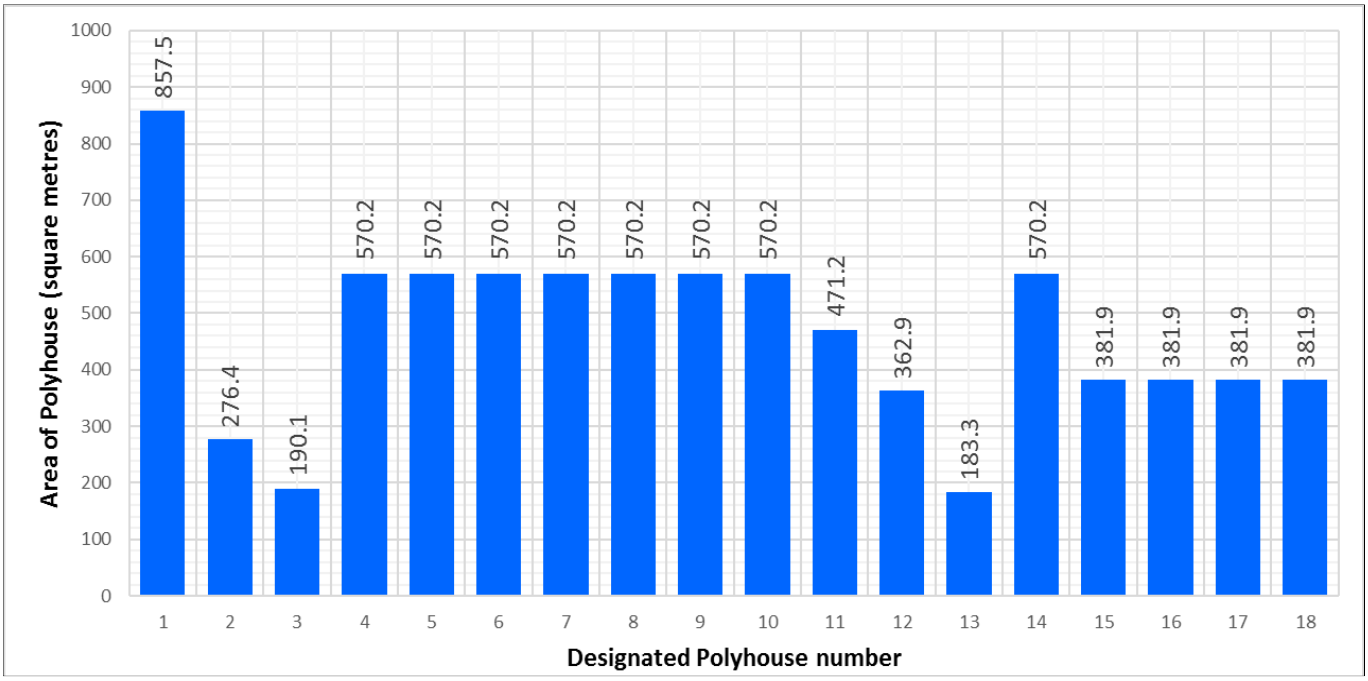

Fig 5: Area of the 18 houses under investigation

3.6 Calculation of the length of laterals

The orientation of the laying of the laterals was selected as already existing. Accordingly, the length of one lateral was considered equal to one of the two dimensions of the poly house. The longest length of the lateral used was for house no 1 whereas the shortest for house no 3 as shown in figure 6. Each lateral's length for the poly house was fixed. Lateral length taken into consideration was equal to 30.25 m for the houses 4, 5, 6, 7, 8, 9, 10 and 14. Lateral length for poly house numbered 15, 16, 17 and 18 was found to be 32.5 m.

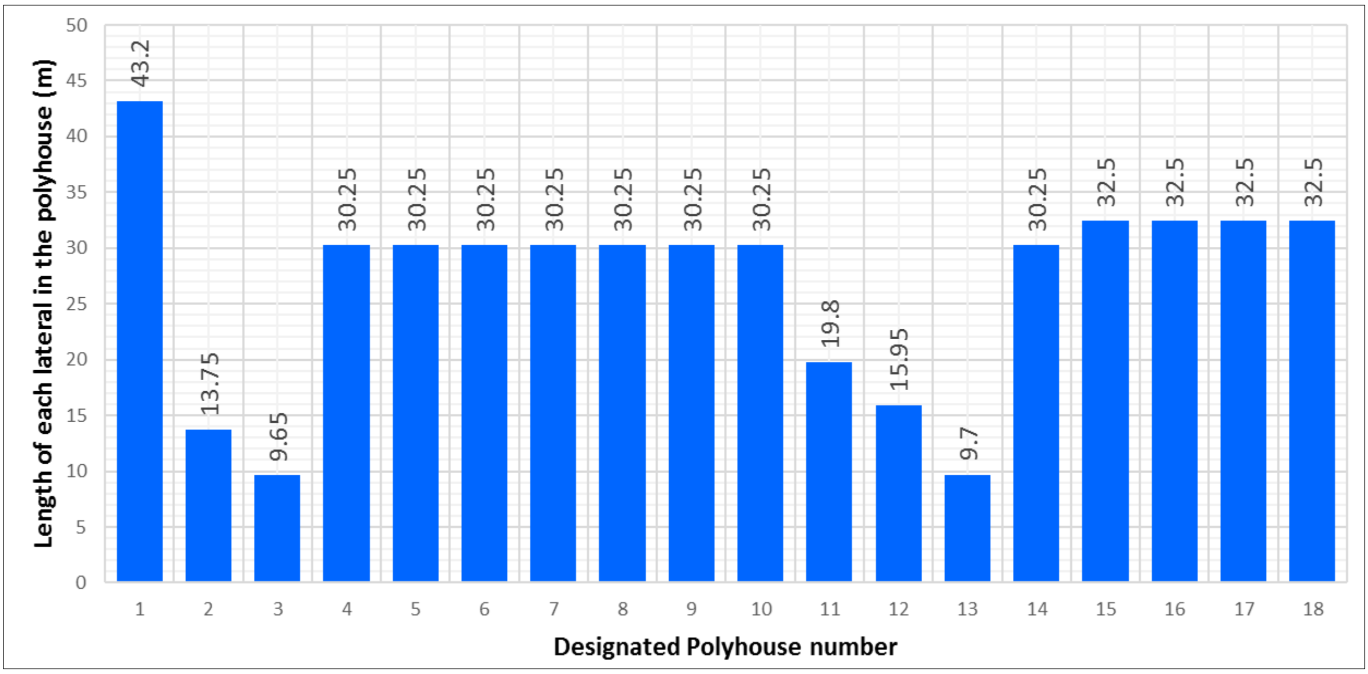

Fig 6: Length of a lateral for a particular house

The total length of the laterals depended upon the row to row spacing, bed width, walking distance between the beds and also on the dimensions of the house. The total length of the laterals was found the highest for house no 1 followed by house no 7. The least value was found for house no 13 as shown in figure 7. The total length of the laterals required for a particular house was calculated and it was found that poly house number 4, 5, 6, 9 and 14 had total lateral's length same and was equal to 847 m. Also, poly house number 8 and 10 had the total lateral's length same as 907.5 m. Each of the poly house numbered as 15, 17 and 18 also had total lateral's length same and the values were equal to 650 m.

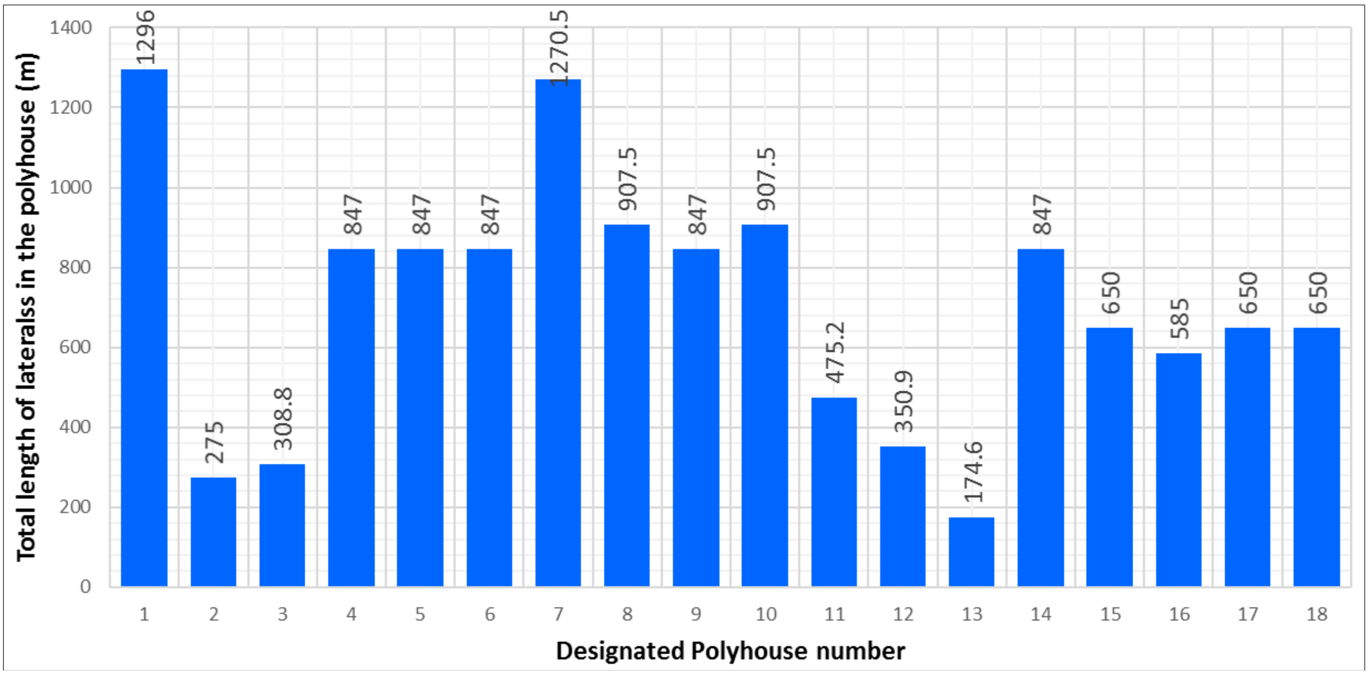

Fig 7: Total calculated length of laterals for each of the houses

3.7 Calculation of no of drippers
No of drippers present in each of the houses mainly depended on the plant to plant spacing. The highest and lowest values for the number of drippers among each of the polyhouses was found to be 3240 and 174, respectively as shown in figure 8. House number 4 and 5 had equal number of drippers and had a value of 2117. Also, house number 15, 17 and 18 had equal number of drippers and was equal to 2166.

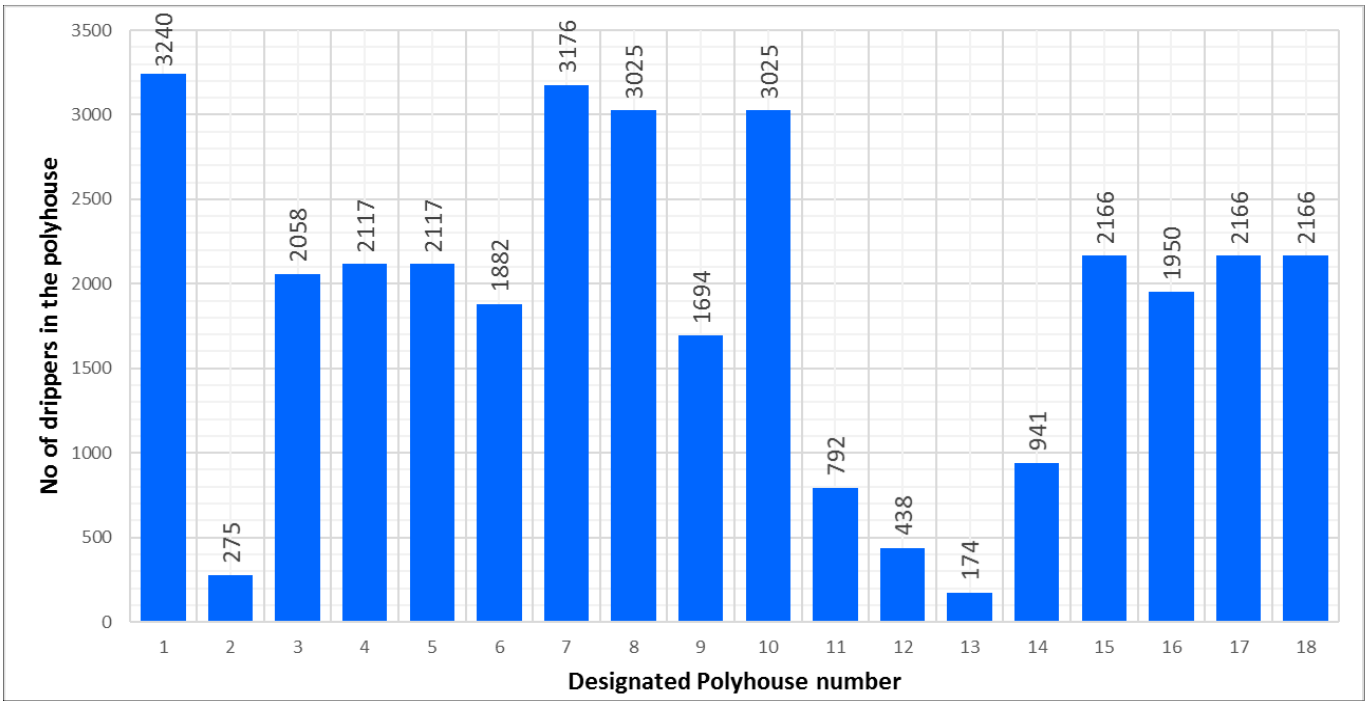

Fig 8: Total number of drippers to be used in each of the houses

3.8 Dripper selection for the plants
Drippers were selected on the basis of volume of water requirement per day for any plant and the discharge capacity of the dripper. 2 lph discharge capacity drippers were selected for all of the crops, except for mango and tomato crop, where 14 and 4 lph drippers were selected for the two crops, respectively.

3.9 Irrigation duration for the poly/net houses
Irrigation requirement for each of the houses was calculated in minutes for the determination of the duration of the water to be supplied. The highest irrigation duration was for house number 2 and 13 and was equal to 71.14 mins followed by house number 12 and 14 with a value of 60 mins as shown in figure 9. The lowest irrigation duration was for house number 3, in which carnation was planted and was equal to 12.6 mins.

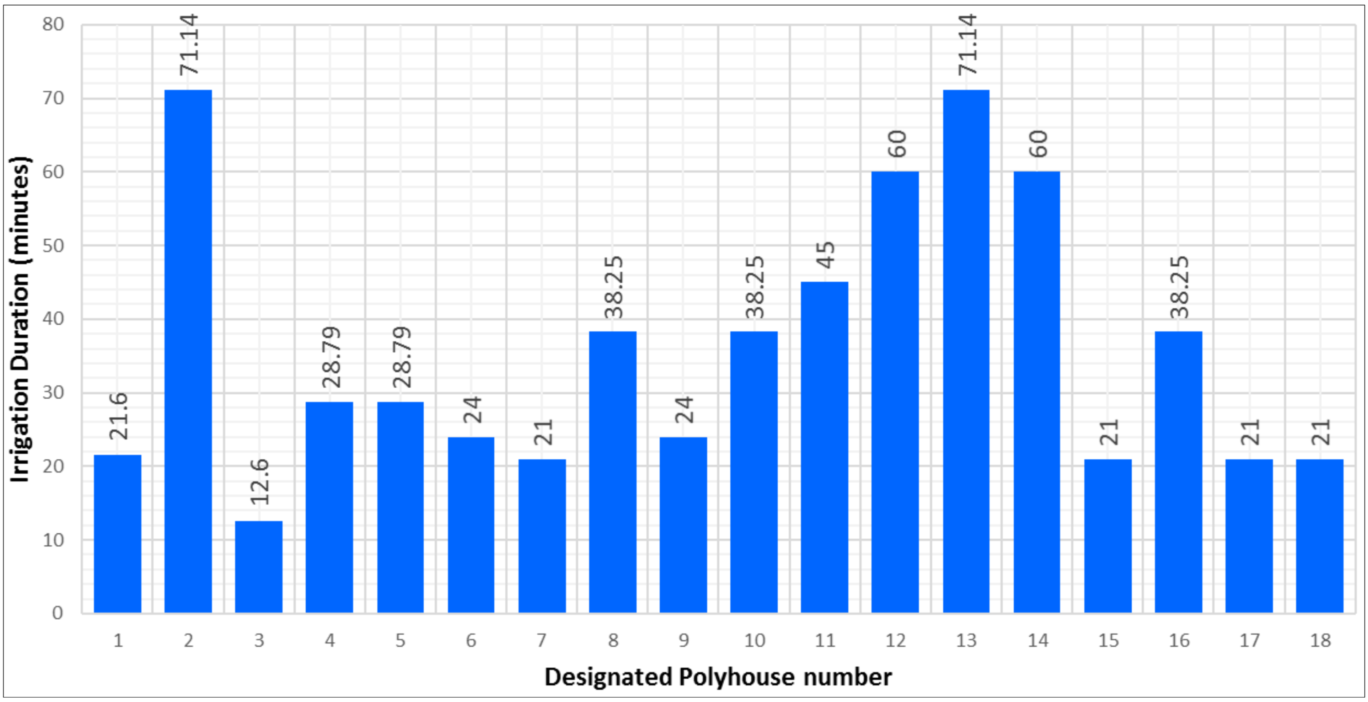

Fig 9: Irrigation duration for each of the houses

3.10 Lateral size determination

The head losses were found to be within permissible limits, when 12 mm lateral size was used for all the houses, except for house number 8, 10 and 16 where head losses in case of 12 mm diameter laterals were found to exceed limits. However, for 16 mm diameter laterals, the head losses were within permissible limits. All the three houses where 16 mm diameter lateral was used, i.e. 8, 10 and 16 had tomato crop planted and the head losses present were 0.8 m, 0.8 m and 0.995 m respectively. The peak value for the head loss was found in case of house number 1 and was equal to 1.267 m. The house having the lowest value of head loss in the laterals was deduced and was found equal to 0.0182 m (house number 12) as shown in figure 10. All the houses except house numbered 1, 15, 17 and 18, the values of head loss was found to be lower than 1 m.

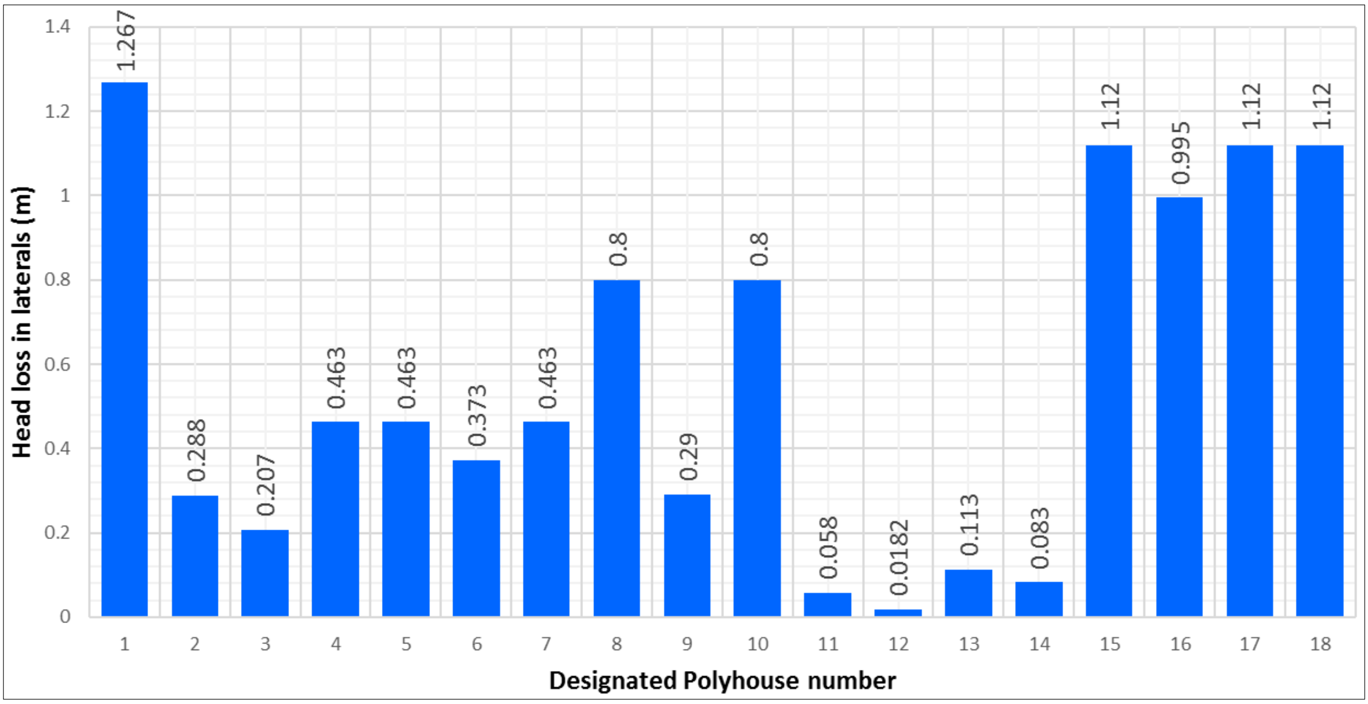

Fig 10: Head loss in the laterals for each of the houses

3.11 Submain size determination

Submain diameter of 50 mm was initially selected and evaluated for the design fulfilment of the head loss minimization. The percentage head variation was the highest for house number 8 and 10 and was equal to 6.56 % and lowest for house number 12 with a value of 0.06 %. The head losses in each of the Submains was found to be under permissible limits as shown in figure 11. Therefore, 50 mm diameter Submain pipes were selected for each of the poly house drip irrigation system.

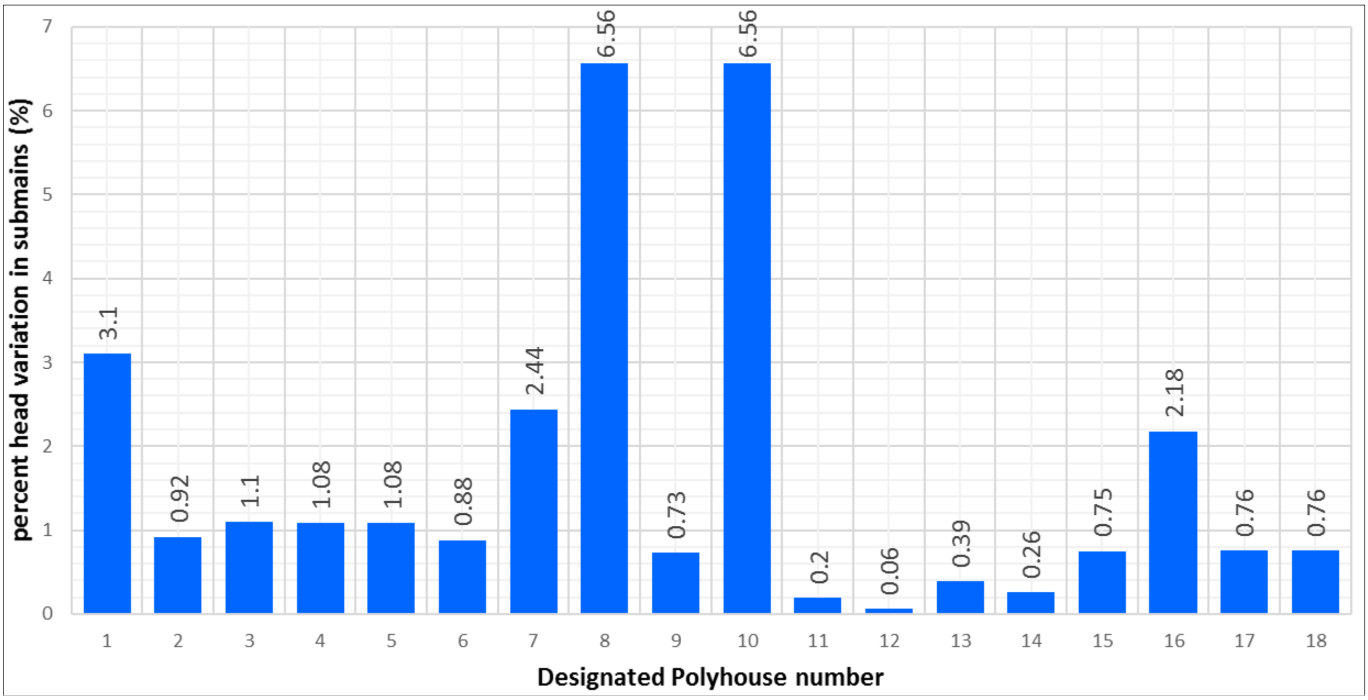

Fig 11: Percentage head variation in the submains

3.12 Main line size determination
Initially, 75 mm diameter size for the mains pipeline was selected and was evaluated. Main line number 7 had the same size as for the submain number 1. i.e. 50 mm. Size of mainlines selected was 75 mm diameter for mainlines numbered 1, 3, 4 and 5. Mains number 2, 6 and 8 had their designed diameter as 90 mm for head losses to be under permissible limits.

3.13 Total dynamic head calculation
The total dynamic head for the entire drip irrigation system unit calculated was by the integration of the head at the inlet of the final main line (mains no 8), static head, filter losses, fitting losses and the safety factor and was found to be 48 m.

3.14 Filter size determination
Filter capacity for the drip irrigation system was calculated at mains no 8 and was found to be 88.72 m^3/hr. The next higher size available in the market was to be installed for proper working of the system.

3.15 Power requirement of the pump
The efficiency of the water pump was assumed as 70% and using the values of the total dynamic head and the discharge at the final main line, the size of the pump was calculated and was found to be 22.5 hp. The next higher size of the pump available in the market was to be installed.

4. Conclusions
Precision farming methods such as drip irrigation system allows the precise application of the water to the plants in an artificially controlled manner and is beneficial especially for the arid regions. Already existing 18 poly/net houses were selected for the study and was designed for the drip irrigation system, which consisted of 12 different crops. The design was based on the friction loss method and was calculated using the Hazen-Williams formula. The 2 lph drippers could be used for all of the crops, except tomato and mango crop, where 4 lph and 14 lph drippers were recommended, respectively. The diameter of the laterals used for all of the crops was calculated and was found to be 12 mm, except for the tomato crop, where 16 mm diameter laterals was recommended. The diameter of all the submain lines was calculated and was found to be 50 mm. The mains diameter recommended was 50, 75 and 90 mm. The total dynamic head and total discharge of the drip irrigation system was found to be 48 m and 88.72 m^3/hr, respectively. Finally, the size of the pump required to irrigate all the 18 poly/net houses simultaneously was found to be 22.5 hp.

5. Acknowledgment
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