Micro Irrigation Systems Design

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Module 1. Micro-irrigation

Lesson 1. Introduction to Micro-Irrigation

1.1 Introduction

Water is one of the most critical inputs for agriculture which consumes more than 80% of the water resources of the country. Availability of adequate quantity and quality of water is, therefore, key factors for achieving higher productivity levels. Investments in conservation of water, improved techniques to ensure its timely supply, and improve its efficient use are some of the imperatives which the country needs to enhance. Poor irrigation efficiency of conventional irrigation system has not only reduced the anticipated outcome of investments made towards water resource development, but has also resulted in environmental problems like water logging and soil salinity thereby affecting crop yields. This, therefore, calls for massive investments in adoption of improved methods of irrigation such as drip and sprinkler, including fertigation.

Various options are available for reducing water demand in agriculture. First, the supply-side management practices include watershed development and water resource development through major, medium and minor irrigation projects. The second is through the demand management practices which include improved water management technologies/practices. The micro-irrigation (MI) technologies such as drip and sprinkler are the key interventions in water saving and improving crop productivity. Evidence shows that upto 40% to 80% of water can be saved and water use efficiency (WUE) can be enhanced up to 100% in a properly designed and managed MI system compared to 30-40% under conventional practice (INCID 1994; Sivanappan 1994 cited in Kumar 2012).

The term "micro-irrigation" describes a family of irrigation systems that apply water through small devices. These devices deliver water onto the soil surface very near the plant or below the soil surface directly into the plant root zone. Micro-irrigation is a method for delivering slow, frequent applications of water to the soil using a low-pressure distributing system and special flow-control outlets. Micro-irrigation is also referred to as drip, subsurface, bubbler or trickle irrigation and all have similar design and management criteria. The systems deliver water to individual plants or rows of plants. The outlets are placed at short intervals along small tubing and only the soil near the plant is watered. The outlets include emitters, orifices, bubblers and sprays or micro sprinklers with discharge ranging from 2 to over 200lh^{-1}.

Drip irrigation was developed originally as a sub-irrigation system and this basic idea underlying drip irrigation can be traced back to experiments in Germany in 1860's. The first work in drip irrigation in the U.S.A was a study carried out by House in Colorado in 1913. An important breakthrough was made in Germany way back in 1920 when perforated pipe drip irrigation was introduced.

During the early 1940's Symcha Blass, an engineer from Israel, observed that a big tree near a leaking tap exhibited more vigorous growth than other trees in the area. This led him to the concept of an irrigation system that would apply water in small quantity literally drop by drop. The earliest drip irrigation system consisted of plastic capillary tubes of small diameter (1 mm) attached to 1arge pipes. One of the refinements made by Blass in his original system was coiled emitter. In his early 1960's, experiments in the Israel reported spectacular results when they applied the Blass system in the desert area of the Negev and Arava. Drip irrigation unit in their current diverse forms were installed widely in U.S.A, Australia, Israel, Mexico and to a lesser extent in Canada, Cyprus, France, Iran, New Zealand, UK, Greece and India. With the increased availability of plastic pipes and development of emitters in Israel, it has since become an important method of irrigation in Australia, Europe, Israel, Japan, Mexico, South Africa and the United States (INCID, 1994).

In India drip irrigation was practiced through indigenous methods such as perforated earthenware pipes, perforated bamboo pipes and pitcher/ porous cups. In Meghalaya some of the tribal farmers are using bamboo drip irrigation system for betel, pepper and arecanut crops by diverting hill streams in hill slopes. Earthenware pitchers and porous cups have been used for growing vegetable crops in Rajasthan and Haryana. In India drip irrigation was introduced in the early 70's at agricultural universities and other research institutions. The growth of drip irrigation has really gained momentum in the last one decade. These developments have taken place mainly in areas of acute water scarcity and in commercial/horticultural crops, such as coconut, grapes, banana, fruit trees, sugarcane and plantation crops in the states of Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and Gujarat.

Micro-irrigation has been accepted mostly in the arid regions for watering high value crops such as fruits and orchard trees, grapes and other vine crops, sugarcane, pineapples, strawberries, flowers and vegetables. Growers, producers and landscapers have adapted micro-irrigation systems to suit their needs for precision water application. Micro-irrigation systems are immensely popular not only in arid regions and urban settings but also in sub-humid and humid zones where water supplies are limited or water is expensive. In urban landscapes, micro-irrigation is widely used with ornamental plantings.

To bring more area under irrigation, it has become necessary to introduce new irrigation techniques viz. Micro & Sprinkler Irrigation for economizing the use of water and increase productivity per unit of water. This technology also arrests water logging and secondary salinization problems of the canal command areas and check the receding water table and deteriorating water quality in the well command areas. Micro-irrigation is to be viewed as a total plant support system starting with planting material to post harvest management and marketing. Therefore, micro-irrigation need be promoted in a holistic manner involving appropriate cultivars, good agronomic practices, post harvest handling, processing and marketing leading to an end-to-end approach. Water source development and recharge of wells through watershed management would also form a part of the technology package (AGRICOOP, 2005).

1.2 Overview

In micro-irrigation, water is carried to the actual root of the plant and not just to the surrounding dirt. It uses pipes, tubes, and a dripper to slowly deliver the water. This method uses much lesser water than normal irrigation and is more efficient and ecological.

In ancient times, a clay pot with holes were filled with water and buried in the ground. Then, a clay pipe was used, which eventually changed into the more common perforated plastic tubing. Even newer developments include a plastic water emitter located where the root sits in which the water drips out. Newer and newer methods make this a valuable contribution to the agriculture world, especially those areas lacking rain and water. Other types of micro-irrigation include the bubbler, where the drip is more spread out, and the micro sprinkler, which is used overhead where the water is emitted in micro-sprays. This is usually in a closed setting such as a greenhouse.

Ideally, the irrigation tube is buried in the dirt, close to the surface. At each plant, the emitter is placed into the tubing (which is perforated). A pump pressurizes the water slowly through the emitters. If drip irrigation is combined with mulching, this form of watering would actually reduce surface evaporation and be quite effective in conservation methods. Drip irrigation can also help reduce foliage diseases that come about with wet and moldy leaves because the water goes directly down to the main root.

Micro-irrigation is used in farms as well as commercial greenhouses. It has proven successful in a commercial sense due to automation. Also, with piping and pressurized pumps, fertilizer can be added to the water. This automates the watering and feeding of plants and is less labor intensive. On land that is hilly or sloped, micro-irrigation can be the answer in avoiding run-off. The cost of micro-irrigation would cost less than leveling the land for any type of farming and can help control erosion. On farms growing crops spaced closely together, such as strawberries, micro-irrigation can help in more direct watering methods. For crops grown under cover, requiring more water, micro-irrigation can help control the flow.

1.3 Status

About 42 million ha area is potential under drip and sprinkler in the country (Raman 2010). Out of this, about 30 million ha are suitable for sprinkler irrigation for crops like cereals, pulses and oilseeds in addition to fodder crops. This is followed by drip with a potential of around 12 million ha under cotton, sugar cane, fruits and vegetables, spices and condiments; and some pulse crops like red gram, etc.

The percentage of actual area against the potential estimated under drip irrigation in different states varied between nil in Nagaland to as much as 49.74% in Andhra Pradesh, followed by Maharashtra (43.22%) and Tamil Nadu with 24.14%. In case of sprinkler irrigation, the percentage of actual area against the potential estimated was as much low as 0.01% (Bihar) and the highest of 51.93% (Andhra Pradesh). Compared to the potential of 42.23 million ha in the country, the present area under MI accounts for 3.87 million ha (1.42 million ha under drip and 2.44 million ha under sprinkler) which is about 9.16% (Table 1). The present figures thus reflect the extent of MI systems covered under different government programmes as well as own investment by the farmers. However, the actual area under MI may vary according to the extent of use by the farmers. (Palanisami et al., 2011)

Table 1. Potential and actual area under MI in different states (Area in '000 ha)

State	Drip			Sprinkler			Total		
	P	A	%	P	A	%	P	A	%
Andhra Pradesh	730	363.07	49.74	387	200.95	51.93	1,117	564.02	50.49
Bihar	142	0.16	0.11	1,708	0.21	0.01	1,850	0.37	0.02
Chattisgarh	22	3.65	16.58	189	59.27	31.36	211	62.92	29.82
Goa	10	0.76	7.62	1	0.33	33.20	11	1.09	9.95
Gujarat	1,599	169.69	10.61	1,679	136.28	8.12	3,278	305.97	9.33
Haryana	398	7.14	1.79	1992	518.37	26.02	2,390	525.50	21.99
Himachal Pradesh	14	0.12	0.83	101	0.58	0.58	115	0.70	0.61
Jharkand	43	0.13	0.31	114	0.37	0.32	157	0.50	0.32
Karnataka	745	177.33	23.80	697	228.62	32.80	1,442	405.95	28.15
Kerala	179	14.12	7.89	35	252	7.19	214	16.64	7.77
Madhya Pradesh	1,376	20.43	1.48	5,015	117.69	235	6,391	138.12	2.16
Maharashtra	1,116	482.34	43.22	1,598	214.67	12.53	2,714	697.02	25.68
Nagaland	11	0.00	0.00	42	3.96	9.43	53	3.96	7.48
Orissa	157	3.63	2.31	62	23.47	37.85	219	27.10	12.37
Punjab	559	11.73	2.10	2,819	10.51	0.37	3,378	22.24	0.66
Rajasthan	727	17.00	2.34	4,931	706.81	14.33	5,658	723.82	12.79
Tamil Nadu	544	131.34	24.14	158	27.19	17.21	702	158.52	22.58
Uttar Pradesh	2,207	10.68	0.48	8,582	10.59	0.12	10,789	21.26	0.20
West Bengal	952	0.15	0.02	280	150.03	53.58	1,232	150.18	12.19
Others	128	15.00	11.72	188	30.000	15.96	316	45.00	14.24
Total	11,659	1,428.46	12.25	30,578	2442.41	7.99	42,237	3,870.86	9.16

P= Potential; A=actual area

Source: Raman(2010) and Indiastat 2010.

1.4 Merits and demerits of micro-irrigation

Merits of micro-irrigation over other irrigation systems

Micro-irrigation systems have many potential advantages when compared to other irrigation methods.

1. Water savings: Irrigation water requirements can be much smaller when compared with other irrigation methods. This is due to irrigation of a smaller portion of the soil volume, decreased evaporation from the soil surface and the reduction or elimination of the runoff. Since the micro-irrigation system allows for a high level of water control application, water can be applied only when needed and deep percolation can be minimized or avoided.

2. Water efficiency: Micro-irrigation can reduce water usage by 25-40% compared to overhead systems, and 45-60% compared to surface irrigation, because do not wet the entire field, less -evaporation, deep percolation and the runoff minimized, too.

3. Low application rates: A low application rate means a less expensive irrigation system and more efficient utilization of pumps, filters and pipelines because these system components may be sized for lower flow rates and used for longer periods of time. Micro-irrigation systems are designed to supply an individual plant's water requirement by a daily application.

4. Uniformity of water application: Micro-irrigation systems have an excellent uniformity of water application; therefore all plants receive the same amount of water. Good uniformity results in more efficient irrigation, which leads to savings of water, power and fertilizer. An even, consistent application of water also results in better, more uniform yields, because each plant is given exactly as much water and nutrients as it needs for optimum growth.

5. Energy saving: A smaller power unit is required compared to other irrigation systems. Usually, the delivery pipe systems operate under low pressure (2 - 4 bar) and hence it requires less energy for pumping.

6. Improved chemical application: Micro-irrigation systems allow for a high level of control of chemical applications. The plants can be supplied with the exact amount of fertilizer required at a given time. Since they are applied directly to the root zone, a reduction in the total amount of fertilizer used is possible (average 25-50% cost savings in chemicals and fertilizers). This application method is more economical, provides better distribution of nutrients throughout the season and decreases ground water pollution due to the high concentration of chemicals that could ordinarily move with deep percolated water. Other chemicals such as herbicides, insecticides, fungicides, growth regulators and carbon dioxide can be efficiently applied through micro-irrigation systems to improve crop production.

7. Weed and disease reduction: Due to limited wetted area, weed growth is inhibited and disease occurrences reduced.

8. Field operations are more flexible: Micro-irrigation can be applied on windy days and during operations, can function without interruption when harvesting.

9. Improved tolerance to salinity: Micro-irrigation reduces the sensitivity of most crops to saline water, soil-water conditions due to the maintenance of high moisture levels in the root zone. The frequent application of water continually replaces moisture removed by the plant and moves salts away from the plant out to the edges of the root zone. These salts precipitate out of the water at the edge of the wetted parameter. This process prevents the harmful combination of high soil salinity and low moisture from occurring. Therefore, crops under micro-irrigation systems are more tolerant of saline water and soil conditions.

10. Improved quality and yield: Crop quality and yield under micro-irrigation is improved because of the slow, regular, uniform application of water and nutrients. In addition damage and losses due to water contact with fruit or foliage are eliminated.

11. Adoption to any topography and soils: Micro-irrigation systems can operate efficiently on any topography, if appropriately designed and managed. The low application rate with micro-irrigation systems is ideal for heavy clay soils with low infiltration rates as the water can be applied slowly enough for the soil to absorb it without surface runoff occurring. On the other hand, very sandy soils frequently cannot store large amounts of water. Micro-irrigation is ideal for these soils too, because of its ability to frequently provide small amounts of water to the crop.

12. Automation: A micro-irrigation system can be easily automated using electrical solenoid valves and a controller. This allows the system to be operated any time of the day or night and for any desired length of time enabling irrigation managers to take advantage of available crop water use information in determining optimum irrigation time.

13. Reduced labour cost: One of the major advantages of the micro-irrigation system is labour savings. Labour requirements are low because of the low application rates allow larger areas to be irrigated at one time and because the systems can be fully automated. In addition to the direct savings in labour, there are often indirect labour savings due to the reduced number of cultivations, the elimination of fertilizer application as a separate operation.

Most of the sprinklers, sprayers and jets are insect protected nozzles are closed after operation to avoid any clogging caused by insects or other debris.

If these benefits are not achieved, the investment in a micro-irrigation system is not worth it. Product life with good quality equipment, good operation and management can last upto 15-20 years.

Demerits of micro-irrigation systems

1. High initial cost: The initial investment and maintenance cost for a micro-irrigation system maybe higher than for some other irrigation methods, but the growers should weight the cost against benefits. Filters, pumps, regulators, valves, gauges, chemical injectors and possible automation components add to the cost of a micro-irrigation system. The emitter itself (drip tube/tape, sprayer, and sprinkler) represents only approximately 35 - 37% of the initial system cost. Actual cost will vary considerably depending on the selection of a particular

micro system. The growers must understand that a well designed, installed and managed system has water saving and important agronomic, environment and economic benefits.

2. Pressurized irrigation water: The irrigation water must be pressurized, resulting in energy costs. The required pressures are generally less than those needed for sprinkler systems, but they are higher than those of flood irrigation systems.

3. Requires some management and maintenance: Farming with micro-irrigation systems typically requires a change in cultivation, planting and harvesting practices. Educating growers of these changes is required before and during the first season of the micro-irrigation. These new practices can quickly become a standard part of the farming operation. Micro-irrigation systems normally have greater maintenance because of the small orifice characteristics which are susceptible to clogging from particulate matters, organic matter, and chemical precipitates. Therefore additional maintenance including filtration, injecting chlorine or acid and flushing lateral lines may be necessary to ensure best performance. Machinery, animals, insects or food traffic in the field can cause leaks in the drip tape. Also in order to realize the many benefits discussed, the grower must constantly be monitoring the growing environment and scheduling irrigation to meet the plant's needs.

4. Clogging: One of the biggest problems encountered in micro-irrigation is clogging of emitters. The small openings can be easily clogged by soil particles, organic matter, bacterial slime, algae or chemical precipitates. The micro-irrigation system requires very good filtration (most often recommended 200 mesh filtration degree) even with a good quality water supply. The filtration system should be chosen based on physical, chemical or biological characteristics of the water.

5. Salt accumulation near the root zone: Unlike surface and sprinkler irrigation systems, which can flush salts below the crop root zone, micro-irrigation systems tend to move salts to the outer edge of the wetted volume of soil and soil surface. Insufficient rainfall can move the salts back into the root zone and cause damage. Careful management is necessary to ensure that the salts do not migrate back into the active root zone. If the need to leach salts from the root zone becomes critical a sprinkler or surface irrigation system may have to be used to accomplish this purpose effectively. In areas, with heavy rainfall the salts will be washed out of the root zone before significant accumulation occurs.

6. Seed germination: Some crops do not germinate well with micro-irrigation systems (usually under drip tube/tape). In these cases portable sprinklers are often used for germination. Once started the crop can be irrigated with micro-irrigation to optimize plant growth.

7. Moisture distribution/restricted root zone: Moisture distribution depends largely on the soil type being irrigated by the micro-irrigation system. In some soils, i.e. deep sands, very little lateral water movement (low capillary forces) can create many problems. Under these conditions it is difficult to wet a significant portion of the root zone. It is also more difficult to manage the irrigation without deep percolation since only a small amount of water can be stored in the wetted volume desired. Increasing the number of emitters per plant may improve water distribution in the soil. Therefore, coarse sands will require much closer spacing of emitters than fine soils. In general, for any soil the amount of emitters and their

spacing must be based on the geometry of wetted soil volume. Particularly in regions of low rainfall, plant root activity is often limited to the soil zone wetted by the emitters. The irrigator must remember that the micro-irrigation system is meant to apply small, frequent irrigations. Cover crops cannot be grown year-around due to the localized nature of the water applications.

Lesson 2. Scope and Applications of Micro-irrigation

2.1 Potential and Applications of Micro Irrigation

The water use efficiency under conventional flood method of irrigation, which is very low due to substantial conveyance and distribution losses. Recognizing the fast decline of irrigation water potential and increasing demand for water from different sectors, a number of demand management strategies and programmes have been introduced to save water and increase the existing water use efficiency in Indian agriculture. One such method introduced relatively recently in Indian agriculture is micro-irrigation, which includes both drip and sprinkler method of irrigation. Micro-irrigation (MI) is proved to be an efficient method in saving water and increasing water use efficiency as compared to the conventional surface method of irrigation, where water use efficiency is only about 35-40 percent.

Studies carried out across different countries including India have confirmed that irrigation plays a paramount role in increasing the use of yield increasing inputs and enhancing cropping intensity as well as productivity of crops. Apart from benefiting the farmers, irrigation development also helps to increase the employment opportunities and wage rate of the agricultural landless labourers, both of which are essential to reduce the poverty among the landless labour households. However, water is becoming increasingly scarce worldwide due to various reasons. With the fast decline of irrigation water potential and continued expansion of population and economic activity in most of the countries located in arid and semi-arid regions, the problems of water scarcity is expected to be aggravated further. Macro-level estimate carried out by the International Water Management Institute (IWMI), Colombo, indicates that one-third of the world population would face absolute water scarcity by the year 2025 (Seckler, et al., 1998; Seckler, et al., 1999). As per this estimate, the worst affected areas would be the semi-arid regions of Asia, the Middle-East and Sub-Saharan Africa, all of which are already having heavy concentration of population living below poverty line. In spite of having the largest irrigated area in the world, India too has started facing sever water scarcity in different regions. Owing to various reasons the demand for water for different purposes has been continuously increasing in India, but the potential water available for future use has been declining at a faster rate (Saleth, 1996; CWC, 2005). The agricultural sector (irrigation), which currently consumes over 80 percent of the available water in India, continues to be the major water-consuming sector due to the intensification of agriculture (Iyer, 2003). Though India has the largest irrigated area in the world, the coverage of irrigation is only about 40 percent of the gross cropped area as of today. One of the main reasons for the low coverage of irrigation is the predominant use of flood (conventional) method of irrigation, where water use efficiency is very low due to various reasons. Available estimates indicate that water use efficiency under flood method of irrigation is only about 35 to 40 percent because of huge conveyance and distribution losses (Rosegrant, 1997; INCID, 1994).

Considering the water availability for future use and the increasing demand for water from different sectors, a number of demand management strategies and programmes (water pricing, warabandhi, waters users' association, etc) have been introduced since late seventies in India to increase the water use efficiency, especially in the use of surface irrigation water. One of the demand management strategies introduced relatively recently to control water consumption in Indian agriculture is micro-irrigation (MI), which includes mainly drip and sprinkler irrigation method. Under micro-irrigation, unlike flood method of irrigation (FMI), water is supplied at a required interval and quantity using pipe network, emitters and nozzles. Therefore, the conveyance and distribution losses are reduced completely which result in higher water use efficiency under MI. Though both drip and sprinkler irrigation methods of irrigation are treated as MI, there are distinct characteristics differences between the two in terms of flow rate, pressure requirement, wetted area and mobility (Kulkarni, 2005). While drip method supplies water directly to the root zone of the crop through a network of pipes with the help of emitters, sprinkler irrigation method (SIM) sprinkles water similar to rainfall into the air through nozzles which subsequently break into small water drops and fall on the field surface. Unlike flood irrigation method, DIM supplies water directly to the root zone of the crop, instead of land, and therefore, the water losses occurring through evaporation and distribution are completely absent. The on-farm irrigation efficiency of properly designed and managed drip irrigation system is estimated to be about 90 percent, while the same is only about 35 to 40 percent for surface method of irrigation (INCID, 1994). In sprinkler irrigation method, water saving is relatively low (up to 70 percent) as compared to drip irrigation since SIM supplies water over the entire field of the crop (Kulkarni, 2005).

Micro-irrigation is introduced primarily to save water and increase the water use efficiency in agriculture. However, it also delivers many other economic and social benefits to the society. Reduction in water consumption due to drip method of irrigation over the surface method of irrigation varies from 30 to 70 percent for different crops (INCID, 1994, Postal, 2001). According to data available from research stations, productivity gain due to use of micro-irrigation is estimated to be in the range of 20 to 90 percent for different crops (INCID, 1994). While increasing the productivity of crops significantly, it also reduces weed problems, soil erosion and cost of cultivation substantially, especially in labour-intensive operations. The reduction in water consumption in micro-irrigation also reduces the energy use (electricity) that is required to lift water from irrigation wells.

Table 2.1 Water saving and productivity gains under drip method of irrigation in India

Crop's Name	Water consumption (mm/ha)		Yield (t/ha)		Water Saving over FIM (%)	Yield Increase over FIM (%)	Water Use Efficiency (yield/ha)/(mm/ha)	
Vegetables:	FIM	DIM	FIM	DIM			FIM	DIM
Ash gourd	840	740	10.84	12.03	12	12	0.013	0.016
Bottle gourd	840	740	38.01	55.79	12	47	0.045	0.075
Brinjal	900	420	28.00	32.00	53	14	0.031	0.076

Beet root	857	177	4.57	4.89	79	7	0.005	0.028
Sweet Potato	631	252	4.24	5.89	61	40	0.007	0.023
Potato	200	200	23.57	34.42	NIL	46	0.118	0.172
Lady's finger	535	86	10.00	11.31	84	13	0.019	0.132
Onion	602	451	9.30	12.20	25	31	0.015	0.0277
Radish	464	108	1.05	1.19	77	13	0.002	0.011
Tomato	498	107	6.18	8.87	79	43	0.012	0.083
Chillies	1097	417	4.23	6.09	62	44	0.004	0.015
Ridge gourd	420	172	17.13	20.00	60	2	0.030	0.075
Cauliflower	389	255	8.33	11.59	34	39	0.021	0.045
Fruit Crops:								
Papaya	2285	734	13.00	23.00	68	77	0.006	0.031
Banana	1760	970	57.50	87.50	45	52	0.033	0.090
Grapes	532	278	26.40	32.50	48	23	0.050	0.117
Lemon	42	8	1.88	2.52	81	35	0.045	0.315
Watermelon	800	800	29.47	88.23	Nil	179	0.037	0.110
Mosambi*	1660	640	100.00	150.00	61	50	0.060	0.234
Pomegranate*	1440	785	55.00	109.00	45	98	0.038	0.139
Other Crops:								
Sugarcane	2150	940	128.00	170.00	65	33	0.060	0.181
Cotton	856	302	2.60	3.26	60	25	0.003	0.011
Coconut	---	---	---	--	60	12	---	---
Groundnut	500	300	1.71	2.84	40	66	0.003	0.009

Notes: *-yield in 1000 numbers

Sources: INCID (1994) and NCPA (1990)

India has enormous potential for both DIM and for SIM. Two of the INCID (1994 and 1998) reports, which present an overview about the development of drip irrigation and sprinkler irrigation in India, indicate that about 80 crops, both narrow and widely spaced crops, can be grown under micro-irrigation. Although DIM is considered to be highly suitable for wide spaced and high value commercial crops, it is also being used for cultivating oilseeds, pulses, cotton and even for wheat crop (INCID, 1994). Closely grown crops such as millets, pulses, wheat, sugarcane, groundnut, cotton, vegetables, fruits, flowers, spices and condiments have been found to be suitable to cultivate under sprinkler irrigation. Importantly, an experimental study suggests that sprinkler irrigation can also be used successfully even for cultivating paddy crop (Kundu, et al., 1998).

2.2 Micro-irrigation applications: Hills, arid lands, coastal and wastelands

Micro-irrigation for hills :

The cultivation of horticultural crops is more remunerative on the small terraces of upland areas, due to favourable climatic conditions. However, due to the non-availability of irrigation water, farmers grow rainfed cereals with very low yields. A check basin irrigation method involving high water losses is commonly used in the valley areas. Plant-to-plant hand watering, as used on a small scale in water-scarce upland areas, is commonly used water application method, but it requires a huge amount of labour. Drip irrigation can replace the hand watering system with minimum water losses and labour. Due to topographical advantages, the gravitational head may be used to operate the system, thus eliminating the initial and operational cost of pumping. Different aspects of the design of drip irrigation systems have been discussed in detail by Keller and Bliesner (1990) assessed the drip irrigation system for the relative effects of hydraulic design, manufacturer's variation, grouping of emitters, and plugging. However, these designs are developed for plain areas and the high water pressure is built up by pumping. Some modifications in the design criteria are essential in order to design drip irrigation systems on hilly terraces. Most of the conventionally available long path turbulent flow emitters require an operating water pressure head of 10 m or more for optimum performance. Additional pressure head is required to meet the friction losses in different components of the system, whereas the elevation difference between two adjacent terraces mostly ranges between 0.5 and 5.0 m. This pressure was found to be insufficient to operate the system using turbulent flow emitters. Bhatnagar et al. (1998) obtained low emission uniformity (64–72%) for emitter operating at pressure head of 4.0–6.5 m. However, replacing the emitters with microtubes (1.0 mm diameter) improved the emission uniformity to 94–98% for the same conditions. Another problem encountered is the large variation in emitter discharge, as the system has to be laid on several terraces having varying elevations, sizes and slopes, and irregular shapes.

Micro-irrigation for arid lands:

Establishing plants in arid lands is a challenging task even with supplemental irrigation. The low relative humidity, extreme temperatures, lack of consistent rainfall, tremendous rate of evaporation, and high wind speeds common in desert environments all play important and interrelated roles in water loss from soil and plants. Deterioration of water quality, drying up of groundwater and salt accumulation in the soil due to inadequate irrigation with saline water problems are often caused by irrigated agriculture in arid lands. Two methods seem to be effective to avoid those problems. One is to irrigate crop with drip irrigation with limited water and the other is to drain the excess water away. These factors make it critical that use of drip irrigation system to deliver water at the root zone of plants in order to maximize survival and growth.

Micro-irrigation for coastal lands:

Coastal regions have problems of cultivating crops due to excess amount of salts in these regions. Research experiments have been conducted to store fresh rainwater in ponds and use this water for irrigating crops with drip system. Cultivation of short duration vegetable crops and salt tolerant crops are found to be successful in these areas.

Micro-irrigation for wastelands:

Wasteland is an important land resource for agriculture and the area where salt-affected soil is widely distributed is usually abundant in resources of light and heat, and therefore has great potential to develop agriculture. Soil salinization is one of factors of soil degradation in the world, and it tends to become increasingly serious. The formation of salt-affected soil is not only related to soil parent materials, climate, and topography, but also induced by anthropogenic activities particularly improper irrigation and drainage. Inappropriate irrigation leads to ground water table rise and makes the salts to get accumulated on the upper soil layer through capillary rise. Drip irrigation was thought to be an effective method to reclaim salt-affected soil. Many research results showed that the leaching efficiency with drip irrigation was higher than other irrigation methods (Bresler et al. 1982). The distribution of soil water and salts under drip irrigation is beneficial for crop growth. The soil water content in the inner of wetted volume is higher than that in the outer where salts accumulate. The key issue of the salt-affected soils reclamation using drip irrigation is that a reasonable irrigation regime needs to be made to ensure not only the normal crop growth but also surplus water for salts leaching.

Lesson 3. Government of India Financial Assistance for Promotion of Micro Irrigation in India

3.1 Financial Assistance under National Mission on Micro Irrigation

India is an agrarian country. Water management is of critical importance to Indian agriculture. While the irrigated area in the country has almost doubled since independence, it is believed that the irrigated area cannot exceed 50% of the cultivable area with the conventional methods of irrigation even if the irrigation potential is fully utilized. To address the judicious and improved methods / technologies for harnessing maximum benefits from available water resources to enhance crop productivity without affecting soil health. The scheme on Micro- Irrigation, which was launched during the year 2005-06, has been upscaled to be implemented as the 'National Mission on Micro-irrigation' (NMMI) during XI Plan period.

The main objectives of NMMI are:

- To increase the area under micro-irrigation through improved technologies.
- To enhance the water use efficiency.
- To increase the productivity of the crops and farmers' income.
- To establish convergence and synergy among ongoing Govt. programmes.
- To promote, develop and disseminate MI technology for agriculture or horticulture development with modern scientific knowledge.
- To create employment opportunities for skilled and unskilled person especially unemployed youth

This is a Centrally Sponsored Scheme under which out of the total cost of the MI System, 40% will be borne by the Central Government, 10% by the State Government and the remaining 50% will be borne by the beneficiary, either through his/her own resources or soft loan from financial institutions. Assistance for beneficiary farmers will be for covering a maximum area of 5ha/ beneficiary.

At least 33% of the allocation is to be utilized for small, marginal and women farmers. The allocation to SC/ST farmers will be proportionate to their population in the district. Farmers who have already availed the benefit of subsidy can again avail subsidy after 10 years.

The assistance for MI demonstrations, to be taken in farms belonging to State/Central Governments, State Agricultural Universities (SAUs) and ICAR Institutions, progressive farmers and Non-Governmental Organizations (NGO)/Trusts, on their own land will be @ 75% of the cost for a maximum area of 0.5 ha per beneficiary, which will be met entirely by the Central Government.

Assistance will be available for both drip and sprinkler irrigation for wide spaced as well as close spaced crops. However, assistance for sprinkler irrigation system will be available only for those crops where drip irrigation is uneconomical. Assistance is also available for irrigation systems for protected cultivation including greenhouses, polyhouses and shadenet houses. Assistance is available for implementation of advanced technology like fertigation with fertilizer tank / venture systems, sand filters / media filters, hydrocyclone filters / sand separators and other different type of filters and valves required for MI system.

The Panchayati Raj Institutions (PRIs) are involved in selecting the beneficiaries. The scheme includes both drip and sprinkler irrigation. However, sprinkler irrigation will be applicable only for those crops where drip irrigation is uneconomical. There will be a strong HRD input for the farmers, field functionaries and other stake holders at different levels. Besides, this there is provision for be publicity campaigns, seminars/workshops at extensive locations to develop skills and improve awareness among farmers about importance of water conservation and management. The Precision Farming Development Centres (PFDCs) provide research and technical support for implementing the scheme. Supply of good quality system both for drip and sprinkler irrigation having BIS marking, proper after sales services to the satisfaction of the farmer is paramount.

At the National Level, the Executive Committee of NMMI reviews the progress of NMMI and approve the Annual Action Plans of States. At the State level, the State Micro-irrigation Committee (SMIC) woversees the implementation of the Mission programme in districts. The District Micro-irrigation Committee (DMIC) coordinates the implementation of NMMI programme at the District level. NCPAH coordinates and monitor the programme of NMMI in different States.

The scheme is implemented by an Implementing Agency (IA) appointed by the State Government, which will be the District Rural Development Agencies (DRDA) or any identified Agency, to whom funds will be released directly on the basis of approved district plans for each year.

The IA shall prepare the Annual Action Plan for the State on the basis of the district plans and get it forwarded by SMIC for approval of the Executive Committee (EC) of NMMI. Payment is made through RTGS to the IA who transfers funds to the identified districts. DMIC provides funds to the system suppliers through the farmers' / beneficiaries'. Registration of System Manufacturers will be done by the SMIC for use in the Districts.

Micro-irrigation systems costs have been standardized upon which the subsidy amount is being calculated, as stated in Tables 3.1, 3.2, 3.3, 3.4, 3.5 and 3.6.

Table 3.1 Indicative cost of installing drip irrigation system for calculation of subsidy

Cost in Rs./ha							
Lateral Spacing (m x m)	0.2	0.4	1	2	3	4	5
12 x 12	8057	13785	18820	29928	46467	57809	73611
100 x 10	8308	14277	20041	32323	50128	62787	79831
9 x 9	8490	14631	20900	34039	52704	66294	84219
8 x 8	8673	15088	22028	36217	56087	70893	89964
6 x 6	9492	16605	26551	44387	71715	86970	109129
5 x 5	10061	17977	30143	51438	74334	94465	126925
4 x 4	11177	18621	31793	55725	86926	113812	135459
3 x 3	12088	20048	36551	63269	97448	122553	153441
2.5 x 2.5	14939	27092	52230	95083	145227	203823	248954
2 x 2	18319	31616	63598	123441	179332	249134	305797
B. Close spaced Crops							
1.5 x 1.5	21514	35973	74437	141858	211855	292595	360002
2.5 x 0.6	15463	26791	54909	100906	154213	214153	262885
1.8 x 0.6	18807	32909	70086	132653	199684	271986	338705
1.2 x 0.6	24063	43816	97598	185565	2800886	378946	474070

Table 3.2 Indicative cost of micro sprinkler and mini sprinkler irrigation system

Cost in Rs		
Area (ha)	Micro Sprinkler	Mini Sprinkler
	Spacing of Sprinkler (m x m)	
	5 x 5	10 x 10
0.2	17019	Not Feasible

0.4	51245	35968
1	90070	74097
2	129830	139142
3	175315	211289
4	221628	271958
5	221628	333150

Table 3.3 Indicative cost of drip irrigation/fogging/misting system under protected cultivation

Cost in Rs. per unit)			
SN	**Particulars**	**504 Sqm**	**100 Sqm**
1.	Green House / Poly House a) High Cost b) Naturally Ventialted	55,000	21,000
2.	Shadenet	45,000	18,000

Table 3.4 Indicative cost of portable sprinkler irrigation system

Area	63 mm	75 mm	90 mm
Up to 0.4 ha	10399	NA	NA
More Than 0.4 ha – 1 ha	16993	19044	NA
More Than1 ha – 2 ha	24533	27280	NA
More Than 2 ha – 3 ha	NA	NA	36822
More Than 3 ha – 4 ha	NA	NA	46438
More Than 4 ha – 5 ha	Na	NA	52573

Table 3.5 Indicative cost of semi-permanent sprinkler irrigation system

Area	Cost (in Rs.)
Up to 0.4 ha	19615
0.4 ha – 1 ha	31832
1 ha – 2 ha	60699
2 ha – 3 ha	81929
3 ha – 4 ha	104689
4 ha – 5 ha	127003

Table 3.6 Indicative cost of large volume sprinklers (rain guns)

Cost in Rs.			
Area	**63 mm**	**75 mm**	**90 mm**
More Than 0.4 ha – 1 ha	24940	30011	NA
More Than 1.0 ha – 2 ha	NA	38075	NA
More Than 2.0 ha – 3 ha	NA	NA	54112
More Than 3.0 ha – 4 ha	NA	NA	62720
More Than 4.0 ha – 5 ha	NA	NA	68878

(Source: Guidelines, NMMI)

The total cost of the scheme is being shared between Central Government, the State Government and the beneficiary either through his/her own resources or soft loan from financial institutions in the ratio of 40%, 10% and 50% respectively. Bankable schemes are being formulated for availing bank loans.

3.2 Financial support from National Bank for Agriculture and Rural Development (NABARD)

Broad guidelines for scheme formulation by banks for financing drip irrigation systems are available at NABARD. The loans are available to farmers from different banks, through NABARD. Some cooperative societies and IFFCO also provide finances required for the initial installation of the micro-irrigation system.

3.3 Financial Assistance from National Horticulture Board (NHB)

National Horticulture Board (NHB) also has a scheme to assist farmers in increasing the produce of horticultural crops. It also includes financial assistance for micro-irrigation. The pattern of assistance of NHB is credit linked back-ended subsidy @ 20% of the total project cost limited to Rs 25 lakh per project in general area and Rs 30.00 lakh in NE Region, Hilly and scheduled areas.

The terms and conditions of the assistance of NHB are as follows:

i) The assistance shall be available for projects covering area above four hectares (above 10 acres) in case of open field cultivation in general area and 5 acres in NE, hilly/scheduled area.

ii) Credit component as means of finance of the project should be term loan from banking or non-banking financial institutions and should be at least 35% (i.e. 15% more than the admissible rate of subsidy.)

iii) Projects shall be appraised to ensure and enable entrepreneur to incorporate essential hitech components in the form of planting material, plantation, irrigation, fertigation, vermicompost unit, precision farming, on farm PHM related infrastructure, GAP etc.; and to that extent, the project shall be integrated in nature.

iv) Normative cost of various components shall be prescribed by NHB.

v) NHB provides financial assistance for creating irrigation infrastructure for digging bore well to a maximum ceiling of Rs. 4.00 lakh per unit maximum upto two units.

vi) Expenses towards sprinkler system upto 10 Acres with maximum ceiling of 1.0 lakh for installation drip system upto 2.0 lakh.

Lesson 4. Types of Micro Irrigation Systems

The micro irrigation system can be classified in respect to variety of parameters. The micro irrigation encompasses several ways of water application to plants: drip, spray, subsurface and bubbler irrigation.

4.1 Drip Irrigation

Drip or trickle irrigation is the newest of all commercial methods of water application. It is described as the frequent, slow application of water to soils through mechanical devices called emitters or applicators located at selected points along the delivery lines. The emitters dissipate the pressure from the distribution system by means of orifices, vortexes and tortuous or long flow paths, thus allowing a limited volume of water to discharge. Most emitters are placed on the ground, but they can also be buried (Fig 4.1). The emitted water moves within the soil system largely by unsaturated flow. The wetted soil area for widely spaced emitters will be normally elliptical in shape. Since the area wetted by each emitter is a function of the soil hydraulic properties, one or more emission points per plant may be necessary (Howell et al., 1980)

4.2 Spray Irrigation

Spray irrigation is a form of irrigation in which pressurized water is sprayed over plants to provide them with water. This type of irrigation is also sometimes called sprinkler irrigation, and it is very widely used all over the world. The spray irrigation sizes can be designed for all size of farms, ranging from a home sprinkler to keep a lawn green to industrial sized sprinklers used to irrigate crops.

Fig 4.1. Water application through drip system

The application of water by a small spray or mist to the soil surface, water travel through the air becomes instrumental in the distribution of water. In this category two types of equipment are in use viz., micro-sprayers and micro-sprinklers. Micro-sprayers and static micro jets are non-rotating type with flow rates ranging from 20 to 150 l/h, whereas, micro-sprinklers are rotating type with flow rates ranging from 100 to 300 l/h. Fig 4.2 shows operation of micro sprinkler for irrigating a flower bed.

Fig 4.2. Water application through micro sprinkler system

This system is similar to the way one may water lawn at home - stand there with a hose and spray the water out in all directions. The systems can simply be long hoses with sprinklers along the length or a center-pivot system that traverses a circle in the fields. With a spray irrigation system, the irrigation sprinklers may be fixed in place, or located on movable frames. Some sprinkler heads will only spray in one direction, requiring careful placement, while others will rotate as they spray, and delivering water across a broader area. Rotating heads are often preferred because it allows for the installation of a single sprinkler array to cover a big area.

The center-pivot systems have a number of metal frames (on rolling wheels) that hold the water tube out into the fields. Electric motors move each frame in a big circle around the field (the tube is fixed at the water source at the center of the circle), squirting water. The depth of water applied is determined by the rate of travel of the system. Single units are ordinarily about 1,250 to 1,300 feet long and irrigate about a 130-acre circular area. In high-pressure systems, there can be very big water guns along the tube.

A more "modern" alternative to the high-pressure water guns is the low-pressure sprinkler system. Here, water is gently sprayed downward onto plants instead of being shot high in the air. Low-pressure systems are more efficient in that much less water evaporates or is blown off the fields, if there is a strong wind present.

Sources of water for spray irrigation vary. The utilization of treated wastewater should be encouraged. This is an environmentally friendly choice which reduces the demand for fresh water, nourishes the plants, and reduces wastewater runoff into waterways. Treated wastewater can be used on ornamental crops and landscaping, but it may be banned for use on crops. The source of water can be from wells, reservoirs, rivers, lakes, and streams.

(Source: http://www.wisegeek.com/what-is-spray-irrigation.htm 17th Aug, 2012

http://ga.water.usgs.gov/edu/irsprayhigh.html 17th Aug, 2012)

4.3 Sub-Surface System

It is a system in which water is applied slowly below the land surface through emitters. Such systems are generally preferred in semi permanent/permanent installations.

Subsurface drip irrigation (SDI) is a low-pressure, high efficiency irrigation system that uses buried drip tubes or drip tape to meet crop water needs. SDI technologies have been a part of irrigated agriculture since the 1960s; with the technology advancing rapidly in the last two decades. A SDI system is a flexible and can provide frequent light irrigations. This is especially suitable for arid, semi-arid, hot, and windy areas with limited water supply. Farm operations also become free of impediments that normally exist above ground with any other pressurized irrigation system. Since the water is applied below the soil surface, the effect of surface infiltration characteristics, such as crusting, saturated condition of pounding water, and potential surface runoff (including soil erosion) are eliminated during irrigation. With an appropriately sized and well-maintained SDI system, water application is highly uniform and efficient. Wetting occurs around the tube and water moves out in all directions. Fig 4.3 shows moisture distribution through a sub surface drip system. Subsurface irrigation saves water and improves yields by eliminating surface water evaporation and reducing the incidence of disease and weeds. Water is applied directly to the root zone of the crop and not to the soil surface where most weed seeds winter over. As a result, germination of annual weed seed is greatly reduced, and lowers weed pressure on beneficial crops. In addition, some crops may benefit from the additional heat provided by dry surface conditions, producing more crop biomass, provided water is sufficient in the root zone. When managed properly, water and fertilizer application efficiencies are enhanced, and labor needs are reduced. Field operations are also possible, even when irrigation is applied.

(Source: Subsurface Drip Irrigation (SDI) by D. Reich, R. Godin, J.L. Chávez, I. Broner1 (3/09); http://www.ext.colostate.edu/pubs/crops/04716.html/ 17th Aug, 2012)

4.4 Bubbler System

In this system the water is applied to the soil surface in a small stream or fountain. The discharge rate for point source bubbler emitters is greater than the drip or subsurface emitters but generally less than 225 l/h. Since the emitter discharge rate generally exceeds the infiltration rate of the soil, a small basin is usually required to contain or control the water. Bubbler systems do not require elaborate filtration systems. These are suitable in situations where large amount of water need to be applied in a short period of time and suitable for irrigating trees with wide root zones and high water requirements.

Lesson 5. Components of Micro Irrigation System (MIS)

Micro irrigation systems components

Irrigation pipeline systems are generally described as branching systems. Various branches are given names such as main, submain, and lateral. Fig 5.1 shows a typical layout of micro-irrigation system. Choosing the right size main, submain, and lateral pipe to match the flow rates from the water source is important. Basic components include a pump and power unit, a backflow prevention device if chemicals are used with water, a filter, a water distribution system, and some devices for controlling the volume of water and pressure in the system. If the water source is from a city/municipal/rural water supply, a direct connection is possible.

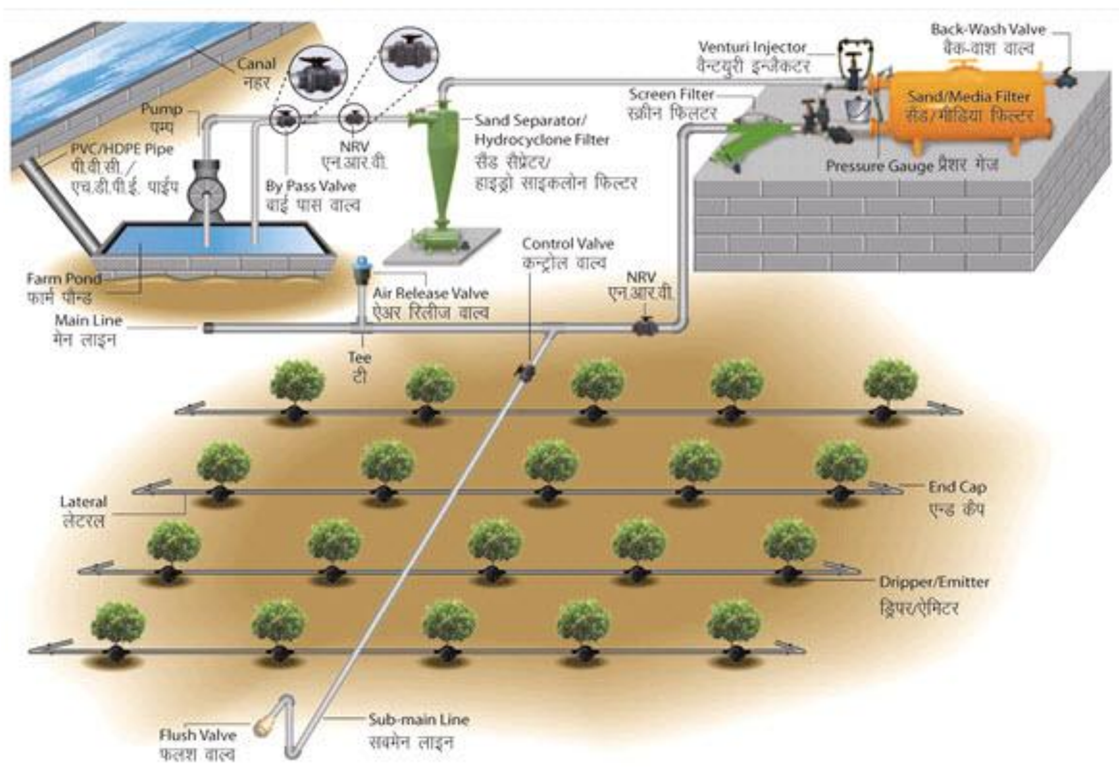


Fig.5.1 Typical layout of a micro-irrigation system

(Image source: http://74.52.53.155/sites/all/themes/ncpah/images/Drip_irrigation.jpg)

Pumps and power unit

Micro-irrigation systems are typically designed to make the best use of the amount of water available. The type and size of pump selected will depend on the amount of water required, the desired pressure and the location of the pump relative to the distribution network. Electric power units or internal combustion engine driven pumps are equally adaptable. However, the electric power unit is preferred because it is easier to automate.

Filters

Filters remove sand and larger suspended particles before they enter the distribution network. However, the filters cannot remove dissolved minerals, bacteria and some algae. The three types generally used are screen, disk and sand filters.

Distribution lines

The water distribution system is a network of pipes and tubes that can range in size from 1/2 inch to 6 inches (12 mm to 150 mm) in diameter. Water from the pump may be carried to the edge of the field by a single large main. Smaller submains may then carry the water to laterals and ultimately to the emitters.

5.1 Control Head

The head control unit of micro-irrigation system includes the following components.

1. Pump/Overhead tank: It is required to provide sufficient pressure in the system. Centrifugal pumps are generally used for low pressure trickle systems. Overhead tanks can be used for small areas or orchard crops with comparatively lesser water requirements.

2. Fertilizer applicator: Application of fertilizer into pressurized irrigation system is done by either a by-pass pressure tank, or by venturi injector or direct injection system.

3. Filters: The hazard of blocking or clogging necessitates the use of filters for efficient and trouble free operation of the micro-irrigation system. The different types of filters used in micro-irrigation system are described below.

a) Gravel or Media filter: Media filters consist of fine gravel or coarse quartz sand, of selected sizes (usually 1.5 – 4 mm in diameter) free of calcium carbonate placed in a cylindrical tank. These filters are effective in removing light suspended materials, such as algae and other organic materials, fine sand and silt particles. This type of filtration is essential for primary filtration of irrigation water from open water reservoirs, canals or reservoirs in which algae may develop. Water is introduced at the top, while a layer of coarse gravel is put near the outlet bottom. Reversing the direction of flow and opening the water drainage valve cleans the filter. Pressure gauges are placed at the inlet and at the outlet ends of the filter to measure the head loss across the filter. If the head loss exceeds more than 30 kPa, filter needs back washing. Different types of media filters are shown through Fig. 5.2

b) Screen filters: Screen filters are always installed for final filtration as an additional safeguard against clogging. While majority of impurities are filtered by sand filter, minute sand particles and other small impurities pass through it. The screen filter, containing screen strainer, which filters physical impurities and allows only clean water to enter into the micro-irrigation system. The screens are usually cylindrical and made of non-corrosive metal or plastic material. Steel wire mesh filter is shown in Fig. 5.3 These are available in a wide variety of types and flow rate capacities with screen sizes ranging from 20 mesh to 200 mesh. The aperture size of the screen opening should be between one seventh and one tenth of the orifice size of emission devices used.

Fig.5.2 Different types of Media filters

(Image source: Report of the task report on Micro-irrigation, Ministry of Agriculture, Dept. of Agriculture & cooperation, Govt. of India, New Delhi, Jan, 2004)

Fig.5.3 Screen filter showing steel wire mesh strainers

c) Centrifugal filters: Centrifugal filters are effective in filtering sand, fine gravel and other high density materials from well or river water. Water is introduced tangentially at the top of a cone and creates a circular motion resulting in a centrifugal force, which throws the heavy suspended particles against the walls. The separated particles are collected in the narrow collecting vessel at the bottom (Fig. 5.4).

Fig.5.4 Hydro cyclone filter **Fig.5.5 Disk filter showing stacks of discs**

(Image source: Report of the task report on Micro-irrigation, Ministry of agriculture, Dept. of Agriculture & cooperation, Govt. of India, New Delhi, Jan, 2004)

d) Disk filters: Disk filter contains stacks of grooved, ring shaped disks that capture debris and are very effective in the filtration of organic material and algae. Fig. 5.5 shows disk filters. During the filtration mode, the disks are pressed together. There is an angle in the alignment of two adjacent disks, resulting in cavities of varying size and partly turbulent flow. The sizes of the groove determine the filtration grade. Disk filters are available in a wide size range (25-400 microns). Back flushing can clean disk filters. However they require back flushing pressure as high as 2 to 3 kg/cm^2.

4. Pressure relief valves, regulators or bye pass arrangement: These valves may be installed at any point where possibility exists for excessively high pressures, either static or surge pressures to occur. A bye pass arrangement is simplest and cost effective means to avoid problems of high pressures instead of using costly pressure relief valves.

5. Check valves or non-return valves: These valves are used to prevent unwanted flow reversal. They are used to prevent damaging back flow from the system to avoid return flow of chemicals and fertilizers from the system into the water source itself to avoid contamination of water source.

Chemical injection equipment

Micro-irrigation's high distribution uniformity gives it great potential for uniformly and efficiently applying agricultural chemicals, a process called chemigation. The main components of a chemigation unit are a chemical solution tank, an injection system and chemigation safety devices.

Chemical Solution Tanks

Chemical solution tanks generally are constructed of poly or fibreglass. A conical form at the tank bottom facilitates flushing it completely so that no material is wasted. Tanks should have an easy-clean screen downstream of the valve to make them easier to clean.

Injection system

The main types of chemical injectors are the venturi injector, injection pump, and the differential tank. The different types of fertilizer / chemical injection system are shown through Fig. 5.6. Criteria for selecting the proper injection system include cost, ease of use/repair, durability and susceptibility to corrosion.

With venturi injectors, water is extracted from the main line, then (1) pressure is added with a centrifugal pump or (2) a pressure differential is created by a valve in the mainline forcing water through the injector at high velocity. The high-velocity water passing through the throat of the venturi creates a vacuum or negative pressure, generating suction to draw chemicals into the injector from the chemical tank. Although the venturi is cheaper than a positive displacement pump, its injection rate is more difficult to control.

With injection pumps, water is pumped into the system using pistons, diaphragms or gears. An injection pump has a small motor powered either by electricity or by energy from the water itself. The motor moves small pumps (diaphragms) or pistons to inject fertilizer into the system. The advantage of injection pumps is that chemicals can be injected with high uniformity at rates easily be adjusted regardless of discharge pressure.

With differential tanks, water is forced through a tank containing the chemical to be injected. As water passes into the tank, fertilizer is injected into the irrigation system. One disadvantage of such a system is that the concentration of the chemical in the tank decreases over time.

5.2 Water Distribution Network

The water distribution network constitutes main line, submains line and laterals with drippers and other accessories (Fig. 5.7).

5.2.1. Mainline

he mainline transports water within the field and distribute to submains. Mainline is made of rigid PVC or High Density Polyethylene (HDPE). Pipelines of 65 mm diameter and above with a pressure rating 4 to 6 kg/cm^2 are used for main line pipes.

5.2.2. Submains

Submains distribute water evenly to a number of lateral lines. For sub main pipes, rigid PVC, HDPE or LDPE (Low Density Polyethylene) of diameter ranging from 32 mm to 75 mm having pressure rating of 2.5 kg/cm^2 are used.

5.2.3. Laterals

Laterals distribute the water uniformly along their length by means of drippers or emitters. These are normally manufactured from LDPE and LLDPE (Fig.5.8). Generally pipes having 10, 12 and 16 mm internal diameter with wall thickness varying from 1 to 3 mm are used as laterals.

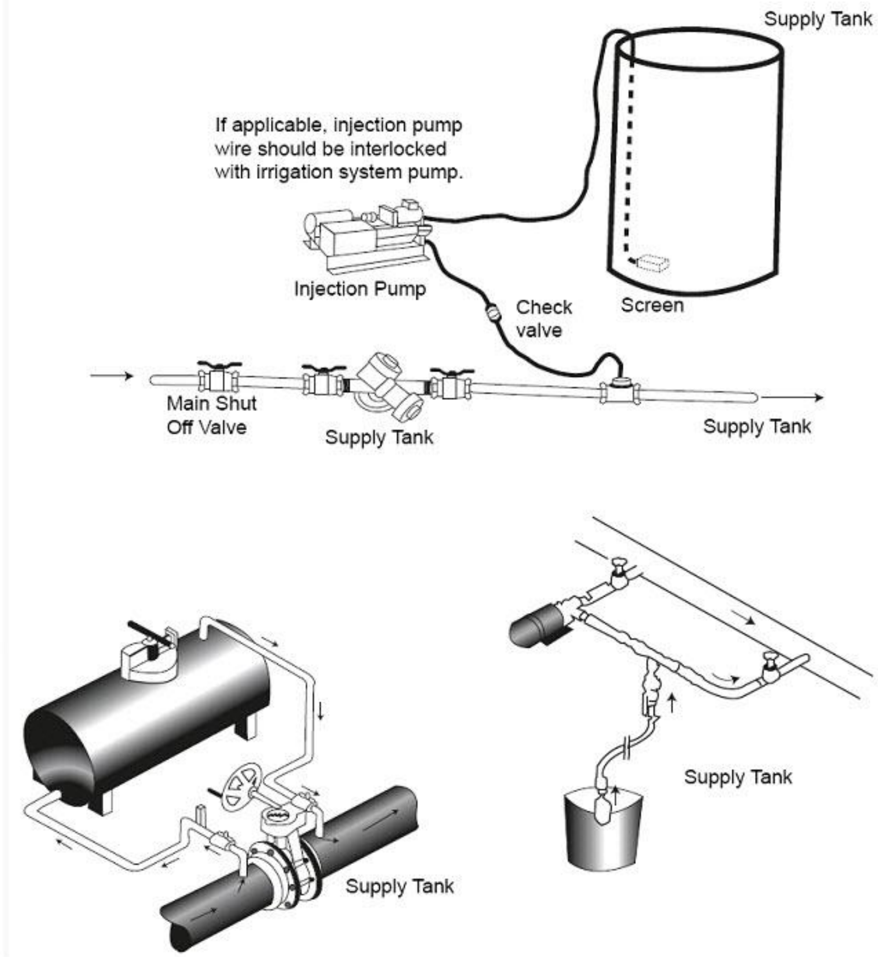


Fig.5.6 Fertilizer injectors

(Source: Enciso, J. and Porter, D. Basics of Micro-irrigation. Texas Cooperative Extension, The Texas A & M University System)

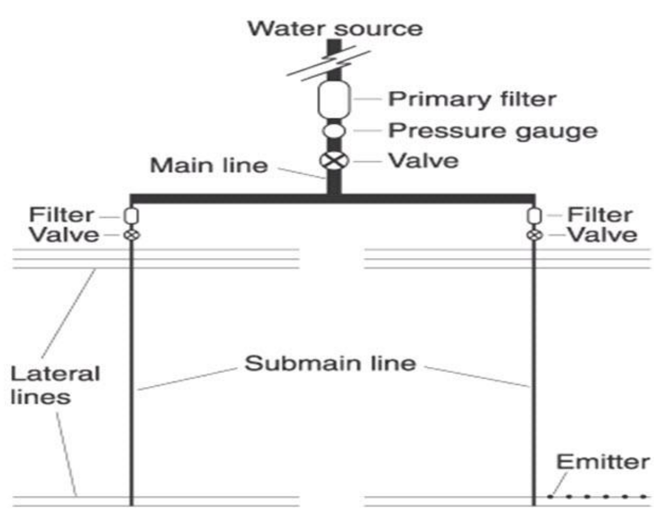


Fig.5.7 Typical water distribution line of a micro-irrigation system

(Source: www.ag.ndsu.edu/pubs/ageng/irrigate/ae1243w.htm 16th Aug, 2012.)

5.3 Emission Devices

The actual application of water in a micro- irrigation system is through an emitter. The emitter is a metering device made from plastic that delivers a small but precise discharge. The quantity of water delivered from these emitters is usually expressed in liters per hour (Lh^{-1}). These emitters dissipate water pressure through the use of long-paths, small orifices or diaphragms. Some emitters are pressure compensating meaning they discharge water at a constant rate over a range of pressures. Emission devices deliver water in three different modes: drip, bubbler and micro-sprinkler. In drip mode, water is applied as droplets or trickles. In bubbler mode, water `bubbles out' from the emitters. Water is sprinkled, sprayed, or misted in the micro-sprinkler mode. Emitters for each of these modes are available in several discharge increments. Some emitters are adapted to apply water to closely spaced crops planted in rows. Other emitters are used to irrigate several plants at once. There are emitters that apply water to a single plant.


Fig.5.8 Laterals pipe


Fig.5.9 Online pressure compensating drippers

Fig.5.10 Online non-pressure compensating drippers

(Image source: Report of the Task Force on Micro-irrigation, Ministry of Agriculture, Dept. of Agriculture & cooperation, Govt. of India, New Delhi, Jan, 2004)

Emitters / Drippers

They function as energy dissipaters, reducing the inlet pressure head (0.5 to 1.5 atmospheres) to zero atmospheres at the outlet. The commonly used drippers are online pressure compensating or online non-pressure compensating, in-line dripper, adjustable discharge type drippers, vortex type drippers and micro tubing of 1 to 4 mm diameter. These are manufactured from Poly- propylene or LLDPE.

A) Online pressure compensating drippers: A pressure compensating type dripper supplies water uniformly on long rows and on uneven slopes. These are manufactured with high quality flexible rubber diaphragm or disc inside the emitter that it changes shape according to operating pressure and delivers uniform discharge (Fig. 5.9). These are most suitable on slopes and difficult topographic terrains.

B) Online non-pressure compensating drippers: In such type of drippers discharge tends to vary with operating pressure. They have simple thread type, labyrinth type, zigzag path, vortex type flow path or have float type arrangement to dissipate energy. However they are cheap and available in affordable price. Different types on line non-pressure compensating types of drippers are shown through Fig. 5.10.

Point source emitters

Point source emitters are typically installed on the outside of the distribution line. Point source emitters dissipate water pressure through a long narrow path and a vortex chamber or a small orifice before discharging into the air (Fig. 5.11). The emitters can take a predetermined water pressure at its inlet and reduce it to almost zero as the water exits. Some can be taken apart and manually cleaned. The typical flow rates range from 2 to 8 Lh^{-1}.

Fig.5.11 Point source emitters

(Image source: http://fvtchort.wikispaces.com/Soils+Group+1)

Line source emitter

Line source emitters are suitable for closely spaced row crops in fields and gardens. Line source emitters are available in two variations:

- Thin wall drip line
- Thick wall drip hose.

A thin walled drip line has internal emitters molded or glued together at set distances within a thin plastic distribution line (Fig. 5.12). The drip line is available in a wide range of diameters, wall thickness, and emitter spacing and flow rates. The emitter spacing is selected to closely fit plant spacing for most row crops. The flow rate is typically expressed in gallons per minute (gpm) along a 100-foot section. Drip lines are either buried below the ground or laid on the surface. Burial of the drip line is preferred to avoid degradation from heat and ultraviolet rays and displacement from strong winds. However, some specialized equipment to install and extract the thin drip distribution line is required.

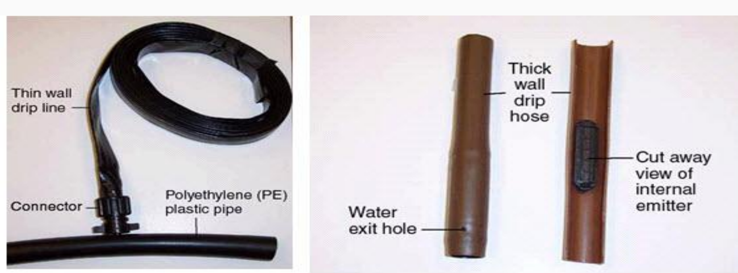


Fig.5.12 Thin wall drip line & Thick wall drip line

(Image source: http://fvtchort.wikispaces.com/Soils+Group+1)

Bubblers

Bubblers typically apply water on a "per plant" basis. Bubblers are very similar to the point source external emitters in shape but differ in performance (Fig. 5.13). Water from the bubbler head either runs down from the emission device or spreads a few inches in an umbrella pattern. The bubbler emitters dissipate water pressure through a variety of diaphragm materials and deflect water through small orifices. Most bubbler emitters are marketed as pressure compensating. The bubblers are equipped with single or multiple port outlets. Most bubbler heads are used in planter boxes, tree wells, or specialized landscape applications where deep localized watering is preferred. The typical flow rate from bubbler emitters varies between 8 and 75 Lh^{-1}.

Micro sprinklers

Micro-sprinklers are emitters commonly known as sprinkler or spray heads (Fig. 5.14). These are of several types. The emitters operate by throwing water through in air, usually in predetermined patterns. Depending on the water throw patterns, the micro-sprinklers are referred to as mini-sprays, micro-sprays, jets, or spinners. The sprinkler heads are external emitters individually connected to the lateral pipe typically using "spaghetti tubing," which is very small (1/8 inch to 1/4 inch) diameter tubing. The sprinkler heads can be mounted on a support stake or connected to the supply pipe. Micro-sprinklers are desirable because fewer sprinkler heads are necessary to cover larger areas. The flow rates of micro-sprinkler emitters vary from 16 lph to 180 lph depending on the orifice size and line pressure

Fig.5.13 Bubblers

(Image source: http://fvtchort.wikispaces.com/Soils+Group+1)

Emission devices selection

The selection of emission devices involves choosing the type of device to be used and then determining the capacity of the device. The type of emission device depends on such factors as the crop to be irrigated, filtration requirements, the need for a cover crop and/or frost protection, cost and grower preference. Micro sprinklers should be strongly considered when a cover crop is needed for erosion, pest or disease control or when frost protection is desired. Line-source emitters are especially well suited for row crops, although closely spaced point-source emitters, bubblers and micro sprinklers can also be used. In situations where filtration requirements are high, bubblers and micro sprinklers may be the most viable alternatives.

Module 2. Drip Irrigation System Design and Installation

Lesson 6. Design Considerations

Prior to designing a drip irrigation system, the following informations are needed to be assessed:

• A scaled plan of the site and area to be irrigated.

• Point-of-connection information, including static pressure and available flow.

• Irrigation water type (potable, non-potable, well, etc.) and characteristics

• Soil type (important for determining drip line emitter and line spacing).

• Proposed planting, including relative water needs of all species, and sizes at planting and maturity.

• Local conditions, including elevation differences, local climate data (ETo), and other site specific information.

6.1 General Considerations

Several important design criteria affect drip irrigation system efficiency. The most important of these are:

- Efficiency of filtration
- Permissible variations of pressure head
- Base operating pressure to be used
- Degree of control of flow or pressure
- Relationship between discharge and pressure at the pump or hydrant supplying water to the system
- Chemical treatment to dissolve or prevent mineral deposits
- Use of secondary safety screening
- Incorporation of flow monitoring

6.2 Wetting Pattern

Drip irrigation systems normally wet only a portion of the horizontal, cross sectional area of soil. The percentage wetted area, P_w compared with the entire cropped area, depends on the volume and rate of discharge at each emission point, spacing of emission points and type of soil being irrigated. The area wetted at each emission point is usually quite small at the soil surface and expands somewhat with depth to form an inverted bulb-shaped cross section. P_w is determined from an estimate of the average area wetted at a depth of 150 to 300 mm beneath the emitters divided by the total cropped area served.

Systems having high P_w provide more stored water. For widely spaced crops, P_w should be held below 67% to keep the strips between rows relatively dry for cultural practices. Low P_w values reduce loss of water due to evaporation even where cover crops are used. Furthermore, it is costly to have a low P_w for more emitters and tubing are required to obtain larger coverage. However, closely spaced crops with rows and emitter laterals spaced less than 1.8m apart, P_w often approaches 100%.

The area wetted by each emitter, A_w, along a horizontal plane about 30 cm below the soil surface depends on the rate and volume of emitter discharge. It also depends on the texture, structure, slope and horizontal layering of the soil. The A_w values are given in the Table 6.1 for various soil textures, depths and degrees of stratification. They are based on daily or alternate irrigation that apply volumes of water sufficient to slightly exceed the crop water use rate.

On sloping land the wetted pattern may be distorted in the down slope direction. On the steep fields this distortion can be extreme; as much as 90% of the pattern may be on the down slope side. Spray emitters wet a larger surface area than the drip emitters. They are often used in the course textured, homogenous soils where wetting a sufficiently large area would require a large number of drip emitters.

Computing percentage wetted area:

For straight single-lateral systems, the percentage wetted area can be computed as

$$P_w = \frac{N_p S_e w}{S_p S_r} \times 100 \qquad --(6.1)$$

Where, P_w = Percentage of soil wetted, %

N_p = Number of emitters per tree

S_p x S_r = Plant spacing & row spacing, m

S_e = Spacing between emitters, m

w = wetted width, m

For spray emitters, the percentage wetted area can be computed as

$$P_w = \frac{N_p\left[A_p + (S_e \times PS)/2\right]}{S_p S_r} \times 100 \qquad --(6.2)$$

Where, P_w = Percentage of soil wetted, %

N_p = Number of emitters per tree

S_p x S_r = Plant spacing & row spacing, m

S_e = Spacing between emitters, m

A_p = Soil surface area directly wetted by the sprayers, m^2

PS =The perimeter of the area directly wetted by the sprayers, m

6.3 Irrigation Water Requirement

The irrigation water requirement for crop production is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. The crop water requirements under drip irrigation may be different from crop requirements under surface and sprinkler irrigation primarily because the land area wetted is reduced resulting in less evaporation from the soil surface. Most methods of estimating crop water requirement presently utilized (Doorenbos and Pruitt, 1977) provide estimates of evapotranspiration which probably contain a significant soil evaporation component.

Table 6.1 Expected maximum diameter of the wetted circle (Aw) formed by a single emission device discharging approximately 4 l/h on various soils.

Sand or root depth and soil texture	Homogeneous (cm)	Varying layers, generally low density (cm)	Varying layers, generally medium density (cm)
Depth 75cm			
Coarse	45	75	110
Medium	90	120	150
Fine	107	150	180
Depth 150cm			
Coarse	75	140	180
Medium	120	215	275
Fine	150	200	245

(Source : James, 1998)

Estimation of evapotranspiration

Weather parameters, crop characteristics, management and environmental aspects affect evaporation and transpiration. The principal weather parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed. Several procedures have been developed to assess the evaporation rate from these parameters. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ETo). The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface. The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions. Crop evapotranspiration under standard conditions (ETc) refers to the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full production under the given climatic conditions.

Factors such as soil salinity, poor land fertility and limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration. Other factors to be considered when assessing ET are ground cover, plant density and the soil water content. Cultivation practices and the type of irrigation method can alter the microclimate, affect the crop characteristics or affect the wetting of the soil and crop surface. A windbreak reduces wind velocities and decreases the ET rate of the field directly beyond the barrier. The effect can be significant especially in windy, warm and dry conditions although evapotranspiration from the trees themselves may offset any reduction in the field.

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith (Allen et al., 1998) method is recommended as the sole method for determining ETo. The method has been selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

The crop evapotranspiration under standard conditions, denoted as ETc, 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.

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application.

Crop coefficient

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate ETc to ETo or ETc = Kc ETo.

The Kc coefficient incorporates crop characteristics and averaged effects of evaporation from the soil. Changes in vegetation and ground cover mean that the crop coefficient Kc varies during the growing period. The trends in Kc during the growing period are represented in the crop coefficient curve. Only three values for Kc are required to describe and construct the crop coefficient curve: those during the initial stage (Kc ini), the mid-season stage (Kc mid) and at the end of the late season stage (Kc end).

The amount of irrigation water requirement was estimated using the crop evapotranspiration (ETc) which was calculated by the FAO Penman–Monteith method (Allen et al., 1998) based on the climatic data. The FAO Penman–Monteith equation is as follows:

$$\mathrm{ETc} = \mathrm{K_c}\,\frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\left(\frac{900}{\mathrm{T_{mean}}} + 273\right)\mathrm{u_2}(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34\mathrm{u_2})} \qquad --(6.3)$$

where ETc is crop evapotranspiration under standard condition (mm day^{-1}), Rn net radiation at the crop surface (MJ m^{-2} day^{-1}), G the soil heat flux density (MJ m^{-2} day^{-1}) which is relatively small and ignored for day period, T_{mean} the mean daily air temperature at 2 m height (°C), u2 the wind speed at 2 m height (m s^{-1}) (es − ea) the vapor pressure deficit (kPa), Δ the slope of vapor pressure curve (kPa °C^{-1}), γ the psychrometric constant (kPa °C^{-1}) and Kc the crop coefficient (varies between 0.45 and 1.05) which is affected by several factors such as crop type, crop height, albedo (reflectance) of the crop-soil surface, aerodynamic properties, leaf and stomata properties and crop stages (Allen et al., 1998).

Net depth per irrigation

Normally, drip irrigation wets only part of the soil area. Therefore, the equations for determining the desirable depth or volume of application per irrigation cycle and the maximum irrigation interval must be adjusted accordingly. The maximum net depth per irrigation, d_x, is the depth of water that will replace the soil moisture deficit when it is equal to MAD. The d_x is computed as a depth over the whole crop area not just the wetted area; however, the percentage area wetted, P_w must be taken into account. Thus for drip irrigation equation can be given as

$$d_x = \frac{MAD}{100}\,\frac{P_w}{100}\,W_a Z \qquad --(6.4)$$

Where

d_x = maximum net depth of water to be applied per irrigation, mm

MAD = Management allowed deficit, %

W_a = available water holding capacity of the soil, mm/m

Z = Plant root depth, m

The net depth to be applied per irrigation, d_n, to meet consumptive use requirements can be computed by

$$d_n = T_d f' \text{ and } \quad f_x = \frac{d_x}{T_d}$$

Where

d_n= net depth of water to be applied per irrigation to meet consumptive use requirements, mm

f′ = irrigation interval or frequency, days

f_x = average daily transpiration during peak-use period, mm

T_d = average daily transpiration during peak-use period, mm

For the design purposes, the T_d for the mature crop should be used for sizing the pipe network. Furthermore, assuming irrigation interval as one day, so that $d_n = T_d$, simplifies design process (Keller and Bliesner, 1990).

Gross irrigation requirements

Gross irrigation depth and volume requirements for drip systems are based on net requirements and efficiencies. The grass depth per irrigation, d, should include sufficient water to allow for unavoidable deep percolation. To minimize avoidable losses, systems should be well designed, accurately scheduled, and carefully maintained. Where $LR_i \leq 0.1$ or the unavoidable deep percolation is greater than the adjusted leaching water required $T_r \geq 0.9/(1.0 - LR_i)$ (Keller and Bliesner, 1990).

$$d = \frac{d_n T_r}{EU/100} \qquad or \qquad d' = \frac{T_d T_r}{EU/100} \qquad --(6.5)$$

Where $LR_i > 0.1$ or $T_r < 0.9/(1.0 - LR_i)$

$$d = \frac{100 d_n}{Eu(1.0 - LR_i)} \qquad or \qquad d' = \frac{100 T_d}{Eu(1.0 - LR_i)} \qquad --(6.6)$$

Where d= gross depth of application per irrigation, mm

d_n= net depth of water to be applied per irrigation to meet consumptive use requirements, mm

d' = maximum gross daily irrigation requirement, mm

T_r = peak use period transmission ratio

T_d = average daily transpiration during peak-use period, mm

Eu = emission uniformity, %

LR_i = leaching requirement under drip irrigation

The gross volume of water required per plant per day, G is a useful design parameter for selecting emitter discharge rates:

$$G = K\, d'\, S_p\, S_r$$

where

G = gross volume of water required per plant or unit length of row per day, L/day

K = Conversion constant, which is 1.0

d′ = maximum gross daily irrigation requirement, mm

S_p = spacing between plants, m

S_r = spacing between row, m

6.4 Capacity of Drip Irrigation System

It is necessary to determine the system capacity and operating time per season to design a pumping plant and pipeline network that are economical and efficient. The capacity of the drip irrigation system, Q_s is the maximum number of emitters operating at any given time multiplied by average emitter discharge, q_a. According to Keller and Bliesner (1990) for uniformly spaced laterals that supply water uniformly spaced emitters

$$Q_s = K \frac{A}{N_s} \frac{q_s}{S_r S_l} \qquad --(6.7)$$

Where,

Qs= Total system capacity, Ls^{-1}

q_a=Average emitter discharge, L/hr

K= Conversion constant, 2.778

S_e = Emitter spacing, m

A= Field area, ha

S_l = Lateral spacing, m

N_s = Number of operating stations

Some systems require extra capacity because of anticipated slow changes in q_a can result from such things as slow clogging due to sedimentation in long path emitters or compression of resilient parts in compensating emitters. Both decrease and increase in q_a necessitates periodic cleaning or replacement of emitters. To prevent the need for frequent cleaning or replenishment of emitters, where decreasing discharge rates are a potential problem, the system should be designed with 10 to 20 % extra capacity.

Lesson 7. Emitter Selection

7.1 Introduction

Emission device selection for drip irrigation systems involves choosing suitable emission device as per the soil and crop need. The type of emission device depends on factors such as the crop to be irrigated, filtration requirements, the need for crop from frost protection, cost and grower preference. Micro sprinklers are considered when a cover crop requires overhead water sprinkling, pest or disease control or for frost protection. Line-source emitters are especially well suited for row crops, although closely spaced point source emitters, bubblers and micro sprinklers can also be used. Bubblers and micro sprinklers will be most viable alternative in situations where water carries large amount of sand and silt filtration requirements are high.

Efficiency of the designed micro-irrigation system depends largely on the emitter selection. The emitters characteristics that affect system efficiency are:

i) Manufacturing characteristics

ii) Hydraulic characteristics and

iii) Operational characteristics.

Further these are elaborated below

- Variations of emitter discharge due to manufacturing tolerances.
- Matching of discharge-pressure relationship as per design specifications.
- Stability of discharge-pressure relationship over a long time.
- Stability of emitter discharge exponent.
- Possible range of suitable operating pressures.
- Loss of pressure on lateral lines caused by the emitters connections.
- Susceptibility to clogging, siltation, accretion of chemical deposits

The choices of discharge, spacing and the emitter itself are major items in system planning. They are dictated partly by physical data, and also by such factors as emitter placements, type of operation, lateral diameter, and user's preference. Selection of emitters requires following four steps:

- Evaluate and choose the general type of emitter that best fits the need of the area to be wetted.

- According to the system's required discharge, spacing, and other planning considerations, choose the specific type of emitter needed.
- Determine the required discharge and pressure head for the average emitter.
- Determine the allowable variation in sub unit pressure head that will give the desired emission uniformity (Eu).

An ideal set of emitters should have the following attributes:

- Durability.
- Low cost.
- Reliable performance with a relatively low rate of discharge that is reasonably uniform among all emitters within the system despite: variances in tolerances inherent in manufacturing, expected differences in pressure head due to friction loss and elevation, and expected changes in temperature of the water.
- Relatively large and self-flushing passageways to reduce or prevent clogging.

7.2 Manufacturing Characteristics

Accurate emitter manufacturing is necessary in order to achieve a high degree of system uniformity. However, the complexity of emitter and their individual components make it difficult to maintain precision during production. Changes in production temperature, mold damage and non-uniform mixing of raw materials are some of the factors affecting emitter homogeneity. Elastomeric materials are used to achieve flushing action and pressure compensation in the manufacturing of pressure compensating emitters. These parts are difficult to manufacture with consistent dimensions. In the manufacturing processes, there will be variations in passage size, shape and final finish. Manufacturing variations exist due to the inability to hold constant pressure and temperature during the processes such as molding and welding and inconsistencies in the materials used. Due to these manufacturing variations, any two emitters of the same type from the same box, tested at the same temperature and pressure can have different flow rates. The flow rate in trickle irrigation emitters is small, therefore any variation in the critical dimensions of the emission devices can cause large variation in relative flow rates. Although the absolute magnitude of the variation might be very small. For these reasons, water application uniformity may be greatly affected by the emitter performance. The manufacturing coefficient of variation (C_{Vm}) is defined as the statistical coefficient of variation (standard deviation divided by the mean discharge rate) in emitter discharge rates when new emitters of the same type are operated at identical pressures and water temperatures. Under these identical operating conditions, differences in flow rates observed are assumed to be due to variations in emitter components. Manufacturing variation reduces uniformity of water application; therefore choose emitters with low values of C_{vm}. When comparing emitters with similar flow properties, the highest uniformity will be obtained by selecting the emitter with the smallest manufacturing variation.

7.3 Hydraulic Characteristics

Drip emitters regulate water flow by dissipating the energy of the flow through frictional resistance. Laminar flow emitters regulate water flow by dissipating the energy via friction against the walls of the water passage. They utilize long and narrow flow paths, narrower or longer the passage the more the frictional resistance to the flow. Microtubes and spiral path emitters are examples of laminar flow emission devices. Turbulent flow emitters regulate water flow by dissipating energy in friction against the walls of the water passage and also between the particles themselves during their turbulent movements. Orifice, nozzle emitters, tortuous path emitters and jets or sprayers are typically fully turbulent emitters. The drip tapes that utilize orifices are also turbulent flow devices.

7.4 Operational Characteristics

Emitter must be resistant to extreme conditions in the environment and must maintain physical characteristics over their lifetime in order to have consistent flow rates. Coefficient of manufacturing variation (CV), Emission Uniformity (EU) and emitter flow variation (q_{var}) are three indexes to determine irrigation uniformity.

7.5 Emitter Spacing, Capacity and Emission Uniformity

Emitter flow theory

Hydraulically, most emitters can be classified as long-path emitters, orifice emitters, vortex emitters, pressure compensating emitters and porous pipe emitters. The hydraulic characteristics of each emitter is directly related to the mode of fluid motion inside the emitter, which is characterized by Reynolds number (R_e).

$$R_e = \frac{Vd}{v} \tag{7.1}$$

Where V is the emitter flow velocity (m s^{-1}), d is the emitter diameter (m), is the kinematic viscosity ($m^2 s^{-1}$). These flow regimes are characterized as (1) laminar, $R_e < 2000$; (2) unstable, $2000 \le R_e \le 4000$; (3) partially turbulent, $4000 \le R_e \le 10{,}000$; and (4) fully turbulent, $10{,}000 \le R_e$.

Emitter spacing

Emitter spacing is a system design characteristic and should be selected taking into account the soil water properties of the site, the specific rooting system of the crop and the climatic characteristics as it affects the extent to which the crop depends on irrigation. For the same application length of time and the same volume of water narrow spacing between drippers on the lateral, renders a narrower and deeper wetting pattern. The width wetted by the drippers increases until adjacent wetted volumes overlap. After the occurrence of overlapping, the majority of the water flow is directed downwards. In case of wide spacing between drippers, it renders a wider and shallower wetting pattern.

Clay soils absorb water slowly and runoff can occur if water is applied too quickly. Clay soils will hold water very well and can stay wet for several days. Drip emitters of 2 L h^{-1} are selected when planting is done in clay soils and spacing tends to be further apart. Sandy soils absorb water very quickly and runoff usually doesn't occur. Sandy soils do not hold water very well and can dry out very quickly. Drip emitters of 4 to 8 L h^{-1} discharge are chosen for planting in sandy soils. The emitter spacing tends to be closer together. Loam soils are an ideal in-between mix of clay and sandy soils. Its absorption rate is greater than that of clay soil but not as fast as sandy soil. When wet, water will move outward and down more evenly. Loam soils will hold water well and dry out at a medium rate. Drip emitters of 2 to 4 L h^{-1} are selected for planting in loamy soils.

Crops and Planting Geometry

Wide spacing crops: Mango, Citrus, Litchi, Sapota are wide spacing fruits. One or more than one drip emitters of higher discharge ranging from 4 to 8 Lph are used to apply water to meet crop water requirement.

Close spacing crops: Spinach, Coriander, Methi etc. are close growing crops. Micro sprinklers are suitable to irrigate such crops

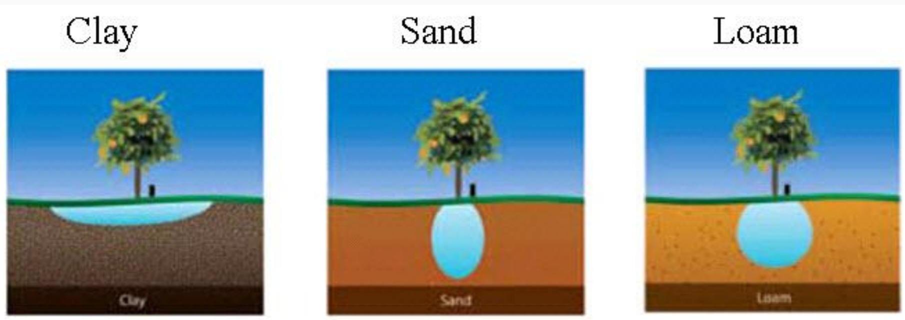


Fig 7.1. Wetting pattern in different soil

(Source:www.irrigationdirect.com)

Table 7.1. Typical spacing of emitters of 2 & 4 L h^{-1} discharge for different soil texture

Emitter Capacity	Type of soil	Typical Spacing (cm)
4 L h^{-1}	Coarse (sand) soil	60
	Medium soil	100
	Fine (clay) soil	130
2 L h^{-1}	Coarse (sand) soil	30
	Medium soil	60
	Fine (clay) soil	100

(Source: www.irrigationtutorial.com/drip)

Emitter Capacity

The capacity of drip irrigation emission device may be computed by using equation

$$Q = \frac{A \times d}{H \times E_a} \qquad (7.2)$$

where

Q = emission device capacity, L h^{-1}

d = depth of water application, mm

A = area irrigated by the emission device, m^2

H = irrigation time, h

E_a = application efficiency

Area Wetted by Emitter

The area wetted by an emission device (A) is computed by following equation

$$A = \frac{L\, S\, W_p}{100\, N_e} \qquad (7.3)$$

where, A = area irrigated, m^2

L = spacing between adjacent plant rows, m

S = spacing between emission points, m

W_p = per cent of cropped area being irrigated;

N_e = number of emission devices at each emission point

The value of W_p varies with crop and growth stage. W_p for wide spacing crops vary between 40 to 60 % and for close spacing crops it varies from 70 to 90 %.

Number of emission devices

The number emission devices needed for the desired wetting pattern requires information describing the horizontal and vertical movement of water through soil. For single laterals with equally spaced emission points, the following equation estimates the number of emission devices per plant, N_e

$$N_e = \frac{100\, W_p\, S\, L}{D_w\, S_e} \qquad (7.4)$$

$$S_e \leq 0.8\, D_w$$

Where,

D_w = maximum diameter of wetted circle formed by a single point source emission device, cm

S_e = spacing between the emission devices of an emission point, cm

W_P = percent of S times L irrigated

L = spacing between adjacent plant rows (m)

S = spacing between emission points, m

In drip systems with double laterals or Zigzag, pigtail, or multi exit layouts, the N_e is computed with following equation.

$$N_e = \frac{2\times100\, W_p\, S\, L}{S_e\,(S_e+D_w)} \qquad (7.5)$$

$$N_e = \frac{W_p\, S\, L}{100\left(A_S+\frac{D_W P_S}{2\times100}\right)} \qquad (7.6)$$

$$S_e = D_T + \frac{D_w}{2\times100} \qquad (7.7)$$

where A_S = area wetted by a single micro sprinkler, m^2

P_S = perimeter of area wetted by micro sprinkler, m

D_T = distance of throw, m

Emission uniformity

Several methods have been proposed for assessing the uniformity of water application in irrigation systems. The term emission uniformity has generally been used to describe the uniformity of emitter flow for a drip irrigation unit or subunit. Emission uniformity can be function of: (1) hydraulic variation caused by elevation changes and friction losses along distribution lines and (2) emitter discharge variation at a given operating pressure caused by manufacturing variability, clogging, water temperature changes and aging. Keller and Karmeli (1975) were the first to define an emission uniformity percentage EU for the drip irrigation system as

$$E_u = 100\left[1-1.27(C_{vm})N_e^{-\frac{1}{2}}\right]\left(\frac{q_n}{\bar{q}}\right) \qquad (7.8)$$

Where C_{vm} is manufacturer's coefficient of variation for point source or line source emitters, Ne is the number of point source emitters per emission point (spacing between plants divided by the unit length of lateral line used to calculate or 1, whichever is greater, for line source emitter); is the minimum emitter discharge rate in the system (Lh^{-1}), is the mean emitter discharge rate (Lh^{-1}). The emission uniformity increases as more emitters are added to each plant. Nakayama et al. (1979) developed a Coefficient of design uniformity C_{ud} based on statistical analysis

$$C_{ud} = 100\left[1 - 0.789(C_{vm})N_e^{-\frac{1}{2}}\right] \quad (7.9)$$

Admittedly, similarities exist between Eqs. (7.8) and (7.9) since both stress the importance of manufacturing variability and the number of emitters per plant. However, the original derivation of EU was based on the ratio of the discharge rate for the lowest 25% of emitters to the average discharge rate, whereas C_{ud} is based on the discharge rate deviations from the average rate.

Sensitivity to Clogging

The filtration of water used for irrigation is required as drip system operates for the low discharge rates, average diameter of openings for emitter range from 0.0025 to 0.25 mm. These small passageways make all emitters susceptible to clogging. Filtering to remove particles 10 or more times smaller than the emitter passageway is a typical recommendation. Self flushing type emitters require less filtration. Long path emitters, which have the largest passageways for a given flow rate, may still require filtering of even the smaller particles to prevent clogging.

7.6 Pressure Head-Discharge Relationship of Emitter

The relationship between in pressure head and discharge is an important characteristic of emitters. The pressure compensating emitters have a low value of the exponent. However, since they have some physical part that responds to pressure their long range performance requires careful consideration. The compensating emitters usually have a high coefficient of manufacturing variation (C_{vm}), and their performance may be affected by temperature, material fatigue or both. On undulating terrain, the design of a highly uniform system is usually constrained by the pressure sensitivity of the average emitter. Compensating emitters provide the solution. Emitters of various sizes may be placed along the lateral to meet pressure variations resulting from changes in elevation. In laminar flow emitters which include the long path, low discharge devices the relationship between the discharge and the operating pressure is linear, i.e., doubling the pressure doubles the discharge. Therefore the variations in operating pressure head within the system are often kept to within ± 5 percent of the desired average. In a turbulent flow emitter the change in discharge varies with the square root of the pressure head, i.e., $x = 0.5$, and the pressure is to be increased four times to double the flow. Therefore, the pressure head in drip irrigation system with turbulent flow emitter is often allowed to vary by ± 10% of the average pressure (US Soil Cons. Service, 1984).

The pressure discharge relationship for emitter is given by

$$Q = C_d H^x \tag{7.10}$$

Where,

Q = flow rate, H = operating pressure head, C_d = coefficient of discharge, x = exponent.

Depending upon the experimental values of x, flow regimes can be obtained. Based on the flow regime and exponent x the emitters can be classified (Table 7.2).

Variety of emitters are commercially available, it is convenient to determine discharge directly from manufacturers curves. Some of these curves are available in standard text books and monographs from which C_d and x are computed using equation 7.10. Emitters made from thermoplastic material may vary in discharge depending on the temperature. Therefore, discharge curve should be corrected for temperature. The pressure in the emission device is controlled by various means such as providing i) small openings, ii) long passage ways, iii) vortex chambers, iv) changing the length or cross section of passageways or size of orifice. They are designed to deliver constant discharge for smaller change in pressure. Porous pipe or bi-wall tubing makes very fine jet to apply water and these are buried below the ground surface.

Table 7.2. Emission device classification

Flow Regime	x - Value	Emitter Type
Variable flow path	0.0 0.1 0.2 0.3	Pressure compensating
Vortex flow	0.4	Vortex
Fully turbulent flow	0.5	Orifice tortuous
Mostly turbulent flow	0.6 0.7 0.8	Long or spiral path
Mostly laminar flow	0.9	Micro tube
Fully laminar flow	1.0	Capillary

(Source: www. agridrip.com/page/437645582)

When laterals are laid above the soil surface, the ambient temperature affects the dripper flow rate. As the water temperature increases, water viscosity decreases and the flow rate of the emitter rises. Lateral heating is more pronounced at the distal ends due to the lower flow velocity. As a result, emitters at the end of the lateral may have higher flow rate than emitters at the beginning of the lateral, where as in normal conditions, it is opposite, the flow rate decreases along the lateral due to friction head losses.

Example 7.1 Determine the emission uniformity of a drip system section that uses drip emitter with coefficient of discharge (C_d) = 0.3, exponent (x) = 0.6 and coefficient of variation (C_{vm}) = 0.06. Two emitters are used for each plant. The average pressure is 100 kPa and minimum pressure is 95 kPa .

Solution:

Given C_d = 0.3, x=0.6

H_1 = 95 kPa, H_2 = 100 kPa,

C_{vm}= 0.06, Ne = 2

Equation 7.10, the dicharge Q_1 at 95 kPa pressure

$${{\rm{Q}}_1}{\rm{}}={\rm{}}{{\rm{C}}_{\rm{d}}}{{\rm{H}}^{\rm{x}}}$$

$$= 0.3 \times (95)^{0.6}$$

$$= 4.61\ Lh^{-1}$$

For 100 kPa pressure, the discharge

$${{\rm{Q}}_2} = {C_d}{H^x}$$

$$= 0.3 \times (100)^{0.6}$$

$$= 4.75\ Lh^{-1}$$

$${E_u} = 100\left[{1 - \frac{{1.27\left({0.06} \right)}}{{\sqrt 2 }}} \right]\frac{{4.61}}{{4.75}}$$

$$=100[0.946]*0.97$$

$$= 91.7\ \%$$

Emission uniformity of the drip system given in the Example 7.1 is in the recommended range. If value of EU is lower than the recommended value the EU could be improved by reducing the difference between Q_1 and Q_2 (by using larger diameter and/or shorter laterals or by using pressure compensating emitters) or by using an emitter with a lower C_{vm}.

Emission uniformity of the drip system given in the Example 7.1 is in the recommended range. If value of EU is lower than the recommended value the EU could be improved by reducing the difference between Q_1 and Q_2 (by using larger diameter and/or shorter laterals or by using pressure compensating emitters) or by using an emitter with a lower C_{vm}.

Lesson 8. Hydraulics of Drip Irrigation System

system are made of plastics and comprise of the main line, sub-mains and laterals. Drip irrigation system design must ensure nearly uniform discharge of the drippers in each section that is controlled by a valve and irrigated as unit of the system. The maximum pressure difference allowable in a system is 20% and the maximum difference in pressure between the head end and the tail end of a lateral should not exceed 10%. The relationship between pressure and discharge for different types of emission devices can be obtained from the manufacturers catalogues. The pressure loss can be estimated from monographs tables or using the relationships expressed in the form of equations. Head loss occurs due to friction between the pipe walls and water as it flows through the system. Obstacles- turns, bends, expansions, contractions of pipes, etc., along the way to flow increase head losses.

The head loss due to friction is a function of the following variables:

1. Pipe length
2. Pipe diameter
3. Pipe wall smoothness
4. Water flow rate
5. Liquid viscosity

8.1 Pressure Variation in Irrigation Pipe Line

The major requirement in most situations is that the irrigation system must apply water uniformly over the entire field. The performance of the drip system is related to operating pressure. The uniform water application from a drip emitter requires required desired optimum pressure. Friction loss in pipes and fittings, and differences in elevation cause pressure to vary in a field. Friction loss causes the pressure to decrease in the downstream direction, while changes in elevation can cause either an increase or decrease in pressure due to pipe running on uphill or downhill. The difference in pressure between locations along pipe line can be estimated as

$$P_d = P_u - 9.81(h_l \pm \Delta Z) \qquad (8.1)$$

Where

P_d & P_u= pressure at down and upstream positions, respectively, kPa

h_l = energy loss in pipe between the up- and downstream positions, m

ΔZ = elevation difference, m (+ve for uphill & -ve for downhill

The energy loss (h_l) includes head loss due to friction and minor loss, which can be estimated as.

The energy loss (h_l) includes head loss due to friction and minor loss, which can be estimated as.

$$h_l = FH_f + M_l \qquad (8.2)$$

where

F =constant; f (number of outlets and method used to estimate, H_f)

H_f = friction loss in pipe between up and downstream locations, m

M_l = minor losses through fittings, m

Major and minor losses are two types of losses that occur in pipe flow.

a) Major losses

Major losses occur while water flow along straight pipes. The universal equation used to calculate friction losses of water flow along a pipe is known as the Hazen-Williams equation, given by

$$H_f(100) = K\left(\frac{Q}{C}\right)^{1.852} \times D^{-4.871} \times F \qquad (8.3)$$

As the length of the pipe increases, the discharge in the pipe decreases due to emission outlets and hence the total energy drop is less than as estimated by the above equation 8.3. For this reason, a reduction factor F is introduced

where,

H_f (100)= head loss due to friction per 100 meter of pipe length, m/100m

K = a constant which is 1.22×10^{12} in metric units

D = inner pipe diameter, mm

C = friction coefficient (indicates inner pipe wall smoothness, the higher the C coefficient, the lower the head loss)

Q = flow rate, L s^{-1}

The Hazen-Williams equation is valid in a limited range of temperature and flow pattern. In small diameter laterals, the Darcy-Weisbach equation gives better results in calculating head loss due to friction in small diameter lateral pipes. It is given by

$$H_f = f\left(\frac{LV^2}{2Dg}\right) \qquad (8.4)$$

where

H_f = head loss, m   L = pipe length, m

f = Darcy-Weisbach friction factor   V = Flow velocity, m s^{-1}

g = gravitation acceleration (9.81, m s^{-2})   D = inner pipe diameter, m

Both the Hazen-Williams and Darcy-Weisbach equations include a parameter for the smoothness of the internal surface of the pipe wall. In Hazen-Williams, it is the dimensionless C coefficient and with Darcy-Weisbach the roughness factor f, as the C coefficient is higher, head loss will be lower. On the opposite, in the Darcy-Weisbach equation, higher values of indicate higher head losses.

b) Minor losses

The minor losses through fittings can be estimated or obtained from standard tables available in text books and hydraulics manuals/ hand books. Minor losses are created by the flow at bends and transitions. If the flow velocities are high through many bends and transitions in the system, minor losses can build up and become substantial losses. Minor head losses are expressed as an equivalent length factor that adds a virtual length of straight pipe of the accessory diameter to the length of the pipe under calculation.

The Darcy-Weisbach, Hazen Williams or Scobey equation can be used to compute head loss due to friction, H_f. The general form of these equations can be written as

$$H_f = \frac{(K)(c)(L)(Q^m)}{D^{2m+n}} \qquad (8.5)$$

where

K = friction factor that depends on pipe material

L = length of pipe, m

Q = flow rate,L min^{-1}

D = diameter of pipe, mm

c, m, n = constants can be obtained from Table 8.1.

Table 8.1 Constants of friction loss equations

Equations for computing H_f	c	m	n
Darcy-Weisbach	277778	2.00	1.00
Hazen-Williams	591722	1.85	1.17
Scobey	610042	1.90	1.10

(Source: James, 1988)

For the Darcy-Weisbach equation, K is given by the equation

$$K = 0.811\left(\frac{f}{g}\right) \quad (8.6a)$$

where

f = friction factor can be obtained from the Moody diagram

g = acceleration due to gravity (9.81 m s^{-2})

K for Hazen-William equation is computed by

$$K = (0.285\ C)^{-1.852} \quad (8.6b)$$

C = Friction coefficient depends on pipe material and diameter.

K for Scobey equation is given by

$$K = \frac{K_S}{348} \quad (8.6c)$$

where Ks = friction factor values depends on pipe diameter and pipe material.

There will be less friction loss along a pipe with several equally spaced discharging outlets such as submains and laterals than along a pipe of equal diameter, length, and material with constant discharge (constant discharge means that inflow to the pipe section equals the outflow from the section). This occurs because the quantity of water in the submain or lateral diminishes in the downstream direction because of outlet discharge (i.e. drippers or sprinklers attached with laterals).

The term F in equation (8.2) equals 1 when there are no outlets between the up and downstream locations along a pipe (i.e. discharge along the pipe is constant). Equations 8.7 and 8.8 can be used to estimate F when there is more than one equally spaced outlet. Equation 8.7 is used when the distance from the pipe line to the first outlet is equal to the outlet spacing.

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2} \qquad (8.7)$$

Equation 8.8 is used when the distance to first outlet is half of the outlet spacing.

$$F = \frac{1}{(2N-1)} + \frac{2}{(2N-1)N^m}\sum_{i=1}^{N-1}(N-1)^m \qquad (8.8)$$

where

m = Exponent, m (can be obtained from Table 8.1) depending on type of equation involved in estimating H_f.

N = Number of emitters

When the discharge varies widely from outlet to outlet, the Equation (8.1) is applied between successive outlets working from the known pressure to unknown pressure.

8.2 Design of lateral, sub main and main pipes

8.2.1 Lateral pipe Design

Drip irrigation lateral lines are the hydraulic link between the supply lines (main or submain lines) and the emitters. The emission devices can be connected directly to the lateral line (online or inline), mounted on a riser (micro sprinkler, jet) from a buried lateral or attached to the lateral on a tree loop. The lateral line will have hydraulic fittings (tees, unions, etc.,) to connect to the submain or main line. Lateral lines are usually made of LLDPE tubing ranging in diameter 12 mm to 16 mm. Laterals with only one diameter tubing are normally recommended to simplify installation and maintenance and provide better flushing characteristics. The procedures include, determining such lateral characteristics as: flow rate and inlet pressure; locating spacing of manifolds, which in effect sets the lateral lengths; and estimating the differences in pressure within the laterals.

In lateral line design a first consideration is acceptable uniformity of emitter flow or emitter flow variation. If the manufacturers variation is not considered, or assumed to be small, the design can be made to achieve a completely uniform emitter flow by using different emitter sizes or micro tube length (Kenworthy, 1972). In general practice the emitter characteristics are usually fixed and the emitter flow rate is determined by pressure at the emitter in the line.

On fields where the average slope in the direction of the laterals is less than 3%, it is usually most economical to connect laterals to both sides of each manifolds. The manifold should be positioned so that starting from a common manifold connection, the minimum pressures along the pair of laterals are equal. Spacing of manifolds is a compromise between field geometry and lateral hydraulics.

Because of the possibility of laminar, turbulent or fully turbulent flow in drip laterals the Darcy-Weisbach equation should be used to compute head loss due to pipe friction. The

Darcy-Weisbach friction factor, f, for small-diameter drip tubing is related to the Reynolds number, R_e the Reynolds number (R_e) is computed with the following equation.

$$R_e = \left(\frac{(\rho)(D)(V)}{(K)(\mu)}\right) \tag{8.9}$$

Where,

R_e= Reynolds number (dimensionless); D = diameter of pipe, cm;

ρ = density of water, g cm^{-3}; V = average velocity, cm s^{-1};

μ = viscosity of the fluid, N s m^{-2}; K = unit constant, 10 with these units

The equation used to compute friction factor (f) depends on the magnitude of N_R. For R_e less than 2000 (laminar flow), the friction factor

$$f = \frac{64}{R_e} \tag{8.10a}$$

For R_e between 2000 and 10,0000 (turbulent flow)

$$f = 0.32 {R_e}^{-0.25} \tag{8.10b}$$

For R_e greater than 10,0000 (fully turbulent flow)

$$f = 0.80 + 2.0 \log\left(\frac{R_e}{\sqrt{f}}\right) \tag{8.10c}$$

The Hazen-Williams equation with C =150 can also be used to estimate head loss due to pipe friction R_e> 1,00,000.

8.2.2 Submain Design

The submain line hydraulics are similar to that of lateral hydraulics. The submain line is designed to allow approximately the same energy loss as compared to the lateral line for several laterals and submain line. Keller and Karmeli (1975) recommended that the lateral energy loss should be 55 percent and the submain energy loss should be 45 percent of the total allowable energy loss.

The submain design depends on the location of flow or pressure regulation. Energy loss in the submain is directly related to the length of the submain line. The energy loss cannot exceed the allowable limits without lowering uniformity. On particularly steep slopes, each lateral may require individual pressure or flow regulation. In this case the length and diameter of the submain line are determined solely by balancing the energy cost and pipe cost. Since each lateral in this case is regulated, uniformity is independent of submain energy loss provided that submain losses do not interfere with the flow regulation.

The position of the inlet to the submain line depends on the field slope. Usually laterals are placed on contours, if possible with submains running with the prevailing field slope. With sloping submain lines, the inlet is positioned so that the uphill run is shorter than the downhill run. On gently sloping land or level areas the submain inlet should be located near the centre of the submain lines. Submain and main lines should be provided with either manual or automatic flushing valves. Each lateral connection at the submain should have a secondary filter screen to prevent entry of foreign material to the lateral and clogging the emitters.

The submain hydraulics characteristics can be computed by assuming the laterals are analogous to emitters on lateral lines. The hydraulic characteristics of submain and main line pipe are usually taken as hydraulically smooth since PVC pipe are normally used. The Hazen-Williams roughness coefficient (C) usually varies between 140 and 150. The energy loss in the submain can be computed with methods similar to those used for the lateral computations. The energy loss at the lateral connection will depend on the type of connection used, i.e., tee, elbow, bends etc. The total submain energy loss should include energy loss through filters, pressure valves, and other minor losses.

8.2.3 Mainline Design

Normally, flow or pressure control or adjustment values are provided at the submain inlet. Therefore, energy losses in the mainline should not affect system uniformity. The mainline pipe size is based on economic comparisons of power costs and pipe costs. The mainline pipe size should be selected to minimize the sum of power costs and capital costs over the life time of the pipeline.

Example 8.1 Design a drip irrigation system for a citrus orchard of 1 ha area with length and breadth of 100 m each. Citrus has been planted at a spacing of 5 m ´ 5.5 m. The maximum pan evaporation during summer is 8 mm day^{-1}. The other relevant data are given below:

Land slope = 0.40 % upward from S – N direction

Water source = A well located at the S–W corner of the field

Soil texture = Sandy loam

Clay content = 18.4 %

Silt = 22.6 %

Sand = 59.0 %

Field capacity = 14.9 %

Wilting point = 8 %

Bulk density = 1.44 gcc^{-1}

Effective root zone depth = 120 cm

Wetting fraction = 0.4

Pan coefficient = 0.7

Crop coefficient = 0.8

Solution:

Solution of this Example is taken from Tiwari (2007).

Step I

Estimation of water requirement

Evapotranspiration of the crop = Evaporation from open pan *Pan coefficient Crop coefficient* Crop coefficient

= 8 * 0.7 * 0.8

= 4.48 mm day^{-1}

Volume of water to be applied = Area covered by each plant * Wetting fraction *Crop evapotranspiration

= (5 * 5.5) * 0.40 * 4.48

= 49.28 L/day ~ 50 L/day

Step II

Emitter selection and irrigation time

Emitters are selected based on the soil texture and crop root zone system. Assuming three emitters of 4 L h^{-1}, placed on each plant root zone in a triangular pattern. These are sufficient to wet the effective root zone of the crop.

Total discharge delivered in one hour = 4 * 3 = 12 L h^{-1}

Irrigation time = 50 / 12 = 4 h 10 minutes

Step III

Discharge through each lateral

A well is located at one corner of the field. Submains will be laid from the center of field (Fig. 8.1). Therefore, the length of main, sub mains, and lateral will be 50 m, 97.25 m and 47.5 m each, respectively. The laterals will extend on both the sides of the submain. Each lateral will supply water to 10 citrus plants.

Total number of laterals = (100/5.5) * 2 = 36.36 (Considering 36)

Discharge carried by each lateral, $Q_{lateral}$ = 10 * 3 * 4 = 120 L h^{-1}

Total discharge carried by 36 laterals = 120 * 36 = 4320 L h^{-1}

Each plant is provided with three emitters, therefore total number of emitters will be 36 * 10 * 3 =1080

Step IV

Size of lateral

Once the discharge carried by each lateral is known, then size of the lateral can be determined by using the Hazen- Williams equation.

The reduction factor (F) can be estimated by Equation 8.7

$$F=\frac{1}{1.852 + 1}+\frac{1}{2 \times 30}+\frac{\sqrt{1.852-1}}{6(30)^2}$$

$$= 0.367$$

The head loss due to friction in lateral pipe can be estimated using equation 8.3,

$$H_f(100) = 1.22 \times 10^{12} \frac{(0.033/130)^{1.852}}{(12)^{4.871}} \times 0.367 = 0.54 \text{ m}$$

H_f = 0.54 * (47.5/100) = 0.26 m

For D = 16 mm, H_f = 0.063 m

The permissible head loss due to friction is 10% of head of 10 m (head required to operate emitters of 4 L h^{-1}discharge), which is 1 m. therefore lateral of 12 mm size is adequate and can be chosen.

Step V

Determination of number of manifolds

Assuming the pump discharge = 2.5 L s^{-1} = 9000 L h^{-1}

Discharge carried by each lateral = 120 L h^{-1}

Number of laterals that can be operated by each manifold = 9000/120 = 75

Therefore, one manifold or sub mains can supply water to all the laterals at a time.

Step VI

Size of sub main

Total discharge through the sub mains = $Q_{lateral}$*Number of laterals

= 120 * 36

= 4320 L h^{-1} = 1.2 L s^{-1}

Assuming the diameter of the sub mains as 50 mm. The values of parameter of the Hazen-Williams equation are

C = 150

Q = 1.2 L s^{-1}

D = 50 mm

K = 1.22 * 10^{12}

$\rm{F}$ = 0.364

$$H_f\,(100) = 1.22 \times 10^{12} \times \frac{(1.2/150)^{1.852}}{50^{4.871}} \times 0.364$$

= 0.31 m

H_f for 97.25 m of pipe length = 0.31 * (97.25/100)

= 0.30 m

Therefore, frictional head loss in the sub mains = 0.30 m

Pressure head required at the inlet of the sub mains = H_{emitter} + $H_{f\text{ lateral}}$ + $H_{f\text{ sub main}}$ + H_{slope}

= 10 + 0.26 + 0.30 + 0.40

= 10.96 m

Pressure head variation = $\dfrac{10.96 - 10.26}{10.96} \times 100$

= 6.38 %

Estimated head loss due to friction in the sub main is much less than the recommended 20% variation, hence reducing the pipe size from 50 to 35 mm will probably be a good option.

$$H_f(100) = 1.22 \times 10^{12} \times \frac{(1.2/150)^{1.852}}{35^{4.871}} \times 0.364$$

= 1.75 m

H_f for 97.25 m pipe = 1.75* (97.25/100)

= 1.70 m

Pressure head required at the inlet of the sub main = $H_{emitter} + H_{f\ lateral} + H_{f\ sub\ main} + H_{slope}$

= 10 + 0.26 + 1.70 + 0.40

= 12.36 m

Pressure head variation = $\frac{12.36 - 10.26}{12.36} \times 100$

= 17%

Pressure head variation lies within the acceptable limit, hence submain pipe of 35 mm is accepted for deisgn.

Step VII

Size of the main line

Assuming the diameter of main as 50 mm

Discharge of main, Q_{main} = Discharge of sub main, $Q_{sub\ main}$

The values of parameter of the Hazen- Williams equation are

C= 150

Q= 1.2 L s^{-1}

D= 50 mm

K= 1.22 ´ 10^{12}

H_f(100) = $1.22 \times 10^{12} \frac{(1.2/150)^{1.852}}{(50)^{4.871}}$

= 0.84 m

$H_f$for 50 m main pipe = 0.84 ´ (50/100) = 0.42 m

Step VIII

Determining the horse power of pump

Assuming static head as 10 m, head variation due to uneven field and the losses due to pump fittings, etc. is taken as 10 % of all other losses.

H_{local} = 10 % of all other loss

Total dynamic head = $(H_{emitter} + H_{f\ lateral} + H_{f\ sub\ main} + H_{slope})+H_{f\ main}+H_{static}+H_{local}$

= 12.36 + 0.42 +10 +1.28

= 24.06 m

Pump Horse power(hp)=$\frac{{H\times Q}}{{75\times{\eta _p}}}$

where,

H= Total dynamic head, m

Q= Total discharge through main line, L s^{-1}

${\eta _p}$= Efficiency of pump

hp=$\frac{{1.2\ \times\ 24.06}}{{75\times 0.60}}$ = 0.64 = 1.0

Hence 1 hp pump is adequate for operating the drip irrigation system to irrigate for 1 ha area of citrus crop.

The design details of components micro irrigation system are estimated as

Length of each lateral= 47.5 m; Total number of laterals = 36;

Diameter of lateral = 12 mm; Length of sub main = 97.25 m;

Number of sub main = 1; Diameter of sub main = 35 mm;

Length of main = 50 m; Number of main = 1;

Diameter of main = 50 mm, Pump horse power required = 1 hp.

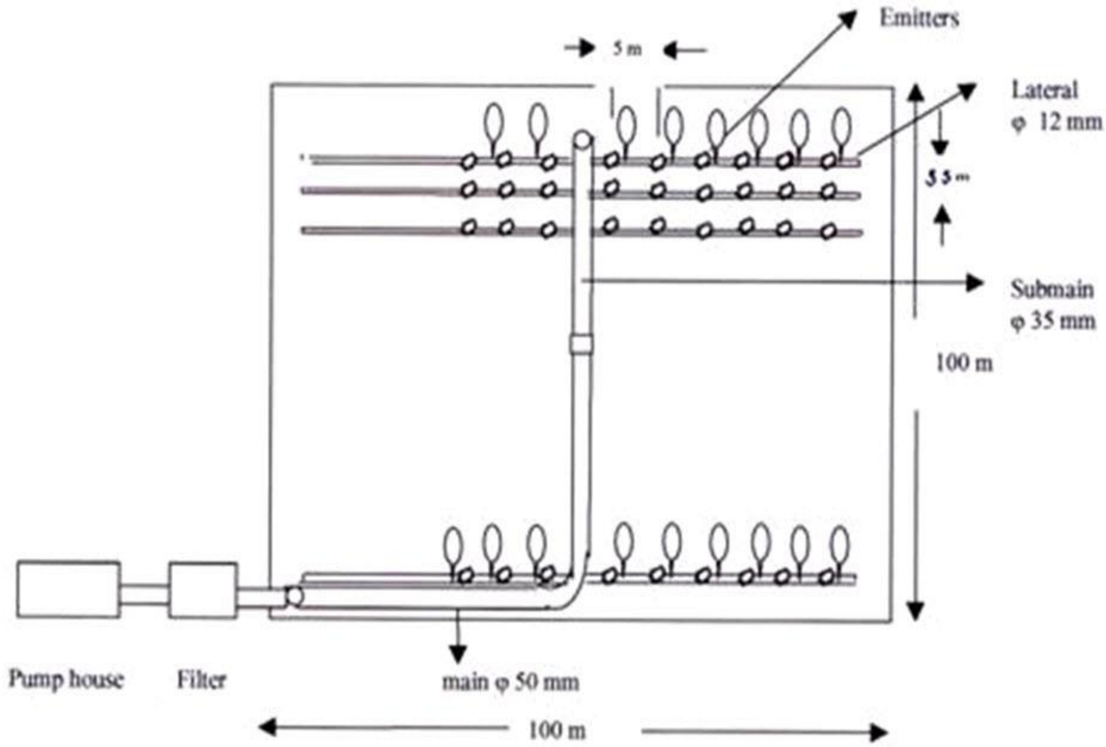


Figure: 8.1 Layout of designed drip irrigation system.

Lesson 9. Pump Selection

All micro-irrigation systems require energy to carry water through the pipe distribution network and discharge it through the sprinklers and drippers.In some instances this energy is provided by gravity as water flows downhill through delivery system. In most irrigation systems, energy is imparted to the water by a pump that in turn receives its energy from either an electric motor or an internal combustion engine. The combination of pump and prime mover (electric motor or engine) is central to the performance of most irrigation systems. Therefore, it is important that both the pump and the prime mover be well-suited and matched to operate the irrigation system.

Wide range of pumps are commercially available forirrigation purposes. Some applications have specialpump requirements, but there are many commonconsiderations in the selection of an appropriatepump. Some of these are listed below:

- Requirement of pressure (or head) and discharge
- Conditionsat suction and pump
- Source of power available
- Cost per unit of powerconsumption
- Capital cost, depreciation and interest charges
- Frequency of operation
- Reliability
- Physical constraints (for example, pump must fit in a limited space such as in borehole)
- Housing of electrical motor and pump further to keep care of water proofing.

9.1 Types of Pumps

Pumps are classified in two main categories, based onhow energy is given to lift water.The two types are:

- Rotodynamic pumps (centrifugal pumps, mixed flow pumps and axial pumps)
- Positive displacement pumps (pistonpumps, and helical-rotorpumps).

The principal requirement for pumping equipment used in commercial micro-irrigation is high efficiency against comparatively high pressures. This requirement usually limits pumps used for spray systems to rotodynamic pumps. Centrifugal pumps are widely used in agriculture andare a good example of the rotodynamic pump group. However, for small systems requiring pump discharge less than 2 Ls^{-1} positive displacement pumps can be used under certainconditions. These are normally used in fertilizer injection equipment. In irrigation terms, a pumping rate of2 Ls^{-1} is a very low flow and would be applicable tonurseries with misting jets, vegetable growers usingdrip irrigation, and domestic irrigation situations.

9.1.1 Rotodynamic Pumps

Rotodynamic pumps have a rotating impeller whichgives energy to the water. The speed and size of theimpeller determine the pressure and the rate of waterflow out of the pump.The two main types of rotodynamic pumps are thevolute pump and the turbine pump.

a) Volute Type Centrifugal Pump

Volute pumps are widely used in irrigation. They areof simple in construction, the only moving parts beingthe impeller and shaft. The impeller is housed in acasing (volute).The volute pump most often used for irrigationpurposes is the (radial-flow) centrifugal pump.It can be installed with the pump shaft in the verticalor horizontal position. Its size is specified by theinternal diameter at the discharge outlet.

The advantages of the centrifugal pump include thefollowing:

• It can be installed above the water surface.

• It can be mounted on skids for rapid removal of water to avoid floods.

• Not being submerged, it is less liable tocorrosion, although most can operate submergedfor short periods without damage.

• It can be installed as a portable unit and used atmore than one pumping site.

• Where its use is applicable, it is easy and simple toinstall.

• It is cheap to maintain.

Where large quantities of water have to be pumpedagainst low heads, mixed-flow volute (MFV) pumpsare used. At low heads, it is possible to get higherefficiencies with MFV pumps than with radialflowcentrifugal pumps. Another advantage is thatthe power requirements (for a given speed) areapproximately constant through the range of head anddischarge.

b) Turbine Pump

Turbine pumps are mixed-flow and radial-flow(centrifugal) pumps which direct water to thedischarge outlet with diffusion vanes. Axial-flowpumps, in which the impeller resembles a ship’s screw,are generally classed with the turbines.Since turbine pumps are most often used for pumpingfrom bores, there is a limit on impeller diameter andthe pressure which can be developed at a given speed.Volute pumps do not have this physical limitation.When high pressures are required from turbinepumps, extra impellers (stages) are added to the pump.Turbine pumps are driven by either a line-shaft or asubmersible electric motor mounted below and closecoupled to the pump.

c) Jet Pumps

Jet pumps are single-stage centrifugal pumps fittedwith a special assembly called an ejector. The ejectorallows the pump to draw water from depths notpossiblewith a conventional centrifugal pump. Thedisadvantage of jet pumps is their very poor efficiencyand discharge when used in high pressure applications.

9.1.2 Positive Displacement Pumps

The positive displacement (or reciprocating pump)consists of a piston (displacer) moving in a cylinderfrom which liquid enters or leaves through a valvearrangement. The positive displacement pump isa low volume, high head pump, and so is not usedextensively in irrigation systems. These pumpsare used, where constant flow is needed such as in drip, fertigation, spray or mistirrigation.

a) Piston Pump

Piston pumps have a horizontal cylinder sealed from both ends with a piston inside. As the piston movesbackwards and forwards, water is drawn in during thesuction stroke and discharged during the compressionstroke. The discharge pulsates because of this needs to be smoothed out using an air chamber in thedelivery line.

b) Helical Rotor Pump

Helical rotor pumps are single screw pumpsconsisting of a rigid screw-like rotor rolling with aslight eccentric motion in a resilient internal rubberlining (stator). The rotor and stator engage so thata constant seal between the two is maintained. Thediameter, pitch and eccentricity of the rotor controlthe pump's performance.

The characteristic curve for helical rotor pumps is verysteep: small changes in flow result in large changes inpressure.All positive displacement pumps require a pressure reliefvalve at downstream of the pump to protect the mainline.

9.2 Size of Pumping Unit

Pump Performance Parameters

Capacity, head, power, efficiency, required netpositive suction head, and specific speed areparameters that describe a pump's performance.

Capacity

The capacity of a pump is the amount of waterpumped per unit time. Capacity is also frequentlycalled discharge or flow rate (Q). Inmetric units it is expressed as liters per minute ($Lmin^{-1}$)or cubic meters per second (m^3s^{-1}).

Head

Head is the net work done on a unit weight ofwater by the pump impeller. It is the amount ofenergy added to the water between the suction and delivery sides of the pump. Pumping head is measuredas pressure difference between the discharge andsuction sides of the pump.

Pressure in water can be thought of as beingcaused by a column of the water due to itsweight, exerts a certain pressure on a surface. Thiscolumn of water is called the head and is usuallyexpressed in meters (m) of the liquid.Pressure and head are two different ways ofexpressing the same value. Usually, when the term"pressure" is used it refers to units in kilopascals (kPa), whereas "head" refers to meter’s (m).

Power Requirements

The power imparted to the water by the pump iscalled water horsepower or water power. To calculate water power, theflow rate and the pump head must be known. Water power can be calculated using thefollowing equation:

$$W_P = \frac{Q \times H}{360} \qquad (9.1)$$

where

WP = water power, kilowatts

Q = flow rate (pump capacity),m^3h^{-1}

H = pump head,m

In any physical process there are always lossesthat must be accounted for. As a result, acertain amount of power is imparted to the water a larger amountof power is imparted to the pump shaft. Thispower is called brake horse power. The efficiency of the pump determines how much more power is requiredat the shaft.

$$BP = \frac{WP}{E} \qquad (9.2)$$

Where, E is the efficiency of the pump expressed as afraction, BP and WP are brake power and waterpower, respectively.

Efficiency

Pump efficiency is the percent of power input tothe pump shaft (the brake power) that is transferredto the water. Since there are losses in the pump, theefficiency of the pump is less than 100% and theamount of energy required to run the pump is greaterthan the actual energy transferred to the water. Theefficiency of the pump can be calculated from thewater horse power (WP) and brake horse power (BP) and is given by

$$E(\%) = \left(\frac{WP}{BP}\right) \times 100 \qquad (9.3)$$

9.3 Power Requirement and Pump Selection

Determination of operating conditions

Before a pump is selected it is necessary todetermine the head (H) and discharge (Q) required for the irrigation system (sprinkler/ drip). The system head versusdischargerelationship is developed for theentire range of operating conditions. Most pumps operate for specific range of head-discharge condition. The selection of pump becomes difficult for satisfying all operation conditions when these existsin wide range of system head discharge variation. Since most pumps are not very efficient over widerange in operating heads, the most prevalentconditions should be determined and a pump thatoperates efficiently over this set of conditions, andcan operate under all other possible conditions,should be selected.

Total dynamic head required by the system

For a given irrigation system a pump mustprovide the required flow rate at the required head(or pressure). The total dynamic head (TDH) curveof the system (Figure 9.1) illustrates the head isrequired to deliver desired flow through the system Fig. 9.1).

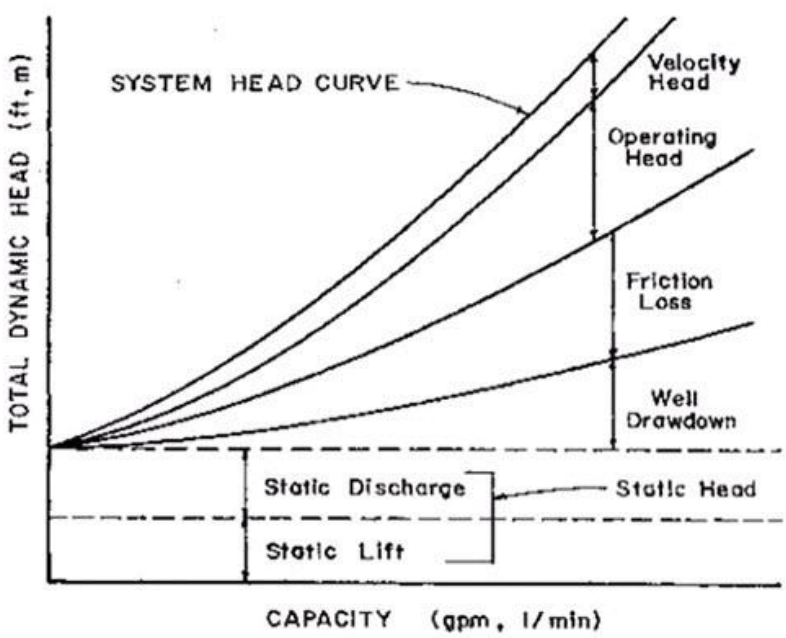


Fig. 9.1. Total system curve and its components.

(Source: Haman et. al., 1992)

The pressure required for operating a given sprinkler nozzle or emitter represents only a portion of thetotal dynamic system head. Additional pressure mustbe produced by the pump to lift water from the wellor other water source, to overcome friction losses inthe pipe and other components of the system, and toprovide velocity for the water to flow through thepipe. As a result, the total dynamic head for thesystem is the sum of static head (distance the watermust be lifted), well drawdown, operatingpressure(pressure required at the emitter or sprinkler head),friction head (energy losses) and velocity head (energyrequired for water to flow). Figure 9.1 illustrates thesecomponents of the system TDH. It can be expressedas:

$$H_t = H_n + H_m + H_j + H_s \tag{9.4}$$

Where,

H_t = total design head against which pump is working, m

H_n = maximum head required at the main to operate the sprinklers/ drip on the lateral at the required average pressure,m

H_m = maximum friction loss in the main and in suction line, m

H_j = elevation difference between the pump and the junction of the lateral and the main, m

H_s = elevation difference between the pump and junction of the lateral and the main, m

Horsepower requirement of pump

The horsepower requirement of pumping unit is computed by using following equation (Michael, 2010).

$$Horse\ power\ (hp) = \frac{Q \times H}{75 \times \eta_p \times \eta_m} \tag{9.5}$$

Where,

H = total head loss, m

Q = Capacity of drip/ sprinkler irrigation system Ls^{-1}

η_p = Efficiency of pump, fraction

η_m = Efficiency of motor, fraction

System head variations

The total system head will vary with time due tovariations in well drawdown, head loss due to friction, operatingconditions, and static water level. The static water level changes due to seasons. The friction losses will increase with the life of pumping system components.This is due to corrosion or deposits in the pipeand other components. The static lift component ofthe total dynamic head may vary due to fluctuatingwater levels throughout the season, or from year toyear.In some systems there is a periodic change in theoperating head of the system. It may not be possibleto select a pump that is efficient under a wide rangeof system heads. In some cases an additional(booster) pump, in series with a main pump, mayprovide the additional head, when necessary.

Pump Selection

Pump selection is the last step in theirrigation system design process.An irrigation designer estimates field sizes,pipe size and layout, the number of valves, typeof filters and the different types of fittings to be used. All oftheseinformationhelpsto determine the pressure andflow rate required by the pump, and thus finally thepump selection is done.

9.4 Head - Discharge Curve

Characteristic curves

A set of four curves known as the pump's characteristic curve is used to describe the operating properties of a centrifugal pump. These four curves relate head, efficiency, power, and net positive suctionhead required to pump capacity (Figure 9.2). Pumpmanufacturers normally publish a set of characteristiccurves for each pump model they make. Data forthese curves are developed by testing several pumpsof a specific model. The operating properties of apump depend on the geometry and dimensions of thepump's impeller and casing.

Head Vs Pump Capacity

This curve relates head produced by a pumpto the volume of water pumped per unit time.Generally, the head produced decreases as theamount of water pumped increases. The shape of thecurve varies with pump's specific speed and impellerdesign. Usually, the highest head is produced at zerodischarge and it is called the shut-off head.

Efficiency Vs Pump Capacity

The efficiency of a pumpsteadily increases to a peak, and then declines as Qincreases further. Efficiency varies between types ofpumps, manufacturers and models.

Brake power Vs pump capacity

The shape of the brake power versus dischargecurve is a function of the head versus discharge andefficiency versus discharge curves. In some cases the highestpower demand is at the lowest discharge rate and itcontinues to decline as the discharge increases. It isimportant to notice that even at zero discharge, whenthe pump is operating against the shut-off head, aninput of energy is needed.

Net Positive Suction Head Required Vs Pump Capacity

One of the curves typically published bymanufacturers is the net positive suction head required (NPSHr) versus capacity (Q). For a typical centrifugal pump the NPSHr steadily increases as Qincreases. To assure that the required energy isavailable, an analysis must be made to determine thenet positive suction head available NPSHa which is a function of the pumping system design.

All pumps come with a head discharge curve graph that shows their operating efficiency at different flow rates and pressures.Most head discharge curve graphs work in meters head for pressure, and cubic meters per hour or litres per minute for flow. It is very important to work in the correct appropriate units. Table 9.1provides conversion of one unit to other required units.

Table 9.1. Pressure conversions and flow conversions for different units

Pressure Conversions			Flow Conversions		
Convert from	To	Multiply by	Convert from	To	Multiply by
kPa	Meters head	0.102	L h^{-1}	L s^{-1}	0.017
Meters head	kPa	9.8	L s^{-1}	L h^{-1}	3600
kPa	psi	0.145	m^3h^{-1}	L h^{-1}	1000
psi	kPa	6.9	L h^{-1}	m^3h^{-1}	0.001

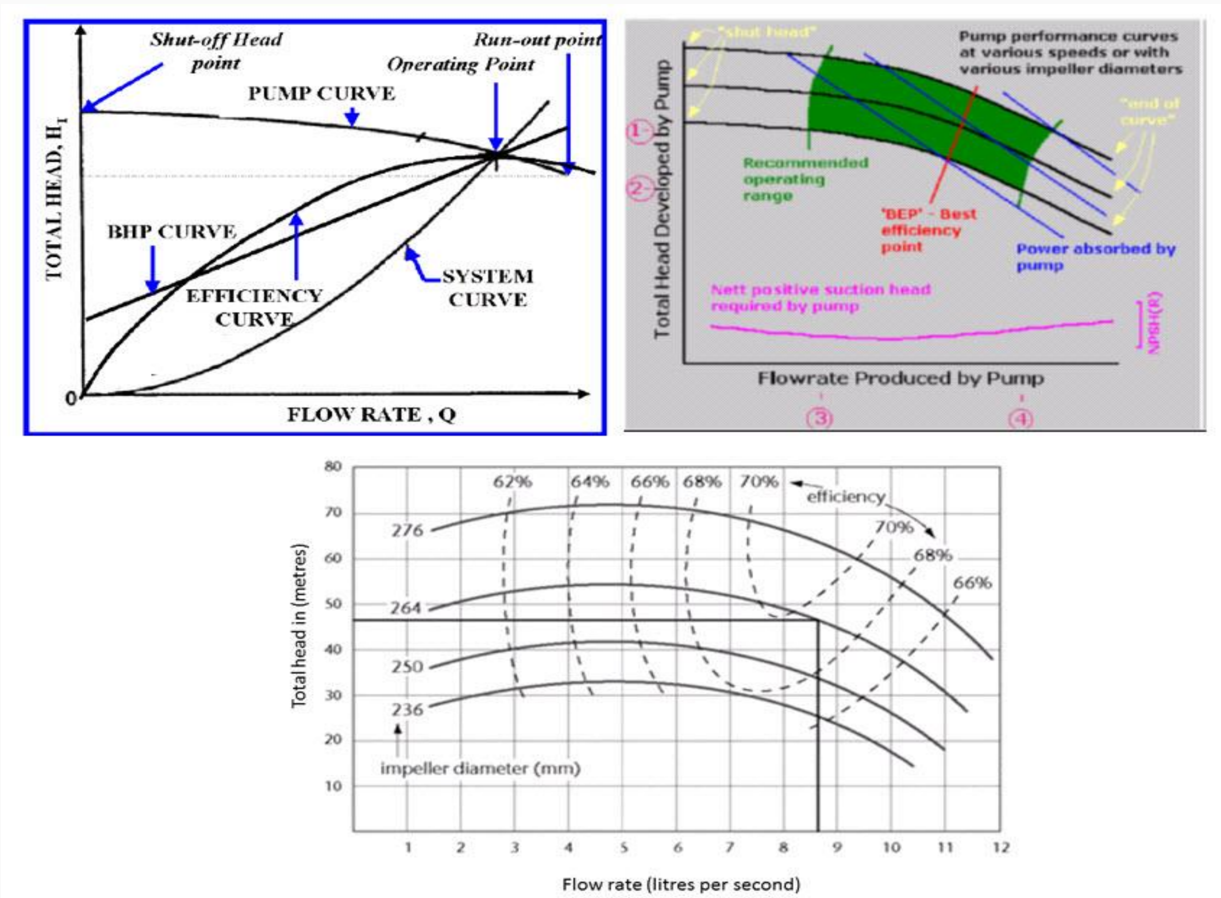


Fig 9.2.Power curve graph for a mixed flow centrifugal pump.

(Source: www. Rainfornet.com/services/pump-training/#System Curve)

Example 9.1: A field has 20 rows of tree with 30 treesper row. One 50 Lh^{-1}microsprinkler is located between each tree, plus one either end of the row. Select the required pumping unit for the system by assuming required data.

The total number of micro sprinklers = 20 (rows) x 31 (micro sprinklers per row)

= 620 micro sprinklers

The required flow rate is calculated bymultiplying the number of emitters by the

output of one sprinkler: 620 x 50 Lh^{-1} =31,000 Lh^{-1}.

This is the same as 31 m^3h^{-1}, 516 L m^{-1} or 8.6 L s^{-1}.

Consider 200 kPa is emitter operating pressure (frommanufacturers specifications)

& 265 kPais system pressure losses (calculated by adesigner), then

Required Pressure = 200 kPa (emitters) + 265 kPa (system losses) = 465 kPa.

Therefore, we need a pump that can deliver discharge of 31,000 Lh^{-1}at a pressure of 465 kPa. Using this information we can now select the pump to best suit this irrigation system.

The pressure requirement is 465 kPa which is equal to 47.4 m head.

The flow rate requirement is 31,000 Lh^{-1} which is equal to 8.6 L s^{-1}

Using these figures and the head-discharge curve graph one can check whether this pump will run the irrigation system efficiently? Normally the pump efficiency should be greater than 60%.

Using the head-discharge curve graph locate 47.4 m total head on the vertical axis and draw a horizontal line across the graph. On the horizontal axis locate 8.6 Ls^{-1}discharge and draw a vertical line up. The point at which these two lines intersect shows the efficiency at which the pump will operate under these flow rate and pressure conditions.The pump selected would be the pump with the 264 mm diameter impeller operating at 2900 rpm. This particular pump is expected to be approximately 69% power efficient. This means that 69% of the energy supplied to the pump from the motor is converted to the required pressure and flow.

There is a large range of pumps available in the market with their own set of head-discharge curve graphs. By knowing the pressure and flow rate required to operate the irrigation system effectively, one can compare one pump against another and select the most efficient pump for a given set of condition.

Lesson 10. Installation and Maintenance Guidelines

10.1 Micro-irrigation System Installation

The main items in the installation of drip irrigation system include installation of the head assembly (control head), comprising the pumping set, non-return valve, water meter, filters, fertilization equipment, and flow control, air release and pressure release valves. The next step for installation include connecting mains, sub mains, laying of drip tape or lateralsand connecting drippers.

10.1.1 Installation of Filters and Fertigation Equipment

A hard base made of concrete is constructed for installation filters and other head control units as per the size. Care should be takento use of minimum number of accessories like elbows and reducersso as to avoid huge head loss. The filter size should be in accordance with the capacity of the system. The delivery pipe of the pump should be connected directly to the hydrocyclone or the media filter followed by the fertilizer equipment and the screen filter then connected with the main pipe.Once the sand/screen filters are installed in the correct position the arrangement for back washing of filter is one of essential requirement.

In pressurized irrigation system the fertilizer injection unit is located between the sand filter (if required) and the screen filter. The general recommendation is that the fertilizer solution should pass through at least two 90-degree turns to ensure adequate time for thorough mixing so as to remove precipitate with the help of the screen filter. It is must that fertigation unit is installed at the upstream end of the screen filter so as to filter theundisolved matter present in the fertilizer solution.

10.1.2 Installation of Mains and Sub-mains

Except for fully portable system, both the mains and sub mains are installed underground at a minimum depth of about 0.5m such that they are unaffected by cultivation or by movement of heavy harvesting machinery. Even for systems, which have portable laterals that are removed at the end of each season, it is common practice to install permanent by underground mains and sub mains. Generally sub mains run across the direction of the rows.

The United States Soil Conservation Service has recommended the following minimum cover of earth over for various pipe sizes (Hamish, 1977):

Pipe size	Depth of earth cover
1.2 to 6 cm diameter	45 cm
6 to 10 cm diameter	60 cm
Over 60 cm diameter	75 cm

It is important to clean mud and other impurities deposited in the pipe before fitting of mains, and sub-mains and gate valves. A ball valve is provided at the inlet end of the sub-main. After the ball valve, air release valve is provided on drip tape and sub-main. A flush valve facing the slope of the sub-mains is provided at the end of each sub-main to facilitate sub-main flushing.

10.1.3 Laying of laterals

Once the gromate take offs are fixed on the sub-mains, lateral/polytube laying is done as per the design. For this, holes are drilled on the sub-main, according to the gromate take off (GTO) i.e., 11.9 mm dia drill for 8 mm ID GTO and 16.5 mm drill for 13 mm ID GTO. Then gromates are fixed in it and then take off are fixed. Lateral is fixed to one end of the take off. Lateral placement is done according to row distance, with sufficient shrinking allowance and extra lateral is provided and the end. The drippers are punched on the laterals as per the crop requirement.

Generally laterals are laid on the ground surface. Usually laterals are placed along contours on sloping field. Burying laterals underground might be necessary or at least have some advantages for some installations. Where this is done, the emission devices should be kept above ground level. The downstream end of the lateral can be closed by simply folding back the pipe and closing it with a ring of larger diameter pipe, known as end plug. This can be easily slipped for flushing.

10.1.4 Punching of Laterals andFixing of Emitters

Punching of laterals should start from sub-main end. Water should be allowed to flow through lateral so as to get bulging in pipe which makes easy punching. The dripper position is fixed as per the crop spacing and requirement. All the drippers should follow straight line. Drippers are fixed on laterals as per the arrows marked and it should be towards the sub-mains.While fixing the dripper, push it inside the lateral and pull it slightly. The end of lateral should be closed with end cap.

10.2 Operation of Drip Irrigation System

The proper operation of a drip irrigation system involves the following steps:

i) Acquiring complete information and instructions from the designer and dealer.

ii) Determining when and how long to irrigate.

iii) Checking the water meter readings and recording the values.

iv) Accurately setting the hydraulic metering valve.

v) Operating the head valve to begin irrigation.

vi) Checking the system along all components for proper operation, beginning with pressure readings at the header.

vii) Checking the emitters discharge, at least on a random basis.

viii) Setting and operating the chemical and fertilizer injection equipment (US Soil Cons. Service, 1984).

10.3 Maintenance of Micro Iirrigation System

Periodic preventive maintenance is required for successful operation of micro irrigation system. The emitter functioning, wetting pattern and leakage of pipes, valves, and fittings should be checked regularly. The placement of emitters should be ascertained. If the placement is disturbed, put the emitter in proper location. Leakage through filter gaskets in the lids, flushing valves & fittings etc. are monitored regularly.

10.3.1 Filter Cleaning

Filter is the heart of a drip system and its failure will lead to clogging of the entire system. Pressure differential across the filter is the correct indication of the timing of cleaning of the filter(Tiwari, 2009).

i) Hydro cyclone filter: Hydro cyclone filter should be installed before sand and screen filter. Hydro cyclone filter requires least maintenance. For cleaning the dirt inside of under flow chamber open back washing valve daily. Flush the chamber by opening flush valve/cap for thorough cleaning.

ii) Sand filter: The sand filter should be backwashed every day for five minutes to remove the silt and other dirt accumulated during the previous day's irrigation. Once in a week, while back washing, the backwash water should be allowed to pass through the lid instead of the backwash valves. The sand in the filter bed is stirred upto the filter candles without damaging them. Thedirt accumulated deep inside the sand bed should be allowed to go with the water through the lid. The need of back washing can be detected by monitoring the pressure drop across the filter. When the pressure drops has increased to a pre-determined level, the filter should be back-flushed. ASAE recommends that this pressure drop should not exceed 70 kPa.

iii) Screen filter: Flushing at scheduled daily interval is necessary to maintain screen filter. It is recommended to flush screen filter, if pressure drops more than 0.5 kg cm^{-2} (5 m water column). Before the start of drip irrigation system, the flush valve on the filter lid should be kept opened so that the dirt and silt is flushed out. The filter element is taken out from the filter and it is cleaned in flowing water. The rubber seals are taken out from both the sides and precaution should be taken while replacing the rubber seals, otherwise they may get damaged.

10.3.2 Maintenance of Fertigation Equipment

Initially theventury injector should be operated with clean water for 10 to 15 minutes after fertilizer application. It will prevent clogging of suction port of ventury from clogging. It is important to note that equipment is resistant to acid attack. The lid of the fertilizer tank should be fully tightened while in operation. In order to check leaks between the body and bell housing in fertigation pump, clean the seal seating and put back the seal or change and keep the position of bell housing at upright.

10.3.3 Sub-main and Lateral / Bi-wall Flushing

Sometimes silt escapes through the filters and settles in sub mains and laterals. Also some algae and bacteria lead to the formation of slimes/pastes in the pipe and laterals. To remove these formations the sub mains should be flushed by opening the flush valves. The lateral lines should be flushed by removing the end caps. By flushing, even the traces of accumulated salts will also be removed. The flushing is stopped once the water going out is appearcleaned.

10.3.4 Chemical Treatment

Clogging or plugging of emitters/orifices of bi-wall is due to precipitation and accumulation of certain dissolved salts like carbonates, bi-carbonates, iron, calcium and manganese salts. The clogging is also due to the presence of microorganisms and the related iron and sulphur slimes due to algae and bacteria.The clogging or plugging is usually removed by chemical treatment. Chemical treatments commonly used in microirrigation system include addition of chloride and/or acid to the water supply. The frequency of chemical treatment is decided on the degree of clogging and quality of water. As a general rule, acid treatment is performed once in ten days and chlorine treatment once in fifteen days.

i) Acid treatment: Hydrochloric acid is injected into the micro irrigation system at the rate suggested in the water analysis report. The acid treatment is performed till a pH of 4 is observed at the end of pipe. After achieving a pH of 4 the system is shutofffor 24 hours. Next day the system is flushed by opening the flush valve and lateral end caps.

ii) Chlorine treatment: Chlorine treatment in the form of bleaching powder is performed to inhibit the growth of microorganism like algae and bacteria. The bleaching powder is dissolved in water and this solution is injected intothe system for about 30 minutes. Then the system is shut off for 24 h. After that the lateral end caps and flush valves are opened to flush out the water with impurities. The recommended chlorine dosage of 0.5 to 1.0 ppm concentration is applied continuously or 20 ppm for 20 minutes at the end of each irrigation cycle for algae while for slimes, 1.0 ppm free residual chlorine is maintained at the end of each laterals. For iron precipitation, 0.64 times the Fe^{++} content are used to maintain 1.0 ppm free residual chlorine at the end of each lateral.Efficiency of chlorine injection is related to pH of the water to be treated. More chlorine is required for a high pH of water. The rate of injection of liquid chlorine or acid depends on the system flow rate and can be determined by using the following equation

$$q_c = 6 \times 10^{-3} \frac{U\,Q_s}{C} \qquad (10.1)$$

where

q_c = Rate of injection of the chemical into the system, L h^{-1}

U= Desired concentration of chemical in irrigation water, ppm

Q_s = Supply flow rate, Lmin^{-1}

C = Concentration of chemical in the solution to be injected, per cent

Module 3. Sprinkler Irrigation

Lesson 11. Sprinkler Irrigation

In this module appraisal of the adoptability, development and use of sprinkler irrigation systems, sprinkler types and components, performance evaluation, design of sprinkler system, maintenance and operation of sprinkler systems have been discussed.

11.1 Introduction

In sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil. In sprinkler Irrigation water is applied through a pressurized system. The pressure causes the water to flow out through the sprinkler nozzle. Sprinkler pipe lines are light in weight, hence can be easily transported and installed in the field. They are highly flexible, crack and impact-proof, sustains high pressure and temperature, hence more durable. In this system the water is moved dynamically from the water source through a sprinkler nozzle to a desired height at a high velocity where it breaks up into small droplets and falls on to the soil or crop surface. Due to sprinkling action water wastage is less and it requires less labour than surface irrigation. It can be adapted more easily on sandy soils where infiltration loss is considerably high. Altering the land surface slope for surface methods is always economical.

In sprinkler irrigation water is applied over the crop canopy in form of fine droplets or spray. Sprinkler irrigation keeps soil moisture at its optimum beneficial level giving higher crop yield. Aeration through soil is good so quantity as well as quality of produce is also good. Sprinkler systems have several other uses such as spraying of water for germination, control of soil temperature, control of humidity and frost protection. Several fertilizers and chemicals can be applied quickly and economically.

11.2 Historical overview

Agricultural sector is the largest consumer of water. The demand of water has been consistently increasing from various sectors like municipal, industry etc. and each of these can often be at the cost of agricultural requirement. The dominant method of irrigation practiced in large parts of the country is surface irrigation, under which crop utilizes less than one half of the water released and remaining half gets lost in conveyance, application, runoff and evaporation. The drip and sprinklers assume high importance due to high water use efficiency. These methods are to be used for efficient distribution and application of water for crop production. To overcome the problem of water scarcity, the sprinkler system was first introduced in the mid-1950s by few progressive farmers of the Narmada valley in Madhya Pradesh, Southern region of Haryana and north eastern part of Rajasthan and parts of Punjab (Michael, 2010). The adoption of sprinkler system later spread in the states of Maharashtra and Karnataka. It is estimated that About 1,35,000 sprinkler sets were in use in India in 1997 (INCID, 1998). In India, the area irrigated by the sprinkler system is about 3.5 M ha, which is less than 2.5 % of the total area under irrigation. Table 11.1 provides statistics of an area under sprinkler and drip irrigation in different states of India. As on March 31, 2012 Rajasthan has largest area under sprinkler irrigation followed by Haryana. About 65 % of the area under sprinkler irrigation is under field crops like cereals, pulses, oilseeds, cotton, sugarcane and vegetables and the rest 40% under tea, coffee and cardamom plantations in the Western Ghats region and in the North Eastern states. The popularization of sprinkler irrigation in India received significant financial support from centrally sponsored subsidy scheme from the Central Government and partial sharing state governments. In India, per hectare investment for irrigation projects has increased enormously. It is necessary to bring more area under micro irrigation because irrigated farms typically get higher yields and can easily grow 1 to 3 crops per year provided adequate water is available. In view of the scarcity of water and the cost escalation of irrigation projects, it is essential and necessary to economize the use of water and at the same time increase the productivity per unit area. This could be achieved only by large-scale adoption of micro-irrigation system for achieving economy and high crop production. The application of sprinkler and drip irrigation was implemented through National Committee on the use of Plastics in Agriculture under the Ministry of Agriculture Government of India, later it is renamed as the National Committee on Plasticulture Applications in Horticulture. The Committee established twenty two Precision Farming Development Centers in different agro climatic regions of the country for conducting research on micro irrigation and to implement the proven technologies in farmers' fields through demonstrations.

Experiments conducted in various places of India on different crops under flood irrigation method (FIM) and sprinkler irrigation method (SIM) are grouped in three categories food grains, oilseeds and other crops for the purpose of comparison (Table 11.2, INCID 1998). This can be seen from the results that average increase in yield of various crops varies from 15.09% to 28.9% and saving in water varies from 30.15% to 40.04% over flood irrigation method (FIM) due to sprinkler irrigation method (SIM).

Table 11.1 Area under Micro Irrigation (Drip & Sprinkler Irrigation)

Area as on 31.03.2012 (ha)				
SN	State	Drip	Sprinkler	Total
1	Rajasthan	55715	1098133	1153848
2	Maharashtra	778660	347623	1126283
3	Andhra pradesh	665661	323457	989118
4	Karnataka	293593	385675	679268

5	Haryana	17772	542431	560204
6	Gujarat	309520	246222	555742
7	Madhya Pradesh	110550	176223	286774
8	Tamil Nadu	206756	28217	234973
9	West Bengal	589	150576	151165
10	Chhattisgarh	11328	136310	147638
11	Orissa	12320	46090	58410
12	Sikkim	3460	2339	14799
13	Punjab	27615	11559	39174
14	UP	13973	17328	31301
15	Kerala	17301	4280	21581
16	Bihar	752	36628	37381
17	Nagaland	0	3962	3962
18	Jharkhand	1273	8842	10115
19	Goa	874	761	1635
20	HP	116	581	697
21	Arunachal Pradesh	613	0	613
22	Assam	116	129	245
23	Mizoram	72	106	178
24	Uttara Khand	38	6	44
25	Manipur	30	0	30
26	Others	15000	30000	45000
Grand Total		2543696	3597479	6150176

Source: NCPAH (2013)

Table 11.2 Saving of irrigation water and yield enhancement with flood and sprinkler irrigation methods

Crops	Location	Yield (q/ha)		Irrigation water (cm)		Water Use efficiency (q\ha\cm)		Benefits over FIM (%)	
		FIM	SIM	FIM	SIM	FIM	SIM	water	Yield
1. Wheat	Rahuri	32.41	36.39	35.00	20.25	0.93	1.79	42.14	12.28
	Udaipur	26.61	33.02	33.02	14.52	0.81	2.27	56.03	24.09
	Hissar	44.80	48.70	33.94	32.68	1.32	1.49	3.89	8.70
2. Bajra	Rahuri	6.97	8.33	17.78	7.82	0.39	1.07	56.02	19.51
3. Jowar	Rahuri	4.92	6.62	25.40	11.27	0.19	0.59	55.63	34.55
4. Sorghum (k)	Rahuri	44.12	54.97	18.00	12.00	2.45	4.58	33.33	24.59
5. Maize (k)	Udaipur	15.62	18.10	12.80	9.00	1.22	2.01	33.00	15.88
6. Barley	Bikaner	24.09	28.15	17.78	7.82	1.35	3.59	56.01	16.85
	Hissar	35.10	34.80	23.87	21.88	1.47	1.59	8.34	-0.85
7. Gram	Hissar	6.55	9.91	17.78	7.82	0.37	1.27	56.02	51.29
Foodgrains (Avg)		**24.12**	**27.90**	**23.54**	**14.51**	**1.05**	**2.03**	**40.04**	**20.69**
8. Oilseeds	Delhi	8.33	9.34	60.00	30.00	0.14	0.31	50.00	12.12
9. Groundnut(s)	Rahuri	23.24	28.98	90.00	62.00	0.26	0.47	31.11	24.69
	Junagarh	13.00	16.00	91.00	65.00	0.14	0.25	28.57	23.08
	Dharwad	33.96	39.86	76.30	63.60	0.45	0.63	16.64	17.37
	Punjab	5.50	11.90	68.60	50.20	0.08	0.24	26.82	116.38
	Navsari	31.00	30.00	56.00	44.00	0.55	0.68	21.43	-3.22
	Rahuri (k)	18.31	22.15	21.00	14.00	0.87	1.58	33.33	20.97
10. Sunflower (r)	Rahuri	16.02	19.19	30.00	20.00	0.53	0.96	33.33	19.79
Oilseeds (Avg)		**18.67**	**22.18**	**61.61**	**43.60**	**0.38**	**0.64**	**30.15**	**28.90**
11. Chillies (k)	Pune	17.41	21.52	36.00	24.00	0.48	0.89	33.33	23.61
	Rahuri	17.15	20.91	39.00	26.00	0.44	0.80	33.33	21.92
12. Garlic	Rahuri	69.99	73.99	84.00	60.00	0.83	1.23	28.57	5.71
13. Onion (s)	Rahuri	334.90	412.70	78.00	52.00	4.29	7.94	29.69	23.23
14. Cotton	Navsari	6.99	7.04	40.64	29.65	0.17	0.24	27.04	0.71
	Punjab	10.00	15.00	91.10	58.60	0.12	0.26	35.68	50.00
15. Sugarcane	Rahur	792.10	866.30	245.00	188.00	3.23	4.61	23.26	9.37
	Dharwad	55.70	48.00	51.40	43.50	1.08	1.10	33.33	-13.82
Others (Avg)		**163.03**	**183.18**	**83.14**	**60.22**	**1.33**	**2.13**	**30.53**	**15.09**

Source: INCID (1998)

11.3 Adoptability and Limitations of Sprinkler Irrigation

Adoptability

i)Suitable to all types of soils except heavy clay.

ii)Suitable for irrigating crops where the plant population per unit area is very high. It is suitable for oil seeds and cereal and vegetable crops.

iii)Water saving & expensive land levelling is not required

iv)Increase in yield. Saves land as no bunds or ridges are required for ponding or guiding water flow.

v)Less problem of clogging of sprinkler nozzles due to sediment laden water as compared to drip irrigation emitters.

vi)Chemical and fertilizer applications can be easily used with sprinkler systems.

vii)Water conservation, saving of labor, fertilizer and pesticides.

viii)Vegetables, citrus, apple, mango, litchi, and other fruit crops can be protected from fog, frost and high solar radiations.

ix)The water use efficiency is high with proper planning and design of sprinkler irrigation systems.

x)Soil moisture can be maintained at optimum level.

xi)Frequent and light irrigation is possible to get better crop response.

Limitations

i)High initial investment as compared to surface irrigation methods.

ii)The fine-textured soils which have a low infiltration rate cannot be irrigated efficiently.

iii)Sprinkler irrigation is not feasible in hot climate and high windy areas, as major portion of water is lost through evaporation and water distribution is affected due to high wind speed.

iv)High operational costs due to higher energy requirements.

v) Not suitable for crops that require ponding water. However, research experiments on paddy crops have given promising results.

vi)In humid regions, crops prone to diseases due to moist environment.

vii)Water with impurities and sediments may damage the system.

Lesson 12. Classification and Components of Sprinkler Systems

Sprinklers, laterals, submains, and mainlines are the primary components of a sprinkler irrigation system. Sprinklers spread water as "rain droplets" over the land surface. Laterals get water from the mainlines and submains convey to the sprinklers. Mainlines convey water from the water source to the submains and laterals. Types and components of sprinkler systems are discussed in this lesson.

12.1 Types of Sprinkler Irrigation Systems

Sprinkler irrigation systems may be classified as portable, semi-portable, semi-permanent, or permanent. On the basis water application the sprinkler systems are classified into the following two major types:

1. Rotating head or revolving sprinkler system.

2. Perforated pipe system.

1) Rotating head

Small size nozzles are placed on riser pipes fixed at uniform intervals along the length of the lateral pipe and the lateral pipes are usually laid on the ground surface. They may also be mounted on posts above the crop height and rotated through 90^{o}, to irrigate a rectangular strip. In rotating type sprinklers, the most common device to rotate the sprinkler heads is with a small hammer activated by the thrust of water striking against a vane connected to it. Fig. 12.1. shows the different types of rotating head sprinkler irrigation systems.

Fig.12.1. Rotating Head Sprinkler Irrigation System

(Source: www.agritech.tnau.ac.in)

2) Perforated pipe system

This method consists of drilled holes or nozzles along their length through which water is sprayed under pressure. This system is usually designed for relatively low pressure (1 kg/cm^2). The application rate ranges from 1.25 mm to 50 mmh^{-1} for various pressures and spacing.

Based on the portability, sprinkler systems are classified into the following types:

(i) Portable system: A portable system has portable mainlines, sub-mains, laterals, and a portable pumping plant. The entire system can be moved from field to field. Fig. 12.2. shows the fully portable sprinkler irrigation system.

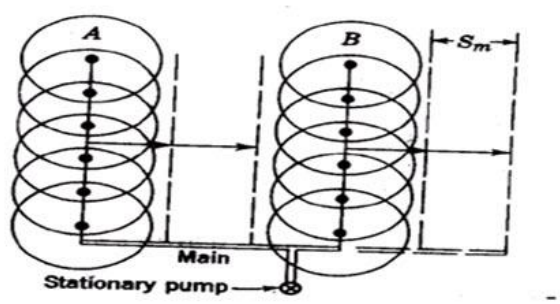


Fig. 12.2. Fully Portable Sprinkler Irrigation System

(Source: www.agritech.tnau.ac.in)

ii) Semi-portable system

A semi-portable system is similar to a fully portable system except that the location of water source and pumping plant is fixed. Such a system may be used on more than one field where there is an extended mainline, but may not be used on more than one farm unless there are additional pumping plants.

iii) Semi-permanent system

A semi-permanent system has portable lateral lines, permanent mainlines, and a stationary water source and pumping plant. The mainline are usually buried, risers are (located at suitable intervals) to connect with laterals.

iv) Permanent system

A fully permanent system has buried mainlines, sub-mains, and laterals with a stationary pumping plant and/or water source. Sprinklers are permanently located on each riser. Such systems are costly and are suited to automation.

v) Solid set system

A solid set system has enough laterals to eliminate their movement. The laterals are installed in the field early in the crop season and remain for the season.

vi) Set-move irrigation systems

Set-move sprinkle systems are moved from one set (irrigation) position to another by hand or mechanically. Set-move systems remain stationary when water is applied. When the desired amount of water has been applied, the water is shut off and the sprinkler laterals are drained and moved to the next set position. When the move is complete the water is turned on and irrigation resumed at the new set position. This sequence is repeated until the entire field has been irrigated. Set-move systems commonly have a single mainline laid through the centre of the field with one or more laterals on each side of the mainline.

a) Hand-move

In hand-move system laterals are moved by uncoupling, picking –up, and carrying sections of lateral pipe by hand to the next set position where the lateral sections are reconnected. Earlier hand-move sprinkler laterals were made up of aluminium now these are replaced with HDPE of 50 to 150 mm(2 to 6 in) in diameter, and 6, 9, or 12 m (20, 30, or 40 ft) long are difficult to handle and may not provide proper spacing for the common sprinkler sizes.

b) Tow-move

Tow-move sprinkler systems are the least expensive type of mechanically moved set-move system. Each section of a tow-move lateral has skids or wheels so that the entire laterals can be pulled to the next set position. Usually a tractor is hooked to the mainline end of the lateral and the lateral is dragged in the other direction across the mainline in an opposite S-shaped curve. The moves are made easier by buried mainlines.

Tow-move system are not used extensively because shifting of lateral is tedious, it requires careful attention, and also damages crops. Tow-move systems are suitable to forage and row crops.

c) Side-roll

A side-roll or wheel-move system, like the one is an extremely popular type of mechanically moved set-move system. Each section of pipe in a side-roll lateral has a wheel, with the pipe serving as the axle of the wheel. A gasoline engine and transmission with a reverse gear at the centre or the end of the lateral supplies the power needed to roll the lateral, which may be as long as 800 m (about one-half mile), from one set position to the next. The lateral is commonly 100 or 125 mm (4 or 5 in) in diameter. Each lateral section is usually 12.2 m (40 ft) long with a wheel at its centre and a sprinkler mounted on a short riser at one end. Often the sprinklers have self –levellers to "right" the sprinkler when the lateral is stopped so that the riser is tilted" from its upright position. A drain valve that opens automatically when there is a loss of pressure is usually located opposite each rise. This allows the lateral to be quickly drained and permits moving of lateral with a minimum time loss. The most common spacing along the mainline is 18.3 m (60 ft). The Fig. 12.3 shows a side-roll lateral sprinkler system used on a potato field.

Fig. 12.3. Side-Roll Lateral Sprinkler System

(Source:http://here4now.typepad.com/.a/6a00d8341d171f53ef00e553baa49e8833i)

d) Gun-type

The set-move system consists of a larger-volume (big-gun) sprinkler mounted on a wheeled cart or trailer that is moved from set to set with a tractor or by hand. Sprinklers with capacities as large as 4700 L min^{-1}(about 1250 gpm), wetted diameters of as much as 180 m (about 600 ft), and a recommended operating pressure range of 480 to 896 kPa (70 to 130 psi) are commonly used. These systems are sometimes used for waste water disposal.

12.2 Components of a Sprinkler System

Sprinklers, laterals, sub-mains, and mainlines are the primary components of a sprinkler irrigation system. Sprinklers spread water as “rainlike” droplets over the land surface. Laterals convey water from the mainline and sub-main to the sprinklers. Mainlines convey water from the water source to the sub-mains and laterals. Fig.12.4. shows the component of a portable sprinkler irrigation system. A sprinkler system usually consists of the following components.

i) A pump unit

ii) Tubing’s- main/sub-mains and laterals

iii) Couplers

iv) Sprinkler head

v) Other accessories such as valves, bends, plugs and risers.

i) Pumping unit

Sprinkler irrigation systems distribute water by spraying it over the fields. The water from the source (ground water / surface water) is pumped under pressure to sprinkler system. The pressure created through pump forces the water through sprinklers or through perforations or nozzles in pipelines and then forms a spray. A high speed centrifugal or turbine pump can be used for operating sprinkler irrigation for individual fields. Centrifugal pump is used when the distance from the pump inlet to the water surface is less than eight meters. For pumping water from deep wells or more than eight meters, a turbine submersible pump is used. The driving unit may be either an electric motor or an internal combustion engine.

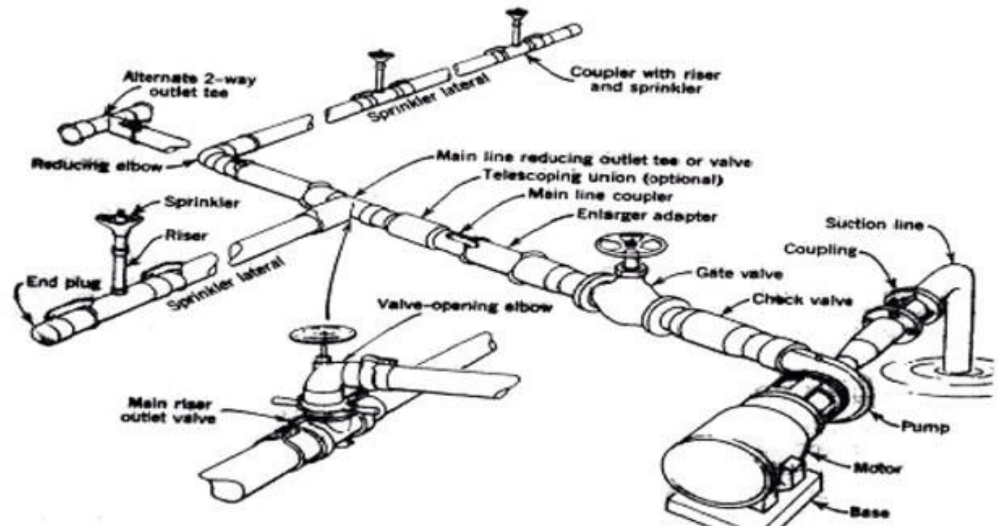


Fig. 12.4. Component of a Portable Sprinkler Irrigation System

(Source: Schwab etal.1993 pp. 427)

ii) Tubings

The tubing consists of mainline, sub-mains and laterals. Main line conveys water from the source and distributes it to the sub-mains. The sub-mains convey water to the laterals which in turn supply water to the sprinklers. Aluminium or PVC or HDPE pipes are generally used for portable systems, while steel pipes are usually used for centre-pivot laterals. Asbestos, cement, PVC and wrapped steel are usually used for buried laterals and main lines.

iii) Couplers

Couplers are used for connecting two pipes and uncoupling quickly and easily. Essentially a coupler should provide

a) a reuse and flexible connection

b) not leak at the joint

c) be simple and easy to couple and uncouple, and

d) be light, non-corrosive, and durable.

iv) Sprinkler head

Sprinkler head distribute water uniformly over the field without runoff or excessive loss due to deep percolation. Different types of sprinklers are available. They are either rotating or fixed type. The rotating type can be adapted for a wide range of application rates and spacing. They are effective with pressure of about 10 to 70 m head at the sprinkler. Pressures ranging from 16 to 40 m head are considered the most practical for most farmers.

Fixed head sprinklers are commonly used to irrigate small lawns and gardens. Perforated lateral lines are sometimes used as sprinklers. They require less pressure than rotating sprinklers. They release more water per unit area than rotating sprinklers. Hence fixed head sprinklers are adaptable for soils with high intake rate. Fig. 12.5. shows the rotating head sprinkler head.

Fig. 12.5. Sprinkler head

(Source:www.jains.com/irrigation/popups%20and%20sprinklers/sprinklersystems htm).

v) Fittings and accessories: Fig 12.5 shows different types of sprinkler fittings and accessories. The following are some of the important fittings and accessories used in sprinkler system.

a) Water meters: It is used to measure the volume of water delivered. This is necessary to operate the system to supply the required quantity of water.

b) Flange, couplings and nipples are used for proper connection to the pump, suction and delivery.

c) Pressure gauge: It is used to measure operating pressure of sprinkler system. to ensure application uniformity, the sprinkler system is operated at desired pressure.

d) Bend, tees, reducers, elbows, hydrants, butterfly valve and plugs are optimal components of a sprinkler system. They are used as per requirements.

Fig 12.6. Different Fittings and Accessories Used in a Sprinkler System.

(Source: www.agritech.tnau.ac.in)

e) Fertilizer applicator: Soluble chemical fertilizers can be injected into the sprinkler system and applied to the crop. The fertilizer applicator consists of a sealed fertilizer tank with necessary tubings and connections. A venturi injector is connected with the main line, which creates the differential pressure suction and allows the fertilizer solution to flow in the main water line.

Lesson 13. Sprinkler Performance Evaluation

The basic purpose of sprinkler irrigation is to apply uniform depth of water to the field crop. The water distribution pattern of a sprinkler nozzle is tested with the sprinkler operating individually under a set of specific conditions. Operating pressure and nozzle geometry (i.e., nozzle opening size, shape, and angle) are the primary factors that control the operation of sprinklers. The performance of a sprinkler is described by its discharge, distance of throw, distribution pattern, application rate and droplet size.

13.1 Sprinkler Discharge, Distance of Throw and Application Rate

i) Sprinkler Discharge: Sprinkler discharge is the volume of water passing out of the sprinkler nozzle. Common units for sprinkler discharge are liters per minute (1/min) and gallons per minute (gpm) in the SI and English systems, respectively. Equation 13.1 can be used to relate sprinkler discharge to operating pressure and nozzle geometry.

$$Q = \sum_{i=1}^{n} K\, C_i\, A_i\, P_i^{x_i} \qquad \text{.... (13.1)}$$

Where,

Q = sprinkler discharge;

n = number of nozzles;

K = constant that depends on unit used;

C = coefficient that depends on shape and roughness of opening in nozzle i;

A = cross-sectional area of the opening in nozzle i;

P = operating pressure in nozzle i;

exponent for nozzle i.

Thus, discharge of a multi nozzle sprinkler is the sum of the nozzle discharges.

Values of C and for each nozzle and normally determined empirically. Since is about 0.5 for most sprinklers, higher pressures and/ or larger nozzle openings will increase sprinkler discharge. Sprinkler manufactures commonly publish tables of pressure and discharge data for various nozzle diameters. Sprinkler discharge is not related to nozzle angle.

ii) Distance of Throw: The spacing between adjacent sprinklers depends, in part, on the distance sprinklers throw water. Spacing usually increases as the distance of throw rises.

The operating pressure, and size, shape and angle of the nozzle opening determine the distance a sprinkler throws water. Distance of throw also tends to increase as nozzle size increases (other things remaining constant). Nozzles opening shapes that create smaller diameter droplets tend to wet a smaller area than nozzle that emit larger droplets. Distance of throw usually increases and then declines as nozzle angle rises above horizontal. Sprinkler manufactures commonly publish wetted diameter or other measures of distance of throw for different operating pressures, and nozzle sizes, shapes, and angles.

iii) Application rate: Application rate is an extremely important parameter that is used to properly match sprinklers to the soil, crop, and terrain on which they operate. When sprinkler application rates are too high, runoff and erosion can occur. Application rate has dimensions of length per unit time. The average application rate of an individual sprinkler can be computed using Eq. 13.2

$$A = K\frac{Q}{a} \qquad .... (13.2)$$

Where

A = application rate (mmh^{-1}, inh^{-1});

Q = sprinkler discharge ($Lmin^{-1}$, $gmin^{-1}$)

a = wetted area of sprinkler ($m,^2$ ft^2)

K = unit constant (K= 60.0 for A in mm/h, Q in $Lmin^{-1}$, and a in m^2.

K = 96.3 for A in inh^{-1} , Q in $gmin^{-1}$, and a in ft^2).

When several identical sprinklers are spaced in a L by S grid. Eq. 13.3 can be used to compute the average application rate.

$$A = \frac{KQ}{LS} \qquad .... (13.3)$$

where

A = application rate (mm/h, in/h);

Q = discharge of individual sprinklers

L = distance between sprinklers along the lateral (m)

S = spacing between adjacent sprinkler lines or lateral set positions (m)

K = K in Eq. 13.2

The average application rate beneath a lateral of sprinklers can be computed using Eq. 13.4

$$A = \frac{KQ_l}{L_l S} \quad \text{.... (13.4)}$$

where, A and S are as previously defined

Q_l = total flow rate into upstream end of lateral (Lmin^{-1}, gmin^{-1});

L_l = length of lateral (m, ft);

K = K in Eq. 13.2

For most sprinklers, variation in operating pressure has little, if any, effect on the average application rate of an individual sprinkler. When operating pressure increases, for example, the increase in Q tends to be offset by the increase in wetted area. The average application rate of several identical overlapping sprinklers, however, tends to be directly related to operating pressure, since L and S remain constant as Q increases. This is also true for the average application rate beneath a sprinkler lateral.

The average application rate for an individual sprinkler varies widely depending upon nozzle geometry. Deflector plate sprinklers, for example have relatively high average application rates, since they wet a much smaller area than relatively high average application rates, since they wet a much smaller area than do other types of sprinklers. Conversely, conventional impact sprinklers are normally designed to achieve the maximum wetted area, and thus lowest possible average application rate. Nozzle opening shapes that create smaller droplets and wet a smaller area tend to have the highest average application rates. Average application rate will usually decrease and then increase as nozzle angle increases above horizontal. Increasing nozzle diameter usually increases the average application rate, since Q normally increases more rapidly than wetted area.

There is also considerable variation in the instantaneous application rate (i.e., the rate at which water is applied to a given point on the soil surface during an instant in time) from sprinkler type to sprinkler type (James and Stillmunkes,1980). Conventional impact sprinklers for example, apply water as a spray that covers all or nearly all of the wetted area continuously. Thus the rate at which water is applied to a given point on the soil surface during an instant of time, the instantaneous application rate, is less for deflector-plate sprinklers than for conventional impact sprinklers. On some soils, lower instantaneous rates of application can decrease the potential for runoff and erosion by reducing soil splash and water ponding on the soil surface.

13.2 Droplet Size

Droplet size is an important factor affecting the formation of ‘‘seals’’ on bare soil surfaces that restrict water movement into the soil. Because small droplets possess less power when they impact the soil surface, ‘‘seals’’ that limit infiltration form more slowly than with larger droplets. For these reasons, it is sometimes possible to reduce runoff and erosion by converting from sprinklers that emit large droplets to ones with smallest droplets.

Droplet size is especially important when sprinklers must operate in winds. Distribution patterns from sprinklers that emit smaller droplets are more subject to wind distortion and lower application uniformity. In addition, increased losses due to wind drift usually occur with small droplet sprinklers.

Higher operating pressures normally increases the volume of water applied as smaller droplets while decreasing the volume of larger droplets. A similar, but a significantly smaller effect occurs on the larger droplets (not on the volume of water) as nozzle opening size is decreased. Nozzle opening shape can have an important effect on droplet size while nozzle angle has little, if any effect.

13.3 Distribution pattern

i) Uniformity coefficients: A measurable index of the degree of uniformity obtainable for any size sprinkler operating under given conditions has been adopted and is known as the uniformity coefficient (C_u). This uniformity coefficient is affected by the pressure nozzle size relations, by sprinkler spacing and by wind conditions. The coefficient is computed from field observations of the depths of water caught in open cans placed at regular intervals within a sprinkled area. It is expressed by the equation developed by Christiansen (1942):

$$C_u = 100(1.0 - \frac{\sum X}{mn}) \qquad \ldots (13.5)$$

in which

C_u = coefficient of uniformity

m = average value of all observations (average application rate), mm

n = total number of observation points

X = numerical deviation of individual observation s from the average application rate, mm.

A uniformity coefficient of 100 per cent (obtained with overlapping sprinklers) is indicative of absolutely uniform application, whereas the water application is less uniform with a lower percentage. A uniformity coefficient of 85 per cent or more is considered to be satisfactory.

ii) Pattern efficiency: The pattern efficiency (also known as distribution efficiency) can be calculated after obtaining the total depths at each of the grid point. The minimum depth is calculated considering average of the lowest one fourth of the cans used in a particular test. Pattern efficiency is given by

$$P_e = \frac{min.\,depth}{average\ depth} \times 100 \qquad \ldots (13.6)$$

The pattern efficiency is useful in calculating the average depth to be applied for a certain minimum depth. The pattern efficiency is influenced by the wind conditions.

Application

$$\text{Application efficiency} = \frac{\text{Min.rate caught}}{\text{Average rate applied}} \quad \text{.... (13.7)}$$

Lesson 14. Design of Sprinkler Irrigation System-I

The sprinkler system is selected considering factors such as land topography, cost of land leveling, soil texture, precipitation intensity of sprinkler nozzle, infiltration capacity of the soil, type of crop being irrigated and overall economics of sprinkler system over conventional irrigation system.

14.1 Sprinkler System Layout

Important factors affecting sprinkler system layout are topography, field shape and the location of the water source. Several alternate layouts are considered to select the best layout after careful analysis and pipe size. Depending on the water source location, the layout of laterals, main and sub mains are decided. The source of water and pumping plant should be located in such a way so as to minimize the pipe length that ultimately affects the pumping cost. In case of drilling a well it should be located in the center of the farm. The layout of the mains will depend on location of well. Fig. 14.1 shows the layout of stationary pump and water source at center of field and laterals are moved to successive position up one side of the main and then down on the other side. Fig. 14.2 shows movable pumping set and portable sprinkler unit drawing water from a field channel running along one edge of the farm. In this system a portable pumping set and sprinkler unit with the lateral extending to the field are used to draw water directly from a stream/ channel and distribute in farm. Another alternative is to have a permanent pumping plant at the source and distribute the water in buried pressure pipelines. These pipelines will usually run down the center of the field so that the outlets offer little hindrance to tillage and other farm operations.

Lateral should be laid across prominent land slopes to minimize the variation of pressure along the lateral. The American Society of Agricultural Engineers (ASAE) recommends that along the lateral pressure variation in set move and solid set systems should not exceed ± 10 per cent of the design lateral pressure. Thus if the design lateral pressure was 300 kPa, the pressure at any sprinkler should not be less than 270 kPa or greater than 330 kPa. When it is necessary to run laterals up and down prominent slopes it is preferable for water to flow down slope rather than up slope. This will compensate the head loss due to friction and also shorten the lateral length for the given pipe size. Laying laterals on uphill should be avoided wherever possible. In case water is required to flow on uphill the length of lateral can be reduced or flow regulators should be used.

Mains or sub mains are normally run up and down the slopes when laterals run across prominent land slopes. Fig 14.3 shows layouts for set move sprinkler system. When it is necessary to run laterals up and downhill, main lines or sub mains should be located on ridges (Fig 14.c, d, e & f) to avoid laterals that run uphill. Split lateral layouts use set move laterals that may operate on either side of them (Fig 14.3 a, b & e). The labour requirement is reduced by eliminating the need for moving lateral pipes back to the starting point (as is necessary in Figs. 14.3 c & d).

To obtain a reasonable degree of uniformity in the discharge of each sprinkler, the mains should be located in the general direction of the steepest slope, with the laterals at right angles thereto and as close as in practical to the contour. The usual design is based on the lateral being level. If the lateral slopes upgrade appreciably, it is difficult to design laterals for a reasonable length. If its slopes downgrade, the length can be longer than usual, but rarely does the slope remain uniform for each setting.

The general guide lines for set-move sprinkler system are stated below:

i) Mains should be laid up and downhill.

ii) Laterals should be laid across slope or nearly on the contour.

iii) For multiple lateral operations, lateral pipe sizes should be limited to not more than two diameters.

iv) If possible, water supply should be chosen nearest the center of area.

v) Layouts should facilitate minimal lateral movement during the season.

vi) Differences in number of sprinklers operating for various setups should be held to minimum.

vii) Booster pumps should be considered where small portions of field would require high pressure at the pump.

viii) Layout should be modified to apply different rates and amounts of water where soils are greatly different in the design area.

ix) Mainline and sub main layout is keyed to lateral layout.

x) When laterals run across prominent slopes, mainline or sub mains will normally run up and down the slopes.

xi) When it is necessary to run laterals up and down hill, mainlines or sub mains should be located on ridges to avoid laterals that run uphill.

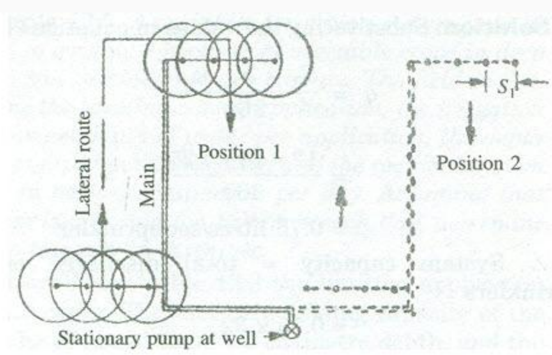


Fig. 14.1. Layout Plan for Sprinkler Irrigation System for Stationary Water Source Well and Pump. (Source: Michael, 2010)

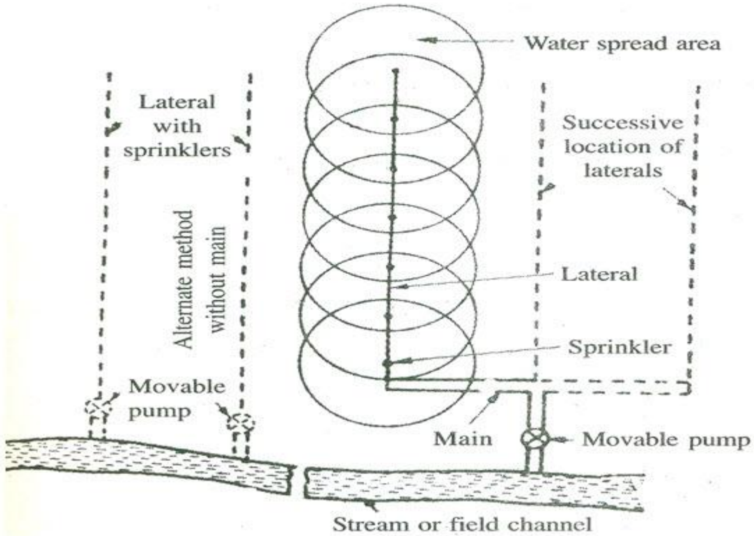


Fig. 14.2. Typical Field Layouts for Fully Portable Sprinkler Units Drawing Water from Streams or Field Channels. (Source: Michael, 2010)

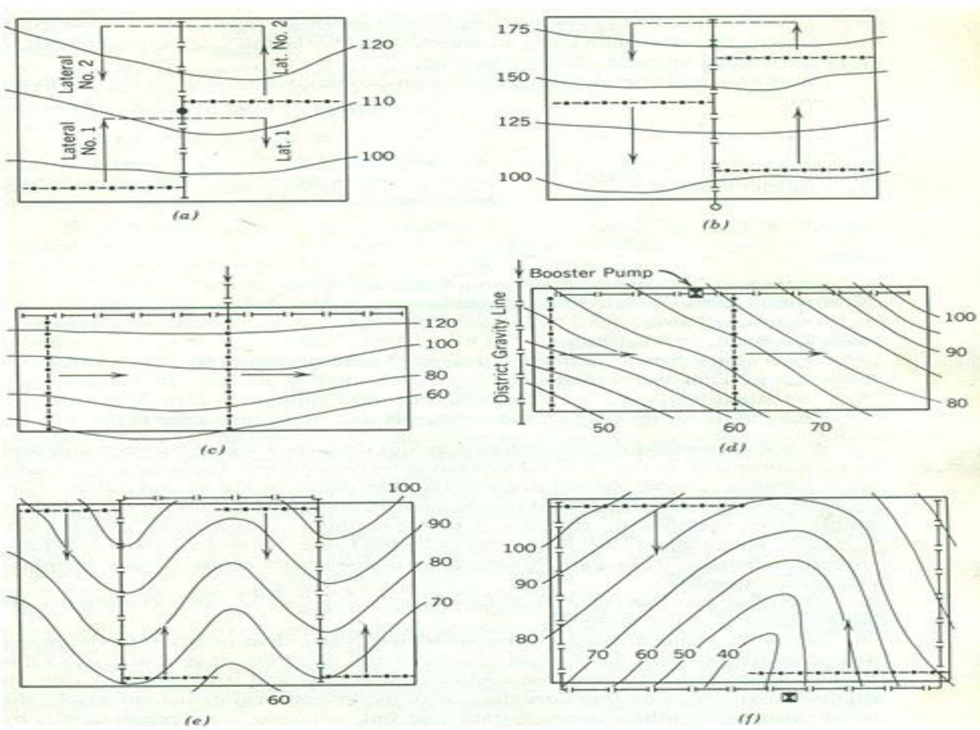


Fig. 14.3. Some layouts for set-move sprinkle systems. (a) Layout on moderate, uniform slopes with water supply at center (b) Layout illustrating use of odd number of laterals to provide required number of operating sprinklers. (c) Layout with gravity pressure where pressure gain approximates friction loss and allows running laterals downhill. (d) Layout illustrating area where laterals have to be laid downslope to avoid wide pressure variation caused by running laterals upslope. (e) Layout with two main lines on ridges to avoid running laterals uphill. (f) Layout with two main lines on the sides of the area to avoid running the laterals uphill.

(Source: James, 1988)

14.2 Parameters for Design of Sprinkler Irrigation System

The basic objective of sprinkler irrigation system is to apply uniform depth of water at predetermined application rate. The sprinkler irrigation system should be designed properly to achieve high irrigation efficiency. The inventory of resources and climatic conditions of the field area are primarily required for the design of sprinkler irrigation system.

14.2.1 Inventory of resources and other parameters

Land: Land is often a major factor in irrigation system design as it influences the selection of sprinkler device, irrigation efficiency, costs of land development, labour requirements, range of possible crops, etc. The major factors of land which have a special bearing on sprinkler irrigation design are: slope, infiltration rate, effective soil depth, texture & structure of soil and size & shape of field.

Water: The source of water supply for sprinkler irrigation can be surface water (river, canal, pond etc.) or ground water (a tube well or open well). Adequate water availability & quality parameters play an important role in the design of sprinkler irrigation system.

Climate: Important climatic data required are solar radiation, temperature, relative humidity, evapotranspiration rate, precipitation or rainfall and wind speed. These climatic parameters are required to estimate peak consumptive use rate as well as total seasonal evapotranspiration of crop(s).

Source of power: Electricity, diesel, solar, wind and biofuels are used to pump water from the source. The selection of pump depends on type of power used to operate pump.

14.2.2 Soil water parameters

Net depth of water application

The depth of water application is the quantity of water, which should be applied during irrigation in order to replenish the water used by the crop during evapotranspiration. The difference between field capacity and permanent wilting point will give the available soil moisture (water holding capacity), which is the total amount of water that the crop can use. Depending on the crop sensitivity to stress, the soil moisture should be allowed to be depleted only partially. For most field crops, a depletion of 60 to 65% of the available moisture is acceptable. This is the moisture that will be easily available to the crop without causing undue stress. The maximum net depth to be applied per irrigation can be calculated, using Equation 14.1.

$$d_{net} = (\theta_{FC} - \theta_{WP}) \times D_{rz} \times P \qquad \text{---- (14.1)}$$

where,

d_{net} = readily available moisture or net depth of water application per irrigation for the selected crop, mm

θ_{FC} = soil moisture at field capacity, mm/m

θ_{WP} = soil moisture at the permanent wilting point, mm/m

D_{rz} = the depth of soil that the roots exploit effectively (m)

P = the allowable portion of available moisture permitted for depletion by the crop before the next irrigation

In order to express the depth of water in terms of the volume, the area proposed for irrigation is multiplied by depth.

Volume of water to be applied (m^3) = 10 x A x d ----(14.2)

where,

A = area proposed for irrigation, ha

d = depth of water application, mm

Example 14.1

A twenty hectare area has medium texture loam soil grown with Wheat crop peak. Daily water use of wheat crop is 6.2 mm day^{-1}. The available soil moisture ($\theta_{FC} - \theta_{WP}$) is 120 mm m^{-1}. The allowable soil moisture depletion is 50%. The crop root zone depth (D_{RZ}) is 0.8 m. Soil infiltration rate is 6 mm h^{-1}. The other climatic data are: average wind speed 10 km h^{-1}. Determine the maximum net depth of water application.

Solution:

Using Equation 14.1, net depth of water application per irrigation for the selected crop is computed as

d_{net} = 120 x 0.8 x 0.5 = 48 mm

For an area of 20 ha, net application of 9600 m^3 (10 x 20 x 48) of water will be required for irrigation to bring the root zone depth of the soil from the 50% allowable depletion level to the field capacity (Equation 14.2).

Irrigation frequency

Irrigation frequency refers to the number of days between irrigations during periods without rainfall. Irrigation frequency depends on crop, soil and climate. After establishing the net depth of water application, the irrigation frequency at peak moisture rate of crop should be determined using the following equation 14.3.

Irrigation frequency (F) = d_{net} / wu ----(14.3)

Where, F = irrigation frequency, days; d_{net} = net depth of water application, mm

wu = peak daily water use, mm day^{-1}.

Example 14.2

The peak demand for wheat was estimated as 6.2mm day^{-1}. Using the data available in Example 14.1, determine the irrigation frequency.

Solution:

Irrigation Frequency (F) =48 mm / 6.2 mm/day = 7.7 days

The irrigation system should be designed to provide 48 mm in every 7.7 days. For practical purposes, fractions of days are not used for irrigation frequency. Hence the irrigation frequency in this example is taken as 8 days. The corresponding net depth of d_{net} of water application

d_{net} = 6.2x 8 = 49.6 mm

The moisture depletion

= 49.6/(120 x 0.8) = 0.52

The question arises as to whether the irrigation system should apply the d_{net} in 8, 7, 6, right down to 1 day. This choice will depend on the flexibility the farmer would like to have and his/her willingness to pay the additional cost for different levels of flexibility. If irrigation is to be completed in 1 day, the system becomes idle for the remaining 7 days, and the cost of the system would be exorbitant, since larger sizes of irrigation equipment would be required. On the other hand, for all practical purposes and in order to accommodate the time for cultural practices (spraying etc), it is advisable that irrigation is completed in less than the irrigation frequency. In the case of our example, 7 days irrigation and 1 day without irrigation is considered adequate. The 7 days required to complete one irrigation in the area under consideration is called the irrigation cycle.

Gross depth of water application

The gross depth of water application (d_{gross}) equals the net depth of irrigation divided by the farm irrigation efficiency. It should be noted that farm irrigation efficiency includes possible losses of water from pipe due to leakage or from other sources.

$d_{gross} = d_{net}/E$ ------(14.4)

Where E = the farm (or unit) irrigation efficiency.

The farm irrigation efficiency of sprinkler systems varies from climate to climate.

Example 14.3

Assuming a moderate climate for the area under consideration and using application efficiency of 75% of sprinkler irrigation, determine the gross depth of irrigation.

d_{gross} =49.6/ 0.75= 66.13 mm

14.2.3 System capacity

The next step is to estimate the system capacity. The system capacity (Q), can be estimated using Equation 14.5 given below

$Q = (10 \times A \times d_{gross}) / (I \times Ns \times T)$ -----(14.5)

Where Q = system capacity, $m^3 h^{-1}$; A = area, ha; d = gross depth of water application, mm; I = irrigation cycle, days; Ns = number of shifts per day; T = irrigation time per shift, h.

Example 14.4

The irrigation system operates for 11 hours per shift. Two shifts per day during peak demand is used in each irrigation cycle of 7 days to complete irrigation in 20 ha area. Determine the capacity of irrigation system.

Solution: A=20 ha, d_{gross}=66.13 mm, N_s=2, I = 7 days, T =11 h.

Substituting values in Equation 14.5, the system capacity is

$Q = (10 \times 20 \times 66.13) / (7 \times 2 \times 11)$

$Q = 85.88\ m^3 h^{-1}$

14.2.4 Sprinkler systems selection parameters

Sprinkler selection and spacing

Based on specifications furnished by the manufacturers of the equipment the sprinkler system components are selected. The important parameters include in selection are diameter of coverage, pressure available, sprinkler discharge, combination of sprinkler spacing and lateral moves, application rate suiting to soil and wind conditions. The required discharge of an individual sprinkler is a function of the water application rate and the two-way spacing of the sprinklers. The maximum application rate for different types of soils at different land slopes is given in Table 14.1.

Discharge from a sprinkler is computed by

$$q = \frac{s_1 \times s_m \times I}{3600} \quad \ldots. (14.6)$$

where,

q = required discharge of individual sprinkle, Ls^{-1}

= spacing of sprinklers along the laterals, m

= spacing of laterals along the main, m

I = optimum application rate, mm h^{-1}

Table 14.1 Maximum application rate for different type of soils at different land slopes, cm h^{-1}

Soil texture and profile	0 to 5% slope	5 to 8 % slope	8 to 12 % slope
Coarse sandy soils to 2 m	5.10	3.75	2.54
Coarse sandy soils over more compact soils	3.75	2.54	1.9
Light sandy loams to 2 m	2.54	2.03	1.5
Light sandy loams over more compact soil	1.9	1.27	1.02
Silt loam to 2 m	1.27	1.02	0.76
Silt loams over more compact soils	0.76	0.63	0.38
Heavy textured clays or clay loams	0.38	0.25	0.20

Source: Adapted from SCS (1993).

Example 14.5

A sprinkler system 18 m spacing along the main and 12 m along the laterals is used to irrigate crop grown on coarse sandy soil over more compact soil land slope of 3 per cent. Twenty sprinklers are used to irrigate field. Determine the total system capacity.

Solution:

Discharge from a single sprinkler $q = \frac{s_1 \times s_m \times I}{3600}$

=12 m, = 18 m, I =3.75 cm h^{-1}= 37.5 mm h^{-1}, q = 0.75 L s^{-1}

System capacity (q) = 20 × 0.75 =15 L s^{-1}

Height of sprinkler riser pipes

Sprinklers are located just above the crops to be irrigated and therefore, the height of the risers depends upon the maximum height of the crop. To avoid excessive turbulence in the riser pipes the minimum height of riser is 300 mm for 25 mm diameter and 150 mm for 15 mm to 20 mm diameter. In general, 900 mm long G.I. pipe of 25mm diameter is used.

Sprinkler spacing

The uniformity of water distribution from sprinklers depends on the pressure of water, wind velocity, rotation of sprinklers, spacing and nozzle diameter. The spacing of sprinklers in a lateral and the laterals spacing are adjusted considering all these parameters. Generally at satisfactory desired operating pressure the water distribution beneath sprinkler head accumulate more and depth decreases gradually with distance from the sprinklers.

Normally sprinklers are spaced at 50 per cent of the diameter of the coverage by an individual sprinkler. If there is a wind of considerable speed, the spacing between sprinklers is reduced. Table 14.2 is used to adopt sprinkler spacing under windy condition. This overlap is desired to achieve uniform application on water.

Table: 14.2 Spacing of sprinklers for different wind speed.

Sl.No.	Average wind speed	Spacing
1	No wind	65% of the water spread area of a sprinkler
2	0-6.5 km h^{-1}	60% of the water spread area of a sprinkler
3	6.5 to 13 km h^{-1}	50% of the water spread area of a sprinkler
4	Above 13 km h^{-1}	30% of the water spread area of a sprinkler

Source: Michael (2010)

Lesson 15. Hydraulic Design of Sprinkler Systems

15.1 Introduction

Sprinkler system pipe lines are classified as mainlines, sub-mains or laterals. Mainline convey water from the source and distribute it to the sub-mains. The sub-mains convey water to the laterals that supplies water to sprinklers. Some lines sprinkler systems do not have sub-mains in such systems laterals are connected directly with the main pipe line.

Pipe line for sprinkler systems is pressurized. The pipe lines must supply water at desired pressure to each sprinkler and lateral. These pipe lines be strong enough to with stand expected operating and surge pressures. The pipe materials and loading of buried pipes are important factors that affect the design and operation of pipe lines for sprinkler systems. Asbestos –cement, Aluminum, steel, Poly vinyl chloride (PVC) plastic and High Density Poly Ethylene (HDPE) are standard pipe materials used for sprinkler system.

15.2 Computation of Pressure Variation in Pipes

The performance of sprinklers system is related to operating pressure in the pipe line, the frictional loss in pipe and fitting, and differentials elevations caused pressures to vary in a field. Frictional loss causes the pressure to decreases in the downstream direction, while chances in evaluations can cause either an increase or decrease in pressure (depending on where the evaluation is downhill or uphill). The difference in pressure between upstream and downstream of a pipe line can be estimated by

$$H_d = H_u - 9.81\,(h_l \pm \Delta Z) \qquad \ldots\ldots (15.1)$$

where

H_d, H_u = pressure at down and upstream positions, respectively (kPa).

h_l = this is energy loss in pipe between up and downstream positions (m).

ΔZ = difference in elevation between up and downstream positions (m).

ΔZ is (+) when change in elevation between the up- and downstream positions is uphill. This sign is (-) when the elevation at the upstream location exceeds the elevation at the downstream location.

$$h_l = F\,H_f + M_l \qquad \ldots.(15.2)$$

F = constant that depends on number of outlets(sprinkler or laterals) removing water from the pipe between the up- and downstream location. The value of F can be selected from Table 15.1. F also depends on the method used estimate head loss due to friction (H_f).

The value of F can be computed from Equation 15.3 when distance to the first sprinkler equals the sprinkler head spacing.

F =
$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2} \qquad \ldots.(15.3)$$

The values of F can be estimated from Equation 15.4 when the distance to the first sprinkler equals one-half of the sprinkler head spacing.

F =
$$F = \frac{1}{2N-1} + \frac{2}{(2N-1)N^m}\left[\sum_{i=1}^{N-1}(N-i)^m\right] \qquad \ldots.(15.4)$$

m = a constant depends on a particular equation to be used to compute H_f

N = no. of sprinklers or outlets.

H_f =friction loss in pipe between up and downstream locations(m)

M_l minor loss through fittings (m)

Minor losses caused by sprinkler risers and other fittings are usually small and these are neglected.

Head loss due to friction (in pipe line can be computed using following equation

$$H_f = \frac{(K)(c)(L)(Q^m)}{D2^{m+n}} \qquad \ldots.(15.5)$$

where

K = friction factor that depends on pipe material

L = length of pipe (m)

Q = flow rate (L min^{-1})

D = diameter of pipe (m)

c, m, n are constants to be used from following Table 15.2

Table 15.1. Correction factor 'F' for friction losses in aluminum pipes with multiple outlets

No. of sprin-klers on lateral	1st sprinkler is one sprinkler interval from main	1st sprinkler is 1/2 sprinkler interval from main	No. of sprinklers on lateral	1st sprinkler is one sprinkler interval from main	1st sprinkler is1/2 sprinkler interval from main
1	1.000	1.000	16	0.365	0.345
2	0.625	0.500	17	0363	0.344
3	0.518	0.422	18	0.361	0.343
4	0.469	0393	19	0.360	0.343
5	0.440	0.378	20	0.359	0.342
6	0.421	0.369	22	0.357	0.341
7	0.408	0.363	24	0.355	0.341
8	0398	0.358	26	0.353	0.340
9	0.391	0.355	28	0.351	0.340
10	0.385	0.353	30	0.350	0.339
11	0.380	0.351	35	0.347	0.338
12	0.376	0.349	40	0.345	0.338
13	0.373	0.348	50	0.343	0.337
14	0.370	0.347	100	0.338	0.337
15	0.367	0.346	>100	0.335	0.335

(Source: Michael A.M (2010))

Table 15.2 Constants needed to use Equation 15.5

Method of Computing,	c (SI Units)	m	n
Darcy –Weisbach	277778	2.0	1.0
Hazen- Williams	591722	1.85	1.17
Scobey	610042	1.90	1.10

For the Darcy- Weisbach equation, K in Eq. 15.5 is given by

K = 0.811 (

$$K = 0.811\,(\frac{f}{g}) \qquad \ldots.\ (15.6)$$

)

where

f = friction factor to be obtained from Moody diagram

g = acceleration due to gravity (9.81 m s^{-2})

For Hazen- Williams Equation, K in Eq. 15.5 is given by

$$K = (0.285\ C)^{-1.852} \qquad \ldots.\ (15.7)$$

The value of C depends on type of pipe material. It ranges from 100 (Brick sewer) to 150(Cement lined). For Plastic pipe, C is 140-150.

For Scobey Equation, K in Eq. 15.5 is given by

$$K = \frac{K_S}{348} \qquad \ldots..\ (15.8)$$

The values of depends on types of pipe material its fittings and diameter. It ranges from 0.33 (75 mm diameter Welded steel pipe) to 0.43 (Aluminum pipe with coupler each of 6 m long).

Table 15.3 is ready reckoner table for estimation of head loss due to friction from Aluminum pipe or choosing size of pipe for a given discharge and friction loss.

Table 15.3 Friction loss in meters per 100 meters in lateral line of portable aluminum pipe with coupling (Based on Scobey's formula and 9 meters pipe length)

Flow litres/sec	Diameter of pipe				
	5.0 cm K_s 0.34	7.5 cm K_s 0.33	10.0 cm K_s 0.32	12.5 cm K_s 0.32	15.0 cm K_s 0.32
1.26	0.32				
1.89	2.53				
2.52	4.49	0.565	0.130		
3.15	6.85	0.858	0.198		
3.79	9.67	1.21	0.280		

4.42	12.9	1.63	0.376	0.122	
5.05	16.7	2.10	0.484	0.157	
5.68	20.8	2.63	0.605	0.196	
6.31	25.4	3.20	0.738	0.240	0.099
7.57		4.54	1.04	0.339	0.140
8.83		6.09	1.40	0.454	0.188
10.10		7.85	1.80	0.590	0.242
11.36		9.82	2.26	0.733	0.302
12.62		12.0	2.76	0.896	0.370
13.88		14.4	3.30	1.07	0.443
15.14		16.9	3.90	1.26	0.522
16.41		19.7	4.54	1.47	0.608
17.67		22.8	5.22	1.70	0.700
18.93		25.9	5.96	1.93	0.798
20.19		29.3	6.74	2.18	0.904
21.45		32.8	7.56	2.45	1.02
22.72		36.6	8.40	2.74	1.13
23.98		40.6	9.36	3.03	1.26
25.24		44.7	10.3	3.34	1.38
26.50			11.3	3.66	1.51
27.76			12.3	4.00	1.66
29.03			13.4	4.35	1.80
30.29			14.6	4.72	1.95
31.55			15.8	5.10	2.12
34.70			18.9	6.12	2.52
37.86			22.2	7.22	2.98

41.01			25.9	8.40	3.46
44.17			29.8	9.68	3.99
47.32			33.8	11.0	4.54
50.48				12.5	5.15
53.63				14.0	5.78
56.79				15.6	6.44
59.94				17.3	7.14
63.10				19.0	7.86

(Source: Michael A.M (2010)

15.3 Design of Sprinkler Laterals

The sprinklers are attached on laterals at equal spacing. The flow through lateral pipe is spatially varied with decreasing discharge. In spatially varied with decreasing discharge. In the beginning, the flow will equal the combined discharge of all the sprinklers. This will decrease along the line until, at the farthest end, there will be only the flow of the last sprinkler. Therefore the friction loss in a lateral will be much less than if the total flows were carried through the entire length of the line. It is recommended that the total pressure variation is the laterals should not exceed more than 20% of the higher pressure.

Where, the friction loss, H_f in the laterals is within 20% of the average pressure.

The average head (H_a) in a sprinkler line can be expressed approximately by

$$H_a = H_O + \frac{1}{4} H_f \qquad \text{.... (15.9)}$$

In which H_O = pressure at the sprinkler at the sprinkler on the farthest end (Fig. 15.1).

H_f = head loss due to friction

If the lateral is on nearly level land or on the contour, the pressure head (H_n) at the main is given by

$$H_n = H_o + H_f \qquad \text{.... (15.10)}$$

By solving for H_o, in (15.9) by substituting in Equation (15.10), and by making an allowance for differences in elevation along the lateral

$$H_n = H_a + \frac{3}{4}H_f \pm \frac{3}{4}H_e + H_r \ldots. (15.11)$$

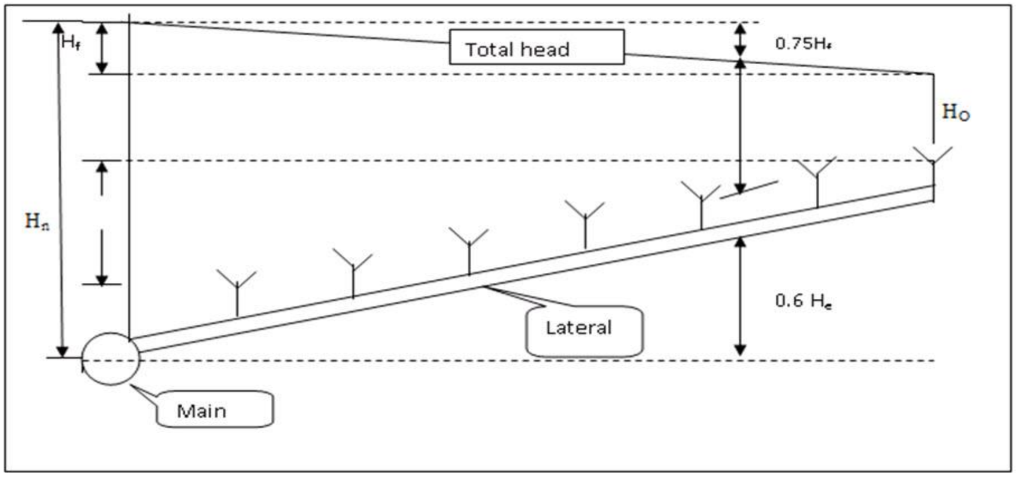


Fig. 15.1 Pressure profile in a lateral laid uphill

in which,

H_e = maximum difference in elevation between the first and last sprinkler, m

H_r = the riser height, m

The term $\frac{3}{4}H_f$ is positive if lateral runs up the slope and negative, if lateral runs down the slope. The term is an approximation since allowance for the difference in elevation varies with number of sprinklers on the laterals.

Allowance due to lateral running on uphill and downhill conditions should be made while determining the head variation. The design capacity for sprinklers on lateral is based on the average operating pressure.

Size of Main Line Pipe

The size of main line is selected such that the annual water application cost is as low as possible. Normally friction loss of 3m for small system and 12m for large systems is allowed.

15.4 Pumps and power units

In selecting a suitable pump, it is necessary to determine the maximum total head against which the pump is working. This may be determined by in which,

$$H_t = H_n + H_m \pm H_J + H_s$$

H_t= total design head against which the pump is working, m
H_n = maximum head required at the main to operate the sprinklers on the lateral at the required average pressure, including the riser height, m

H_m = maximum friction loss in the main and in the suction line, m

H_J = elevation difference between the pump and the junction of the lateral and the main, m, and

H_s= elevation difference between the pump and the source of water after drawdown, m

The amount of water that will be required is determined by multiplying the number of sprinklers by the capacity of each. When the rates of pumping are known, the pump may be selected from rating curves or tables provided by manufactures.

The horse power requirement of pump can be estimated by

$$h_p = \frac{\gamma Q H}{75\eta}$$

where,

= unit of water

Q= pump discharge

H= Total head (m)

= efficiency of pump

Example: 37.1

Design a sprinkler irrigation system to irrigate 5 ha Wheat crop.

Assume

Soil type = silt loam

Infiltration rate at field capacity = 1.25 cm/h

Water holding capacity = 15 cm/m

Root zone depth = 1.5 m

Daily consumptive use rate = 6 mm d^{-1}

Sprinkler type = Rotating head

Solution:

Step I

Maximum water application rate = 1.25 cm/h

Step II

Total water holding capacity of the soil =15 x 1.5 = 22.5 cm

Let the water be applied at 50% depletion, hence the depth of water to be applied

= 0.50 x 22.5 = 11.25cm

Let the water application efficiency be 90 per cent

Depth of water to be supplied = 11.25 / 0.9 = 12.5 cm

Step III

For daily consumptive use rate of 0.60 cm;

Irrigation interval = 11.25 / 0.6 = 19 days

In period of 19 days, 12.5 cm of water is to be applied on an area of 5 ha. Hence assuming 10 hrs. of pumping per day, the sprinkler system capacity would be

$$= \; = \frac{5 \times 10^{4} \times 12.5 \times 10^{-2}}{19 \times 10 \times 3600} = 0.009 \text{ m}^3\text{s}^{-1} \; = 0.009 \text{ m}^3\text{s}^{-1}$$

Step IV

Spacing of lateral (Sm) = 18 m

Spacing of Sprinklers in lateral (Si) = 12 m

This selection is based on after the following consideration:

Operating pressure of nozzle = 2.5 kg/cm^2

Maximum application rate = 1.25 cm/h

Referring sprinkler manufacturer's M/S NOCIL, Akola chart (Table 15.4), the nozzle specifications with this operating pressure and application rate is:

Nozzle size : 5.5563 x 3.175 mm

Operating pressure : 2.47 kg/cm^2 and

Application rate : 1.10 cm/hr (which is less than the maximum allowable application rate)

Diameter of coverage : 29.99 ≈ 30.0 m

Discharge of the nozzle : 0.637 L s^{-1} = 0.637 x 10^{-3} m^{3}s^{-1}

Step V

Total no. of sprinkler required = $\frac{0.009}{0.637 \times 10^{-3}}$ = 14.12 ≈ 14 sprinklers

Therefore 7 nos. of sprinklers on each lateral.

Step VI

The sprinklers will be spaced at 12m intervals on each of two lateral lines spaced 18 m apart.

Step VII

Total length of each lateral = 12 x 7 = 84

Operating pressure = 2.47 kg/cm^2

Total allowable pressure variation in the pressure head is 20%, hence maximum allowable pressure variation in pressure = 0.2 x 2.47 = 0.494 kg/cm^2 = 4.94 m

Variation of pressure due to elevation = 2 m

Permissible head loss due to friction = 4.94 – 2 = 2.94 m

Total flow through the lateral = 7 x 0.637 x 10^{-3} = 4.459 x 10^{-3} m^{3}s^{-1}

$$\text{Reduction factor (F)} = \frac{1}{3} + \frac{1}{2 \times 7} + \frac{1}{6 \times 7^2} = 0.333 + 0.071 + 0.0034 = 0.407$$

Head loss due to friction =

$$H_f = \frac{0.811 \times 0.04 \times 277778 \times 84 \times (4.459 \times 60)^2}{9.81 \times D^5} \times 0.407$$

$$\text{Or, } 2.94 = \frac{0.811 \times 0.04 \times 277778 \times 84 \times (4.459 \times 60)^2}{9.81 \times D^5} \times 0.407$$

$$\Rightarrow D^5 = \frac{0.811 \times 0.04 \times 277778 \times 84 \times (4.459 \times 60)^2}{9.81 \times 2.94} \times 0.407$$

$$\Rightarrow D = 59.79 \approx 63 \text{ mm}$$

Hence diameter of lateral = 63 mm

The head required to operate the lateral lines (H_m) = 24.7 + 2.94 + 2 + 1 = 30.6 m

Frictional head loss in main pipe line (H_f) = 30.6 0.2 = 6.12 m

Calculating in the same way as done in case of lateral

$$6.12 = \frac{0.811 \times 0.04 \times 277778 \times 36 \times (0.009 \times 1000 \times 60)^2}{9.81 \times D^5}$$

$$D^5 = \frac{0.811 \times 0.04 \times 277778 \times 36 \times (0.009 \times 1000 \times 60)^2}{9.81 \times 6.12}$$

Or, D = 69.10 ≈ 75 mm

Total design head (H) = $H_m + H_f + H_j + H_s$

Where

H_j = Difference in highest junction point of the lateral and main from pump

level = 0.5 m (assume)

H_s = Suction lift (20 m, assume)

H = 30.6 + 6.12 + 0.5 + 20 = 57.22 m

The pump has to deliver 0.009 m^3s^{-1} of water against a required head of 57.22 m

Hence, the horse power of a pump with 60% efficiency

$$= \frac{0.009 \times 57.22 \times 10^3}{0.6 \times 75}$$ = 11.44 hp

(Source: Tiwari, 2009)

Table: 15.4 Design specifications of sprinkler with different nozzle size and operating pressure for high pressure models Model HP.

Nozzle Size		Operatin g Pressure		Dia of Spray		Discharge		Application rate									
								12 x 12		12 x 18		18 x 18		18 x 24		24 x 24	
Range	Sprea d	Kg/c m^2	p si	m	ft	L s^{-1}	gp m	cm /h	in/ h	cm /h	in/ h	cm /h	in/ h	cm /h	in/ h	cm /h	in/ h
7/32" 5.5563 mm	1/8" 3.175 mm	2.11 2.47 2.82 3.17 3.52 4.23	3 0 3 5 4 0 4 5 5	27 .7 29 .9 32 .0 33 .9 35	92. 3 99. 7 10 6.7 11 3.0 11	0.5 88 0.6 37 0.6 80 0.7 21 0.7	7.7 6 8.4 0 8.9 7 9.5 1 10.	1.5 0 1.6 0 1.7 0 1.8 0 1.9	0. 58 0. 63 0. 67 0. 71 0.	NA 1.1 0 1.1 0 1.2 0 1.3 0	N A 0. 42 0. 45 0. 47 0.	NA 0.7 1 0.7 6 0.8 0 0.7 4	N A 0. 28 0. 30 0. 32 0.	NA NA NA NA 0.6 3 0.6 9	N A N A N A N A 0.	NA NA NA NA NA 0.5 2	N A N A N A N A N

			0 6 0	.8 39 .2	9.3 13 0.7	60 0.8 33	03 10. 99	0 2.1 0	75 0. 82	1.4 0	50 0. 53	0.9 3	33 0. 36		25 0. 27		A 0. 20
9/32″ 7.1438 mm	1/8″ 3.175 mm	2.11 2.47 2.82 3.17 3.52 4.23	3 0 3 5 4 0 4 5 5 0 6 0	31 .4 34 .0 36 .3 38 .5 40 .6 44 .5	10 4.7 11 3.3 12 1.0 12 8.3 13 5.3 14 8.3	0.8 78 0.9 50 1.0 16 1.0 77 1.1 35 1.2 44	11. 59 12. 54 13. 41 14. 21 14. 98 16. 42	2.2 0 2.4 0 2.5 0 2.7 0 2.8 0 3.1 0	0. 86 0. 94 1. 00 1. 10 1. 10 1. 20	1.5 0 1.6 0 1.7 0 1.8 0 1.9 0 2.1 0	0. 58 0. 62 0. 67 0. 71 0. 74 0. 82	0.9 8 1.1 0 1.1 0 1.2 0 1.3 0 1.4 0	0. 39 0. 42 0. 44 0. 47 0. 50 0. 54	NA NA 0.8 5 0.9 0 0.9 5 1.0 0	N A N A 0. 33 0. 35 0. 37 0. 41	NA NA NA NA 0.7 1 0.7 8	N A N A N A 0. 28 0. 31
3/8″ 9.525 mm	1/8″ 3.175 mm	2.11 2.47 2.82 3.17 3.52 4.23	3 0 3 5 4 0 4 5 5 0 6 0	36 .3 39 .2 41 .9 44 .5 46 .9 51 .4	12 1.0 13 0.7 13 9.7 14 8.3 15 6.3 17 1.3	1.4 49 1.5 68 1.6 76 1.7 77 1.8 72 2.0 52	19. 12 20. 69 22. 12 23. 45 24. 71 27. 08	3.6 0 3.9 0 4.2 0 4.4 0 4.7 0 5.1 0	1. 40 1. 50 1. 60 1. 70 1. 80 2. 00	2.4 0 2.6 0 2.8 0 3.0 0 3.1 0 3.4 0	0. 95 1. 00 1. 10 1. 20 1. 20 1. 30	1.6 0 1.7 0 1.9 0 2.0 0 2.1 0 2.3 0	0. 63 0. 69 0. 73 0. 70 0. 82 0. 90	1.2 0 1.3 0 1.4 0 1.5 0 1.6 0 1.7 0	0. 48 0. 51 0. 55 0. 58 0. 61 0. 67	NA 0.9 8 1.0 0 1.1 0 1.2 0 1.3 0	N A 0. 39 0. 41 0. 44 0. 46 0. 50

Table:15.5 Design specifications of sprinkler with different nozzle size and operating pressure for low pressure models Model LP

Nozzle Size		Operating Pressure		Dia of Spray		Discharge		Application rate									
								6 x 6		6 x 9		9 x 9		6 x 12		12 x 12	
Range	Spread	Kg/cm²	psi	m	ft	L s⁻¹	gpm	cm/h	in/h	cm/h	in/h	cm/h	in/h	cm/h	in/h	cm/h	in/h
7/32″ 5.556 3mm	1/8″ 3.175 mm	1.06 1.41 1.76 2.11 2.47 2.87	15 20 25 30 35 40	19 .6 22 .6 25 .3 27 .7 29 .9	65. 3 75. 3 84. 3 92. 3 99. 7	0.41 7 0.48 1 0.53 7 0.58 8 0.63 7	5.5 0 6.3 4 7.0 8 707 6 8.4 0	4. 20 4. 80 N A N A N A	1.6 0 1.9 0 NA NA NA NA	2. 80 3. 20 3. 60 3. 90 4. 20	1.1 0 1.3 0 1.4 0 1.5 0 1.7 0	1. 90 2. 10 2. 40 2. 60 2. 80	0.7 3 0.8 4 0.9 4 1.0 0 1.1 0	2. 10 2. 40 2. 70 2. 90 3. 20	0.8 2 0.9 5 1.1 0 1.2 0 1.3 0	1. 00 1. 20 1. 30 1. 50 1. 60	0. 4 1 0. 4 7 0. 5 3 0.

				32.0	106.7	0.680	8.97	NA		4.50	1.80	3.00	1.20	3.40	1.30	1.70	58 0.63 0.67
13/64" 5.1594mm	1/8" 3.175 mm	1.06 1.41 1.76 2.11 2.47 2.82	15 20 25 30 35 40	18.9 21.8 24.3 26.7 28.9 30.8	63.0 72.7 81.0 89.0 96.3 102.7	0.374 0.431 0.482 0.527 0.571 0.610	4.93 5.68 6.36 6.95 7.53 8.05	3.70 4.30 4.80 NA NA NA	1.50 1.70 1.90 NA NA NA	2.50 2.90 3.20 3.50 3.80 4.10	0.98 1.10 1.30 1.40 1.50 1.60	1.70 1.90 2.10 2.30 2.50 2.70	0.65 0.75 0.84 0.92 1.00 1.10	1.90 2.20 2.40 2.60 2.90 3.10	0.74 0.85 0.95 1.00 1.10 1.20	NA 1.11 1.20 1.30 1.40 1.50	NA 0.42 0.47 0.52 0.56 0.60
5/32" 3.9688mm	1/8" 3.175 mm	1.06 1.41 1.76 2.11 2.47 2.82	15 20 25 30 35 40	16.5 19.1 21.3 23.4 25.3 27.0	55.0 63.7 71.0 78.0 84.3 90.0	0.263 0.303 0.339 0.371 0.401 0.429	3.47 4.00 4.47 4.89 5.29 5.66	2.60 3.00 3.40 3.70 4.00 4.30	1.00 1.20 1.30 1.50 1.60 1.70	1.80 2.00 2.30 2.50 2.70 2.90	0.69 0.80 0.89 0.97 1.10 1.10	1.20 1.30 1.50 1.60 1.80 1.90	0.46 0.53 0.59 0.65 0.70 0.75	1.30 1.50 1.70 1.90 2.00 2.20	0.52 0.60 0.67 0.73 0.79 0.84	NA NA 0.88 0.93 1.00 1.10	NA NA 0.35 0.37 0.39 0.42

Lesson 16. Multipurpose and Special Applications

Sprinkler irrigation system is adaptable to a variety of special uses in addition to ordinary irrigation to control soil moisture. Chemigation involves injecting a water soluble-fertilizer, herbicide, insecticide, fungicide or namaticide into the irrigation system. When fertilizer is injected is called fertigation, which is an important multipurpose function of all types of sprinkle system. Germination, frost protection, bloom delay, micro climate control and disposing of waste water the most important special use functions of sprinkler systems. Some additional special uses of sprinkler equipment are: providing farm fire protection, providing cooling and dust control for feed lots and poultry building, providing moisture for earth fill construction and curing log piles.

16.1 Germination

Application of sprinkler irrigation has been found very effective in seed germination. Particularly when salts contained in irrigation water accumulate on the surface of the furrow irrigated beds, sprinkler irrigation is applied during seed germination to provide a low salinity seed bed (*Robinson, 1968*). This allows seedling roots to penetrate below the zone of salt accumulated on the surface of furrow irrigated beds. Sprinkling water enhances initial radical development.

16.2 Environmental Control

i) Preventing frost damage

Portable and fixed lateral sprinkler irrigation systems can be used to protect crops from frost. The equipment must be specially set up for frost control. There are two approaches to protecting against frost. One is to protect the leaves, flowers or fruit from freezing when temperatures fall. The other is to use evaporative cooling to delay early bud formation on fruit trees until after the last expected frost. The first is called frost protection and the later bloom delay.

Overhead systems are the most versatile and can protect some crops down to temperature as low 7^0C. The liquids in the plant parts being protected have higher freezing point than water due to salts and sugars in them. Buds, blossoms, leaves or young fruit for the crops of greatest interest for frost protection can survive wet bulb temperatures ranging from roughly -1 to -3^0C. The actual lethal temperature depends on the crops and stage development. The protective effect of overhead sprinkling is mainly from the release of 80 kcal/L of latent heat as water freezes. The freezing water encases the plant parts being protected in ice this keeps their temperature at 0^0C, the freezing point of water, which is higher than the lethal temperature. The plant parts being protected will remain at the freezing point of water as long as ice continues to form around them. The main design consideration for overhead frost protection by sprinkling is the recommended application rate for different environmental situations, crops and crop growth stages. The required rate can be easily converted to system capacity, because the area being protected by overhead sprinkling must be watered continuously.

In the fall, deciduous tree, vines and bushes lose their leaves and enter a condition known as winter rest. Plants are normally incapable of growth during this period and fruit buds do not develop until the rest period has been completed. After rest is completed, changes occur in the buds that will eventually cause blossoming and leafing of the trees. The rate of bud development depends upon the air temperature around the buds after the completion of rest. Bud development accelerates and the trees blossom early if the early spring temperatures are above normal. If early bud development is followed by a sudden cold spell, the potential for frost damage becomes serious. Overhead sprinkling can be used to cool the buds before they develop and keep them dormant until after the major danger of frost damage is past. The cooling is caused by evaporation. Therefore, overhead sprinkling for bud delay is not effective during periods of high humidity.

Evaporative cooling with sprinklers during early spring months, when frost danger is still prevalent, seems to be an effective way to delay bud development. Automated sprinkler system has been used to actuate and deactivate irrigation system to delay bud development.

ii) Foliar spraying for micro climate control

Research studies in California, Lousiana and Georgia on some of the crops cooled by sprinkler irrigation are almonds, apples, beans, cherries, carton, cucumbers, grapes, strawberries. At intermittent sprinkling rate of 2 mm h^{-1} with a 15 min on- 15 min off period gave good temperature reduction and improves crop quality. The color of the red delicious apples was found to be enhanced by reducing fruit temperature by over-head sprinkling.

Foliar cooling requires two to six short applications of water every hour, which is practical only with automated fixed sprinkler systems. The small amounts water intermittently applied cool the air and plant, raise humidity and to improve the produce quality and yield. When water is applied on the plant surfaces, the plant is cooled and the excessive transpiration demand reduced. Each crop has an upper demand above which it can no longer function efficiently. Fixed sprinkler systems used for foliar cooling require high quality water and up to double the capacity of ordinary high-frequency system. Foliar cooling systems must have sufficient capacity to satisfy the excess transpiration demand on a minute-by-minute basis through out the peak water use rate days. To accomplish this, the system capacity must be 1.5 to 2.5 times greater than for a conventional periodic move system in similar environment.

iii) Frost and freeze protection

Frost control is another special use for irrigation by coating plants with water, the heat of fusion is released as the water freezes, maintaining plant temperatures that would otherwise drop well below freezing. The ice coating on the plant must be continually in contact with unfrozen water until the ice melts. Sprinkler has been successfully used for frost protection in small fruits, potatoes and grapes (Addink et al., 1980).

16.3 Fertilizer and Chemical Applications

Sprinkler systems are also used to apply fertilizer, herbicides, and pesticides. Both liquid forms that dissolve and dry powder in water suspension can be injected through sprinkler irrigation systems. The main consideration in the design of sprinkler systems for chemical application is the method of injection. The methods to inject chemicals and fertilizers are:

(a) delivering the liquid to the suction side of a centrifugal pump from a supply tank, (b) injecting the chemical into the main lines using a pressure pump, (c) pressurizing the chemical supply tank from the main sprinkler lines and injecting the liquid at the low pressure area of a pitot tube, and (d) pressurizing a supply tank with a pitot tube facing in the upstream direction of flow and then injecting the liquid into the system with a second pitot tube facing downstream.

The most important consideration in designing the injection system is preventing contamination of the water supply. It is also important to provide check and vacuum relief valves (anti-siphon devices) for preventing the chemical from draining or siphoning back into the irrigation well or other water supply. The vacuum and check valves must be located between the pump and the point of chemical injection. If water is bled from the main irrigation supply into the chemical supply tank, the connecting line too must be equipped with a check valve to prevent the supply tank from overflowing and contaminating the adjacent area with chemical solution. In some countries codes are developed for proper plumbing of chemical injection systems into irrigation systems.

The coefficient uniformity of (CU) should be between 80 to 90% for uniform application of the chemicals to the area that is being fertilized or treated with herbicides or pesticides. Non uniform systems would results in poor placement of the chemicals and therefore, poor control.

The sizing of the pump or rate of injection into the sprinkler system should be checked closely so that sufficient quantities of the chemicals can be injected to obtain the desired application rate of the chemical. The rate of injection depends also on whether a continuous injection is made or whether the entire volume of chemical is injected in the beginning or at the end of the irrigation set. Intermittent injection allows the system to be flushed and chemicals to be either flushed from or left on the crop canopy.

16.4 Irrigation for Turf

Turf grasses are used in urban areas to provide multiple benefits to society and the environment. They cover millions of acres of home lawns, commercial properties, roadsides, parks, etc. A turf grass can be watered with a moveable sprinkler or an underground irrigation system. In either case, they require spray overlap for even coverage. Typical lawn sprinklers are inexpensive and must be moved throughout the lawn. A pop-up spray head system allows for greater flexibility in timing cycles and proper application rates. Pop-up lawn spray heads are those which raise

The nozzle above the surrounding grass during operation then drop down to the level of the ground when not in use. The pop-up feature minimizes the need for trimming the grass around the heads and at the same time improves water distribution since the head is high above the grass when in operation. Pop-up spray heads are usually spring-operated and require a certain pressure level to operate the pop-up mechanism. Operation of the pop-up mechanism may be a problem where the water contains large amounts of sulfur, iron or alkalines. Average precipitation of spray nozzles is relatively high, approximately 25 mm h^{-1}. These nozzles are used for rapid watering of lawns. However, use on steep slopes and heavy (clayey) soils may result in runoff. Therefore all irrigated areas of the system should be examined for proper selection and location of nozzles to avoid runoff.

16.5 Effluent Irrigation

Land application of waste waters by sprinkler irrigation can be a cost-effective alternative to conventional waste water treatment. Waste waters are divided into municipal, industrial and agricultural categories. Municipal sewage requires extensive treatment before it can be safely discharged into the natural drainage system. Industrial waste waters may also require extensive treatment. It can range from simple screening to primary and secondary treatment for removing oils, greases, metals, harmful chemicals and pH adjustment and chlorination. The design of a system for land application of waste water is similar to the design of an ordinary sprinkle irrigation system. The rules of good design must be followed, keeping in mind that the effluent is not plain water, but a mixture of water and both dissolved and suspended wastes. Furthermore, waste waters that contain abrasive or corrosive materials will shorten the life of the system. Deep sandy or loamy soils are most suitable for land application of waste water. The soils must be well-drained; therefore, some sites may require subsurface drainage. For best results the application rate should be less than 75% of the infiltration rate of the soil. Either portable aluminum or buried plastic or corrosion resistant pipe may be used for main and lateral lines of periodic-move or fixed sprinkler systems. Single nozzle sprinklers should be used to reduce nozzle clogging.

16.6 Erosion control

Keeping the soil surface continually moist by using sprinkler can control soil erosion by wind. In areas with high winds and sandy soils, it may be necessary to irrigate daily or even more frequently to keep the surface wet for satisfactory erosion control. Solids set systems are found most suitable for wind erosion control. It has been estimated that sprinkling rate of 2.5 mm h^{-1} is adequate for erosion control.

Lesson 17. Operation and Maintenance of Sprinkler System

17.1 Operation of Sprinkler System

Good operation of any irrigation system includes matching the irrigation duration with the rate of application and the intake rate of soil to maximize the fraction of water stored in the root zone. To realize the full benefit of sprinkler system, it must be operated according to design. To achieve uniform application, the sprinkler spacing or move distance need to be adjusted to compensate for variations due to wind or exceptionally hot summer days.

The system should be operated in keeping with good irrigation practices. It should be ensured that the prime mover and the pump are in alignment. For these the drive shaft as well as the pump shaft should lie at nearly the same height to prevent too great an angle on the universal shaft.

While laying the main and lateral pipes, always begin laying at the pump. This necessarily gives the correct connection of all quick coupling pipes. While joining couplings, it is ensured that both the couplings and the rubber seal rings are clean. In starting the sprinkler system, the motor or engine is started with the valves closed. The pump must attain the pressure stated on type-plate or otherwise there is a fault in the suction line. After the pump reaches the regulation pressure, the delivery valve is opened slowly. Similarly, the delivery valve is closed after stopping the power unit. The pipes and sprinkler-lines are shifted as required after stopping. Dismantling of the installation takes place in the reverse order to the assembly described above.

The principle of operation of the hand-move system is based on the movement of the laterals from one position to the next after a predetermined irrigation event. Each irrigation event has a set time that depends on the amount of water required by the crop at that stage of growth. For the semi portable irrigation system, the lateral is coupled directly to the valve control, elbow or to a header, which intern coupled directly to the valve control elbow. After irrigating in one position, the lateral is uncoupled and moved to the next position. Pipes should not be dragged along the ground as this result in damage and besides that soil would enter the pipes. Care should be also taken that when the pipes are moved is an area with electricity lines, there is a no contact with the lines. For drag-hose sprinkler systems, the hose is lateral. The hose is connected with garden tap or turf hydrant at one end and the riser on the other end. Hose clips and adapters are used to secure the hose. After irrigating one position, all sprinklers, risers and tripod are moved to the next position. Of particular importance to this system is that users should clearly mark on the hose all position of the sprinkler, so as to ensure that they place the sprinkler at the same position each time that position is irrigated and also to ensure that the overlap envisaged in the design is maintained.

17.2 Maintenance of Sprinkler System

Irrigation system maintenance is necessary to ensure most efficient use of water that is being applied. The best design cannot compensate for inadequate system maintenance. Maintenance actually deals with system installation. Improper installation will cause trouble throughout the life of the system. A sprinkler system like any other farm equipment needs maintenance to keep it operating at peak efficiency. Parts of the system subject to wear are the rotating sprinkler heads, the pumping set, the couplers and the pipeline. General principle regarding the maintenance of the pipes and fittings and sprinkler heads are given below:

i) Pipes and fittings:

The pipes and fittings normally do not need much maintenance. The following precautions can be observed for pipes and fittings:

Any dirt or sand accumulated on the groove of the coupler in which the rubber sealing ring fits be occasionally cleaned. The pipes made up of Aluminum or plastics should not be dumped on the damp concrete or fertilizer sacks. The pipes are automatically emptied and ready to be moved. When the pump is first started and before the pressure has built up in the system the seals may give a little leakage. With full pressure in the system the couplers and fittings will be effectively leak free.

ii) Sprinkler heads:

The sprinkler heads should be given the following attention.

(a) When moving the sprinkler lines make sure that the sprinklers are not damaged or pushed into the soil.

(b) Do not apply oil, grease or any lubricant to the sprinklers. They are water lubricated and using oil, grease or any other lubricant may stop them from working.

(c) Sprinkler usually has a sealed bearing and the bottom of the bearing there are washers. Usually it is the washers that wear and not the more expensive metal parts. The washers be checked for wear once a season or every six months this is especially important where water is sandy. Replace the washers if worn.

(d) After several seasons operation the swing arm spring may need tightening. This is done by pulling out the spring end at the top and rebending it. This will increase the spring tension. In general check all equipment at the end of the season and make any repairs and adjustment and order the spare parts immediately so that the equipment is in perfect condition to start in the next season.

As a rule, the underground component of the system requires no maintenance. However, at times, because of careless errors during cultural practices, pipes have to be replaced in order for the system to operate at designated pressure. The above ground components of the sprinkler system, it carefully operated and maintained, are expected to last for about 15 years. This would require careful movement of aluminum/ plastic pipe, after each riser and sprinklers have been disconnected from the pipe to facilitate ease of movement to the next position. Portable aluminum / PVC pipes connected through coupling with rubber rings in order to ensure water tight connections. These rings have a life of 2 years and need to be replaced accordingly.

The hoses used for sprinkler systems are rated at 7 meters pressure and are reinforced. There life expectancy is 8 years. However, at times perforations or cuts occur during cultivation. Line joiners can be used to repair the hoses.

With respect to sprinklers, it is necessary that all nozzles are replaced at least every two years (four seasons), in order to maintain the correct flow and distribution of water from the sprinkler. This is particularly important when surface water with high load of suspended solids is used for irrigation. The tension of the sprinkler spring and rear of some of the plastic seals also require attention. It is therefore necessary that every 4-5 years the sprinklers are taken to the supplier for an overall check up.

17.3 Trouble Shooting and Remedies

The following are the general guidelines to identify and remove the common troubles in the sprinkler systems:

1) Pump does not prime or deliver water

a) The pump suction lift should be checked, is it within the limits? If not lower the pump closer to the water surface.

b) Air leak from the suction pipeline and all connections should be checked. All connections and flanges should be made air tight.

c) The strainer of the foot valve should be checked for blockage.

d) Check that the flap in the foot valve in free to open fully.

e) Check the pump gland (s) for air leaks. If required repack the gland (s) using a thick grease to seal the gland satisfactorily.

f) Check that the gate valve on the delivery pipe is fully closed during priming and opens fully when the pump is running.

g) Check that the direction of rotation of the pump is correct.

2. Sprinklers do not turn

a) The operation pressure of pump should be checked.

b) Check that the nozzle is not blocked. Preferably unscrew the nozzle or use a small soft piece of wood to clear the blockage.

c) Sprinkler bearing should be free and smooth. Sprinkler can usually be pushed down towards the riser pipes so that the water pressure flushes out the bearing. If the bearing is still stiff dismantle and then clean it. Oil, grease or any lubricant should not be used.

d) The condition of washers at the bottom of the bearing should be checked and it should be replaced then, if found worn or damaged.

e) The swing arm should be checked for free movement further the spoon which moves into the water stream is not bent by comparing it with a sprinkler which is operating correctly. If it is bent then very carefully bend it bring into position.

f) Adjust the swing arm spring tension. Usually it should not be necessary to pull up the spring by more than about 6 mm.

3. Leakage from Coupler or Fittings

The sealing rings in the couplers and fittings are usually designed to drain the water from the pipes when the pressure is turned off. This ensures that the pipes are automatically emptied and ready to be moved. When the pump is first started and before the pressure has built up in the system the seals may give a little leakage. With full pressure in the system the couplers and fittings will be effectively leak-free. If, however, there is a leakage, check the following:

a) There is no accumulation of dirt or sand in the groove in the coupler in which the sealing ring fits. Clean out any dirt or sand and refit the sealing ring.

b) The end of the pipe going inside the coupler is smooth, clean and not distorted.

c) In the case of fittings such as bends, tees and reducers ensure that the fitting has been properly connected into the coupler.

(Source: Michael, 2010)

Module 4. Fertigation System

Lesson 18. Fertigation

18.1 Introduction

Fertigation is precise application of plant nutrients with irrigation system in the crop root zone according to the crop demand during crop growing season.

In fertigation, fertilizer application is made in a small and frequent dose that feed within scheduled irrigation interval matching the plant water use to avoid leaching. The right combination of water and nutrients is the key for high yield and quality of produce. Table 18.1 provides details of saving in the use of fertilizers and increase in yield.

Table: 18.1 Saving in fertilizer and increase in crop yield due to fertigation as compared to conventional method of fertilizer application

S. No.	Crop	Saving in fertilizer, %	Increase in yield, %
1	Okra	40	18
2	Onion	40	16
3	Broccoli	40	10
4	Banana	20	11
5	Castor	60	32
6	Cotton	30	20
7	Potato	40	30
8	Tomato	40	33
9	Sugarcane	50	40

(Source: Anonymous, 2001)

18.2Need of Fertigation

It has been reported that Indian soils are deficient in nutrients. In order to achieve high crop production it is required to supplement nutrient by adding chemical fertilizers and nutrients. These fertilizers are expensive. Large quantities of fertilizers are imported to meet the growing demand. On the other hand country is facing low fertilizer utilization efficiency hence there is need for using fertigation system.

Fertigation has been seen as a tool that can help to accomplish the goals of agronomic and aesthetic lushness with relative ease. It enhances the efficiency of meeting the nutritional needs of plants. Fertigation allows the selection of nutrient inputs as needed or whatever fits the "prescription" to match stage of growth, time of year, as well as saving in operating money. It is a safer application method, as it eliminates the danger of affecting roots due to higher dose.

18.3Advantages and Limitations of Fertigation

Advantages

- Synchronization with plant requirement: In drip fertigation, fertilizer application is synchronized with plant need which varies from plant to plant. In drip fertigation, the amount and form of nutrient supply is regulated as per the need of critical stages of plant growth.
- Economics: Saving in amount of fertilizer, due to better fertilizer use efficiency and reduction in leaching. Reduction in labour and energy cost by uniform water and nutrient distribution.
- Balanced nutrient availability: Optimization of nutrient balance in soils by supplying the nutrients directly to the effective root zones as per the requirement.
- Higher yield: Greater yield and quality of produce is obtained.
- Higher fertilizer use efficiency: Ensures a uniform flow of water and nutrients. Timely application of small but precise amounts of fertilizers directly at the plant roots zone, this improves fertilizer use efficiency and reduces nutrient leaching below the root zone. Improves availability of nutrients and their uptake by crop.
- Safer application method, as it eliminates the danger affecting roots due to higher dose.

Limitations

- High initial investment: The drip and fertigation equipment components are expensive.
- Relatively higher maintenance cost: The maintenance cost of drip and fertigation system is higher.
- Clogging of drip emitter: Good quality water is very essential. Due to precipitation of chemicals, clogging of drip emitters may cause a serious problem.
- Availability of water soluble fertilizers& its compatibility: It needs water soluble fertilizers, the availability of these types of fertilizers is limited. Adjustment of fertilizers to suit the need is not easy.

- Subsidy in drip system: Area under micro irrigation is increasing mainly because of subsidy in micro-irrigation, if subsidy is withdrawn, the area under micro-irrigation may also reduce. So same may be the fate of fertigation.

- Overdosing: Due to fear of yield loss, because of relatively lower dose of fertilizers in fertigation, farmers have the tendency to add additional fertilizers and irrigation water by traditional methods too. This may result in crop loading (sugar cane) lower yield and lower profits.

18.4 Types of Fertilizers

A large range of fertilizers, both solid and liquid, are suitable for fertigation depending on the physicochemical properties of the fertilizer solution. For large scale field operations, solid fertilizer sources are typically a less expensive alternative to the commonly used liquid formulations. The solubility of these fertilizers does vary greatly.

The main fertilizers/chemicals used for fertigation are:

Nitrogen: Nitrogen is usually applied through the system as anhydrous ammonia, aqua ammonia, ammonium phosphate, urea, ammonium nitrate, calcium nitrate or several other mixtures. Careful consideration must be made for the pH in irrigation water since some nitrogen sources, particularly aqua ammonia and anhydrous ammonia will increase pH. The increased pH can result in precipitation of insoluble calcium and magnesium carbonates that can clog the drip system. Urea and urea-ammonium nitrate mixture are highly soluble and usually do not cause large pH shifts.

Phosphorus: Phosphoric acid is soluble and with low pH water has no clogging problems. Sulfuric acid injection together with phosphoric acid may be sufficient to prevent precipitation of calcium and magnesium especially as the phosphoric acid boundary passes. Inorganic phosphate, orthophosphate and glycerophosphate have also been used to supply phosphorus.

Potassium: Potassium can be applied as potassium chloride and potassium nitrate. These potassium sources are soluble and have few precipitation problems. The Potassic fertilizers are water soluble and quick acting such as potassium chloride or muriate of potash, potassium sulphate, potassium magnesium sulphate, also known as Sulphate of potash magnesia.

The K ions are absorbed in the soil and thus remain available, and largely protected against leaching. However, split application is advisable where higher leaching losses may be expected. Some immobilization into clay lattice layers reduces availability but strong fixation into completely unavailable forms is limited to a few special soil types.

All types of fully-water soluble granular and liquid fertilizers are suitable for fertigation. However, for higher yield and quality, chloride-free fertilizers such as Multi-K (potassium nitrate), Mono ammonium Phosphate and Mono Potassium Phosphate are preferred. Soluble dry fertilizers containing N, P and K in different combinations are also available in the market.

Micronutrients: Manganese, zinc,iron, copper, etc., may be applied as soluble salts through the irrigation system. These should be injected separately and apart from other fertilizers and chemicals to avoid chemical interaction and precipitation. Iron, copper, zinc and manganese may react with salt in irrigation water and result in precipitation. However, the more soluble chelated forms such as iron or zinc EDTA (ethyl-enediaminetetraacetatedidhydrate) usually cause little clogging problem.

18.5 Fertilizers solubility and their compatibility

Solubility of Fertilizers

The quantity of fertilizer that can be dissolved in unit quantity of water is called the solubility. Normally nitrogen and potassic fertilizers do not have solubility problem.However, phosphatic fertilizers such as DAP & SSP do not readily dissolve in water. The solubility is greatly affected by the temperature variations. The solubility decreases with decrease in temperature. Table 18.2 provides the solubility limit (g/l) of nitrogenous, potassic and phosphatic and micro nutrient fertilizers.

Table: 18.2a Solubility of Nitrogenous Fertilizers

Types of Fertilizer	Nitrogen content(%)	Solubility(g/L)
Ammonium Sulphate	21	750
Urea	46	1100
Ammonium Nitrate	34	1920
Calcium Nitrate	15.5	1290

Table: 18.2b Characteristic of Nitrogenous Fertilizers Suitable for Fertigation

Fertilizers	Grade	Formula	pH(1g/L at 20^0C)
Urea	46-0-0	$CO(NH_2)_2$	5.8
Potassium Nitrate	13-0-46	KNO_3	7.0
Only Fertigation grade			
Ammonium Sulphate	21-0-0	$(NH_4)_2SO_4$	5.5
Urea Ammonium nitrate	32-0-0	$CO(NH_2)_2.NH_4NO_3$	
Ammonium Nitrate	34-0-0	NH_4NO_3	5.7
Mono Ammonium Phosphate	12-61-0	$NH_4H_2PO_4$	4.9

Calcium Nitrate	15-0-0	$Ca(NO_3)_2$	5.8
Magnesium nitrate	11-0-0	$Mg(NO_3)_2$	5.4

Table: 18.2c Solubility of PotassicFertilizers

Fertilizer	K content (%)	Solubility (g/L)
Potassium Sulphate	50	110
Potassium Chloride	60	340
Potassium Nitrate	44	133

Table: 18.2d Characteristic of Potassic Fertilizers Suitable for Fertigation

Fertilizers	Grade	Formula	pH(g/L at 20^0C)	Other Nutrients
Potassium Chloride@	0-0-60	KCl	7.0	46% Cl
Potassium Nitrate	13-0-46	KNO_3	7.0	13% N
Potassium Sulphate#	0-0-50	K_2SO_4	3.7	18% S
Potassium Thiosulphate*	0-0-25	$K_2S_2O_3$	-	17% S
Monopotassium Phosphate	0-52-34	KH_2PO_4	5.5	52% P_2O_5

@ only white, # only Fertigation grade, * liquid.

Phosphatic Fertilizers:

- P + Ca = Calcium phosphate (insoluble).
- P +Ammonium + Magnesium = Magnesium ammonium phosphate (insoluble).
- P + Iron = Iron phosphate (insoluble).
- Even good P sources like poly phosphates get precipitated if Ca + Mg in water is> 50ppm and Bicarbonate > 150ppm. If Bicarbonate content is < 100ppm, the Ca + Mg content can go upto 75ppm.

Table: 18.2e Characteristics of Phosphorus Fertilizers suitable for fertigation

Fertilizers	Grade	Formula	pH (1g/ L at 20^0C)
Phosphoric acid	0-52-0	H_3PO_4	2.6
Mono- potassium Phosphate	0-52-34	KH_2PO_4	5.5
Mono ammonium phosphate	12-61-0	$NH_4H_2PO_4$	4.9

Table: 18.2f Solubility of Micro-nutrient Fertilizers

Fertilizer	Content (%)	Solubility (g/L)
Solubor	20B	220
Copper Sulphate	25 Cu	320
Iron Sulphate	20 Fe	160
Magnesium Sulphate	10	710
Ammonium Molybdate	54	430
Zinc Sulphate	36	965
Manganese Sulphate	27	1050

(Source: http://www.ncpahindia.com/articles/article17.pdf; Oct 09, 2012)

Compatibility

Mixing the solutions of two or more than two water soluble fertilizers can sometimes result in the formation of a precipitate. Their solutions should be prepared in two separate tanks. Table 18.3 gives compatibility chart of different water soluble fertilizers.

Interaction between fertilizers nutrients-compatibility

When preparing fertilizer solution, the solubility product of the different materials must be taken into consideration. The solubility of the mixture fertilizer, getr required due to formation of precipitates:

a) Calcium nitrate with any sulphates= formation of $CaSO_4$ precipitate (gypsum)

$Ca(NO_3)_2 + (NH_4)_2SO_4$ ◊ $CaSO_4\downarrow$ + ………….

b) Calcium nitrate with any phosphates = formation of Ca phosphate precipitate

$Ca(NO_3)_2 + NH_4PO_4$ ◊ $CaHPO_4\downarrow$ +…………

c) Magnesium with mono-ammonium phosphate = formation of magnesium phosphate precipitate

$Mg(NO_3)_2 + NH_4H_2PO_4$ ◊ $MgHPO_4\downarrow$ + ………..

d) Ammonium Sulphate with KCl or KNO_3 : formation of K_2SO_4 precipitate

$SO_4(NH_4)_2$ + KCl or KNO_3 ◊ $K_2SO_4\downarrow$ + ……….

e) Phosphorus with iron = formation of iron phosphates precipitate.

Table: 18.3 Compatibility chart for different water soluble fertilizers

Fertilizers	Urea	Ammonium Nitrate	Ammonium Sulphate	Calcium Nitrate	Mono Ammonium Phosphate	Mono Potassium Phosphate	Potassium Nitrate
Urea		C	C	C	C	C	C
Ammonium Nitrate	C		C	C	C	C	C
Ammonium Sulphate	C	C		LC	C	C	LC
Calcium Nitrate	C	C	LC		NC	NC	C
Mono Ammonium Phosphate	C	C	C	NC		C	C
Mono Potassium Phosphate	C	C	C	NC	C		C
Potassium Nitrate	C	C	LC	C	C	C	

C=COMPATIBLE, NC=NOT COMPATIBLE, LC=LIMITED COMPATIBLE.

Table: 18.3b Fertilizer evaluation for suitability to fertigation

Property	NH_4NO_3	$(NH_4)_2SO_4$	K_2SO_4	KCl	KNO_3	H_3PO_4	MAP
Solubility	High	Medium	Low	Medium	Medium	High	Medium
Precipitation	Low	High	High	Low	Low	Low	High
Compatibility	Good	Poor	Poor	Medium	Medium	Medium	Good
Corrosion	Medium	Poor	Poor	Poor	Good	Poor	Medium

(Source: http://www.ncpahindia.com/articles/article17.pdf)

18.6 Safety precautions and back flow prevention

Fertigation safety devices

Backflow can occur in a system due to cross connection between a water source and an irrigation system. For example, water may be turned off, but the chemical injection unit may continue to work, which contaminate the water source. To protect groundwater and drinking water supplies from chemical contamination, backflow – whether from backsiphonage or backpressure – must be prevented. The main chemigation safety devices which are used to prevent backflow are shown in the Fig 18.1.

Backsiphonage is the reversal of normal system flow, caused by negative pressure (vacuum or partial vacuum) in the supplying pipe. Backsiphonage occurs due to low pressure in the water source. For example, the mainline source pipe may break at a spot lower than the irrigation system or pressure may be reduced drastically because a supply pump fails. Such situations can be avoided by installing check valves, vacuum relief valves or vacuum breaker valves.

Backpressure is the reversal of normal system flow due to downstream pressure increasing above supply pressure. Backpressure may occur if a system operates at higher pressures than its water supply, perhaps due to use of booster pumps or interconnection of a water source to other water systems. Such situations can be avoided by installing double check valves or special valves that combine check valves with reduced pressure zones commonly known as reduced pressure principle backflow prevention valves (Encisoand Porter, 2005)

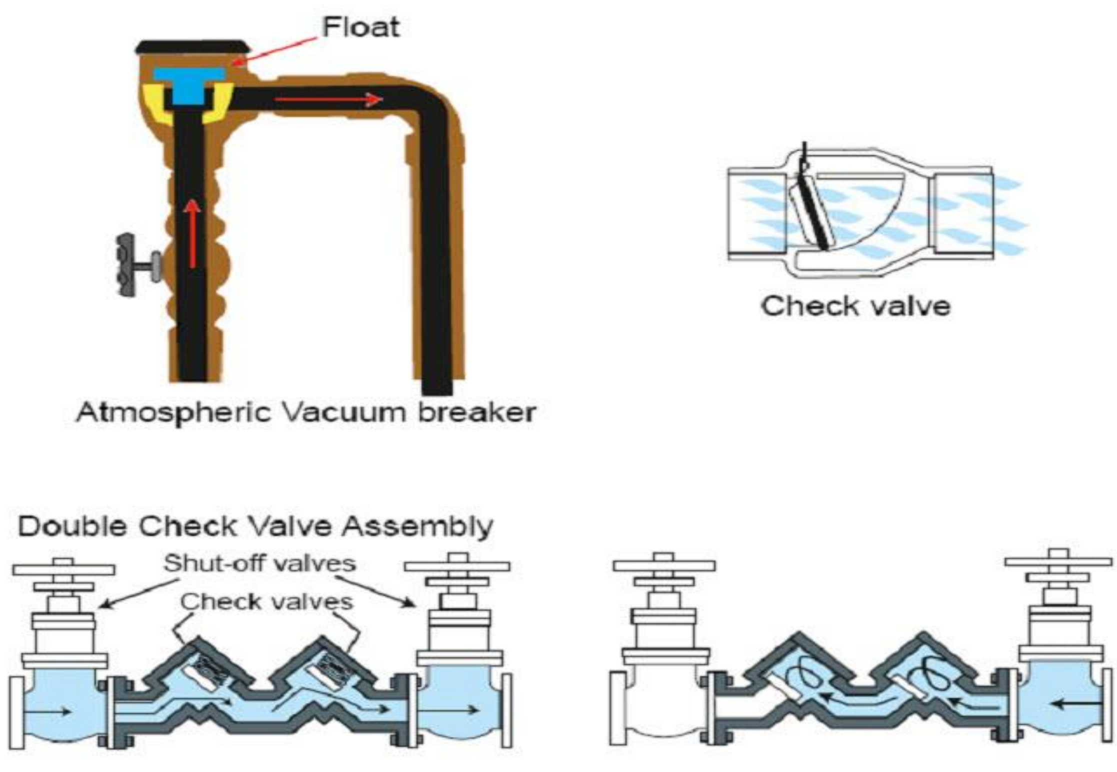


Fig.18.1 Fertigation safety devices

(Source: Encisoand Porter, 2005)

The following safety precautions should be observed for successful fertigation system.

1. Operating pressure variations should be minimum in order to achieve uniform mixing of nutrients and irrigation water in the drip irrigation system.

2. Compatibility of two fertilizers should be checked to avoid precipitation that may cause clogging of drip emitters and filter system.

3. To eliminate entry of solid particles or undissolved fertilizers a small screen/ strainers should be placed at the end of suction line.

4. Adjustment of the water pH should be made as per the pH of fertilizer solution.

5. Pesticides and chlorine should not be injected in combination with fertilizer solution.

6. To remove undissolved fertilizer particles or precipitates, the fertilizer injection point must be at the upstream end of the filter system so that the adequate filtration can be made.

7. Irrigation and fertilizer injection pumps should be compatible to prevent entry of fertilizer in the irrigation line. The controlfor the motors of both the pumps should be electronically interlocked.

8. Check valves should be installed in the fertigation injection line to prevent the back flow of water from irrigation system into fertilizer supply tank.

9. Check and vacuum relief valves should be installed to prevent water or mixture of water and fertilizer from draining or siphoning back into water source.

Lesson 19. Fertigation System Design

In drip irrigation the wetted soil volume is limited, the root system is confined and concentrated. The nutrients from the root zone are depleted quickly, therefore continuous application of nutrients along with the irrigation water is desired.

Factors crucial for effective fertigation design include (i) estimation of available nutrients in soil, (ii) estimation of amount of fertilizer required, (iii) frequency of fertigation, (iv) fertilizer tank capacity, (v) irrigation water requirement, (vi) capacity of drip system, (vii) injection duration, (viii) estimation of concentration of nutrients in irrigation water and (ix) injection rate.

19.1 Fertigation Parameters

For the effective fertigation, four criterions must be considered. These items are pedalogical and related with plant as stated below

- the kind of fertilizer required by crop,
- climatic conditions,
- physical and chemical properties of soil,
- exchange capacity of soil.

With fertigation system, the, plant nutrients can be applied alongwith irrigation water in a given interval at required concentration. With this approach, leaching of nutrients especially nitrogen decreases and improves the fertilizer use efficiency. Fertigation reduces fluctuations of soil solution salinity due to fertilizer thereby improving soil solution conditions particularly for salt sensitive crops (Phene and Beale, 1976; Popadopoulos and Eliades, 1987). In general with fertigation, chemical fertilizers can be dissolved and applied for long time on sustainable basis without contaminating soil and water (Source: http://www.iamb.it/par/activities /research/wasia/pdf/theme2_guidelines.pdf).

19.2 Estimation of Fertilizer Requirement

Requirement of fertilizers changes according to the stage of plant growth. The amount of nutrients to be applied during fertigation and the total amount to be applied during active crop production season depend on the frequency of fertigation, soil type, nutrient requirements of the crop and its availability in the soil. Required amount of fertilizer may be estimated by using the following equation

$$F_n = (R - A_n) \times F_{cf} \qquad (19.1)$$

Where

F_n= nutrient requirement, kg ha^{-1}

R= recommended dose of fertilizer for the crop, kg ha^{-1}

A_n= available fertilizer in the soil, kg ha^{-1}

F_{cf}= fertilizer correction factor (based on factors modifying nutrient requirements i.e. manure, pre-crop residue incorporation, irrigation etc.)

To determine the quantity of fertilizer to be injected into the system for each setting, the area irrigated in each setting of the lateral line is obtained by multiplying the length of the lateral coverage and the move of the lateral. The quantity of fertilizer to be injected is calculated using the following equation

$$D_f = \frac{D_S \times D_e \times N_S \times W_f}{10000} \quad (19.2)$$

where

D_f = amount of fertilizer per setting, kg.

D_S = distance between sprinklers, m

D_e= distance between laterals, m

N_s = number of sprinklers, and

W_f = recommended fertilizer dose, kg ha^{-1}.

Example 19.1 A lateral has 20 sprinkles spaced 10 meters apart. The laterals are spaced 20 meters on the main line. Determine the amount of fertilizer to be applied at each setting when the recommended fertilizer does is 100 kg ha^{-1}.

Solution: Using the Eq. 19.2, D_s = 10 m, D_e = 20 m, N_s = 20 and W_f = 100 kg ha^{-1}. The quantity of fertilizer to be applied is estimated as

$$D_f = \frac{10 \times 20 \times 20 \times 100}{10000}$$

= 40 kg

19.3 Frequency of Fertigation, Duration and Capacity of Fertilizer Tank

a) Frequency of fertigation

Fertilizers can be injected into the irrigation system at various frequencies once a day or once in every two days or once in a week. The frequency depends on system design, irrigation scheduling, soil type, nutrients requirement of the crop and the farmer's preference. It is also important to monitor the application of water, as fertilizer application is linked to water application (Locascio and Smajstrla, 1989). In any cases, it is extremely important that the nutrients applied in irrigation are not subject to leaching either during the same irrigation or during subsequent irrigation.

b) Injection Duration in Fertigation

The maximum injection duration depends soil type and nutrient and water requirements of the crop. A maximum duration of 45 to 60 minutes (Clark et al., 1990) is generally recommended with enough time for flushing of fertilizer residues from the lines before shutting the pump off. The injection duration is sufficient for uniform distribution of nutrients throughout the fertigation zone. Better to inject for long duration to leave enough time to flush chemicals out of system rather than in a "slug" where highly concentrated solutions of fertilizer usually injected in much less than 45 minutes.

Injection duration is kept within permissible limits to prevent the application of too much water, because excessive water leaches plant nutrients below the root zone. In addition, too much water saturates the soil, causing damage to roots and plants.

c) Fertilizer Concentration

The actual concentration of nutrients needed in the irrigation water depends on the type of crop. Many systems will have flowing water with a requirement to maintain a desired concentration of a chemical in the system. This requires injecting a supply mixture at proper rate to maintain the desired concentration level.

According to Howell et al. (1980) fertilizer concentration in the irrigation water is estimated by

$$C_f = \frac{100\, F_r}{T_r \times I_d} \qquad (19.3)$$

Where,

C_f = concentration of nutrients in irrigation water, ppm

T_r = ratio between fertilization time and irrigation time

I_d = gross irrigation depth, mm

F_r = rate of fertilizing irrigation cycle, kg ha^{-1}

d) Fertilizer Injection Rate

The fertilizer injection rate into the system depends on the concentration of the liquid fertilizer and the desired quantity of nutrients to be applied during irrigation.

The following equation is used to determine the fertilizer injection rate. The injection rate may be predetermined by the capacity of the injector or the flow rate of the irrigation system.

The desired injection rate can also be calculated by using the following formula if all the parameters are known.

$$q_{fi} = \frac{F_r \times A}{c \times t_r \times I_t} \qquad (19.4)$$

Where, q_{fi} = injection rate of liquid fertilizer solution into the system, L h^{-1}

F_r = rate of fertilizing (quantity of nutrient to be applied) per irrigation cycle, kg ha^{-1}

A = area irrigated (ha) in time, I_t

c = concentration of nutrient in liquid fertilizer, kg L^{-1}.

t_r = ratio between fertilization time and irrigation time

I_t = duration of irrigation, h.

Injection time should be limited to prevent over-application of water that will leach chemicals.

e) Fertilizer Tank Capacity

The size of the fertilizer tank will depend on the volume of chemical mixture to be injected, which in turn will depend on either the total amount or volume of chemicals to be applied or on the length of the injection period. Low cost tanks are practical where an injection pump or venturi is used. A large tank provides a good place to store fertilizer tank ranges from 30 to 600 L. This is not enough, because some fertilizers need larger, the capacity varies from 300 to 600 L. This is not enough, because some fertilizers need larger quantities because of high application rates or low solubility. The stock solution is prepared based on the solubility of the fertilizers used. Normally highest concentration is not desirable and it is recommended that stock solution is prepared with slightly lesser concentration.

The fertilizer tank capacity is computed by using following equation

$$C_t = \frac{F_r \times A}{c} \qquad (19.5)$$

where

C_t = capacity of fertilizer tank, L

F_r = rate of fertilizing per irrigation cycle, kg ha^{-1}

A = area irrigated (ha) in time, I_t

c = concentration of nutrient in liquid fertilizer, kg L^{-1}.

Lesson 20. Fertilizers Application Methods

Fertilizers are substances containing chemical elements that improve the growth of plants. They give nutrition to the crops. Fertilizers do not only assist in increasing yields but also promote healthy growth and development of plants. They contain nitrogen which acts as a growth booster which can be characterized by the green color of plants. Phosphorus substance in fertilizers aids in the faster formation of seeds and root development. In order to get maximum benefit from manures and fertilizers, they should not only be applied in proper time and in right manner but any other aspects should also be given careful consideration. Different soils react differently with fertilizer application. Similarly, the N, P, K requirements of different crops are different and even for a single crop the nutrient requirements are not the same at different stages of growth.

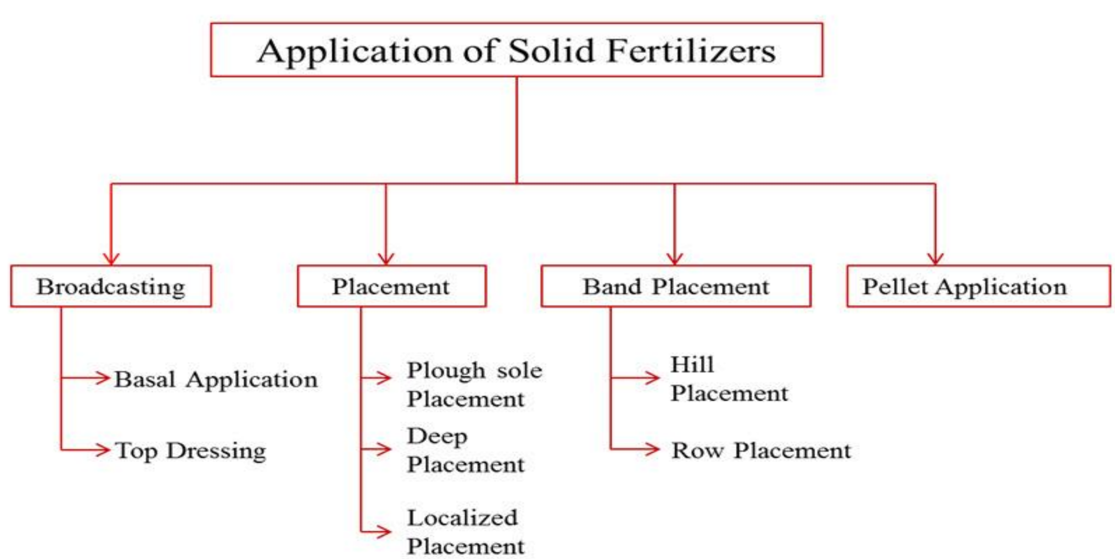
Theses fertilizers are available in solid granules and are fully soluble or partially soluble. Fertilizers are also available in liquid form. The modes of application solid and liquid fertilizers differ.

20.1 Solid Fertilizers Application Methods

The different methods of solid fertilizer application are shown through the following classification chart.

20.1.1 Broadcasting

The broadcasting refers to spreading fertilizers uniformly all over the field. It is suitable to crops with dense stand, the plant roots permeate the whole volume of the soil. Normally broadcasting increases application of high doses. Insoluble phosphatic fertilizers such as rock phosphate are used in this method of application. The broadcasting of fertilizers is of two types.



a) Broadcasting at sowing or planting (Basal application)

The main objectives of broadcasting the fertilizers at sowing time are to uniformly distribute the fertilizer over the entire field and to mix it with soil.

b) Top dressing

It is the broadcasting of fertilizers particularly nitrogenous fertilizers in closely sown crops like paddy and wheat, with the objective of supplying nitrogen in readily available form to growing plants.

Disadvantages of broadcasting

The main disadvantages of application of fertilizers through broadcasting are:

i) Nutrients cannot be fully utilized by plant roots as they move laterally over long distances.

ii) The weed growth is stimulated all over the field.

iii) Nutrients are fixed in the soil as they come in contact with a large mass of soil.

20.1.2 Placement

1. It refers to the placement of fertilizers in soil at a specific place with or without reference to the position of the seed.
2. Placement of fertilizers is normally recommended in small quantity of fertilizers application. Due to poor root development and low soil fertility and Phosphatic and Potassic fertilizer requirements, this method is preferred.

The most common methods of placement are as follows:

a) Plough sole placement

1. In this method, fertilizer is placed at the bottom of the plough furrow in a continuous band during the process of ploughing.
2. Every band is covered as the next furrow is turned.
3. This method is suitable for areas where soil becomes quite dry upto few centimeters below the soil surface and soils having a heavy clay pan just below the plough sole layer.

b) Deep placement

It is the placement of ammoniacal nitrogenous fertilizers in the reduction zone of soil particularly in paddy fields, where ammoniacal nitrogen remains available to the crop. This method ensures better distribution of fertilizer in the root zone soil and prevents loss of nutrients by runoff.

c) Localized placement

It refers to the application of fertilizers into the soil close to the seed or plant in order to supply the nutrients in adequate amounts to the roots of growing plants. The common methods to place fertilizers close to the seed or plant are as follows:

Drilling:

In this method, the fertilizer is applied at the time of sowing by means of a seed-cum-fertilizer drill. This places fertilizer and the seed in the same row but at different depths. Although this method has been found suitable for the application of Phosphatic and Potassic fertilizers in cereal crops, but sometimes germination of seeds and young plants may get damaged due to higher concentration of soluble salts.

Side dressing:

It refers to the spreading of fertilizer in between the rows and around the plants. The common methods of side dressing are:

1) Placement of nitrogenous fertilizers by hand in between the rows of crops like maize, sugarcane, cotton etc., to apply additional doses of nitrogen to the growing crops and

2) Placement of fertilizers around the trees like mango, apple, grapes, papaya etc.

20.1.3 Band placement

If refers to the placement of fertilizer in bands. There are two types of band placement of fertilizer and these are stated below:

a) Hill placement

It is practiced for the application of fertilizers in orchards. In this method, fertilizers are placed close to the plant in bands on one or both sides of the plant. The length and depth of the band varies with the nature of the crop.

b) Row placement

When the crops like sugarcane, potato, maize, cereals etc., are sown close together in rows, the fertilizer is applied in continuous bands on one or both sides of the row, which is known as row placement. Fig. 20.1 shows the row placement of fertilizer.

20.1.4 Pellet application

1. It refers to the placement of nitrogenous fertilizer in the form of pellets 2.5 to 5 cm deep between the rows of the paddy crop.

2. The fertilizer is mixed with the soil in the ratio of 1:10 and made small pellets of convenient size to deposit in the mud of paddy fields.

(Source:http://agritech.tnau.ac.in/agriculture/agri_nutrientmgt_methodsoffertilizerappln.html)

The main advantages are as follows:
i) When the fertilizer is placed, there is minimum contact between the soil and the fertilizer, and thus fixation of nutrients is greatly reduced.
ii) The weeds all over the field cannot make use of the fertilizers.
iii) Residual response of fertilizers is usually higher.
iv) Utilization of fertilizers by the plants is higher.
v) Loss of nitrogen by leaching is reduced.
vi) Being immobile, phosphates are better utilized when placed.

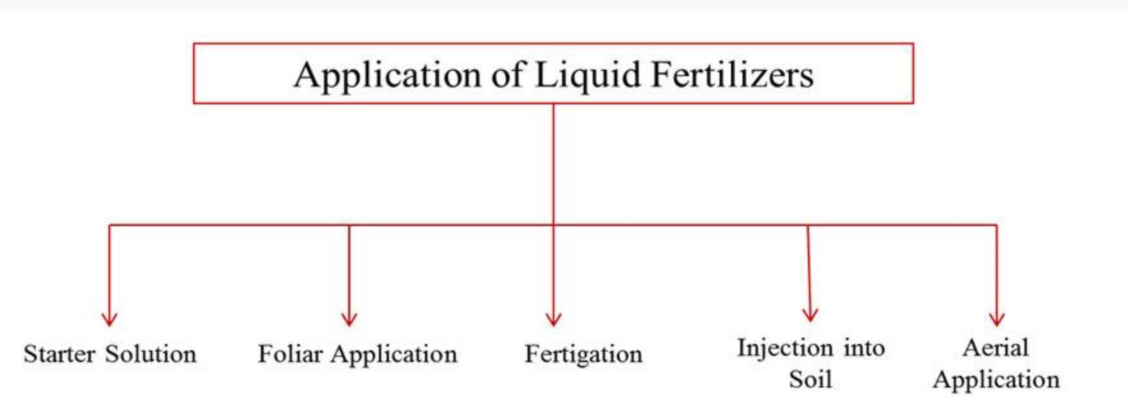
20.2 Liquid fertilizers application methods

Liquid fertilizers and water soluble granular fertilizers can be applied in different ways. These methods are shown through following classification chart.

20.2.1 Starter solutions

It refers to the application of solution of N, P_2O_5 and K_2O in the ratio of 1:2:1 and 1:1:2 to young plants at the time of transplanting particularly for vegetables. Starter solution helps in rapid establishment and quick growth of seedlings.
The disadvantages of starter solutions are

(i) Extra labour is required, and
(ii) The fixation of phosphate is higher.



20.2.2 Foliar application

1. It refers to the spraying of fertilizer solutions containing one or more nutrients on the foliage of growing plants.

2. Several nutrient elements are readily absorbed by leaves when they are dissolved in water and sprayed on them.

3. The concentration of the spray solution has to be controlled; otherwise serious damage may result due to scorching of the leaves.

4. Foliar application is effective for the application of minor nutrients like iron, copper, boron, zinc and manganese. Sometimes insecticides are also applied along with fertilizers.

20.2.3 Injection into soil

1. Liquid fertilizers for injection into the soil may be of either pressure or non-pressure types.

2. Non-pressure solutions may be applied either on the surface or in furrows without appreciable loss of plant nutrients under most conditions.

3. Anhydrous ammonia must be placed in narrow furrows at a depth of 12-15 cm and covered immediately to prevent loss of ammonia.

20.2.4 Aerial application.

In areas, where ground application is not practicable, the fertilizer solutions are applied by aircraft particularly in hilly areas, forest lands, grass lands, sugarcane fields etc. In this method considerable amount of fertilizer is lost. In a very special case this method is adopted.

20.2.5 Fertigation

The combined application water soluble solid or liquid fertilizers with irrigation water through pressurized irrigation system is known as fertigation. Generally nitrogenous fertilizers such as urea and other ammoniatic fertilizers easily water soluble are applied along with irrigation water. The fertigation increases yield minimizes soil and water pollution. This also saves fertilizers. Therefore, it saves foreign revenue, as these fertilizers are expensive and imported from other countries.

20.3 Methods of Fertigation

Three principal methods are used for the injection of fertilizers or soluble chemicals into the micro-irrigation system.

1. Pressure Differential
2. The Venturi (vacuum)
3. Injection pump

20.3.1 Pressure Differential

In the pressure differential system, the tank is under pressure (usually main line pressure). A pressure difference is created by a valve and pressure regulator between the tank inlet and outlet. The difference in pressure between the connection and the constriction in pipe is sufficient to cause the flow of water through the tank under pressure. A gradient of 0.1 to 0.2 bars (1 to 2 m) is required to redirect an adequate stream of water through a connecting tube of 9-12 mm diameter. A sealed airtight pressure supply tank is required to withstand maximum operating pressure. Precise control valves are necessary to maintain a preset injection rate. The pressure differential device is cheap and simple. A wide dilution ratio can be attained with no source of external source of energy.

The nutrient cannot be precisely regulated prior to each application, the tank has to be refilled with fertilizer. Valve throttling generates pressure losses, and the system is not straight forward automated. Two types of fertilizer tanks shown through Figs. 20.2 and 20.3 are generally used in this method.

Proportional models are generally vertical tanks with the size varies from 10 to 300 litres. Quantitative models are: 5, 30, 60, 90, 120 L of capacity (vertical tanks) and 120, 220 litres (horizontal tanks).

Fertilizer tanks are made up of mild steel. These tanks are powder coated with more than 70 micron thick deep blue colored epoxy-polyester from both inside and outside surface for protection against corrosion and weather effects. Normally fertilizer tanks have a 100 micron protective coating of extra durable polyester applied electrostatically and oven cured on a zinc-phosphate layer for maximal anti-corrosion protection.

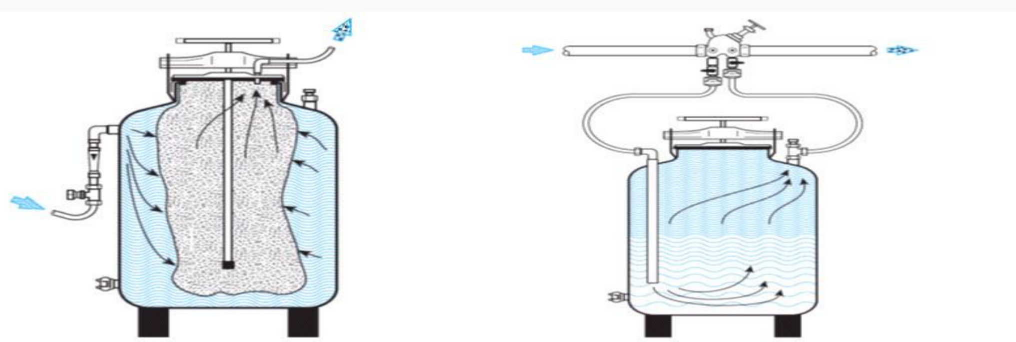


Fig 20.2 Proportional model of fertigation tank **Fig 20.3 Standard model of fertigation tank**

(Source: http://www.odis.co.il)

20.3.2 Venturi Injection Method

Suction of the fertilizer solution is generated by water flow through a constricted passageway. The high flow velocity of water in the constriction reduces water pressure below atmospheric pressure so that the fertilizer solution is sucked from an open tank in to the constriction through a small diameter tube. The process of injection of fertilizer solution can be explained by Bernoulli's principle, assuming inlet and outlet ports of venturi are at same elevation and total energy at a point is constant. This can be given by energy equation

$$\frac{P}{\gamma} + \frac{V^2}{2g} + Z = \text{constant} \qquad (20.1)$$

where P = Pressure, V = Velocity, Z = Elevation, γ = unit weight of water g = acceleration due to gravity.

Considering inlet and outlet ends of a venturi injector are as points 1 and 2 respectively and they are located at same elevations, therefore $Z_1=Z_2$. The equation (20.1) becomes

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} \qquad (20.2)$$

Or

$$\frac{1}{\gamma}(P_1 - P_2) = \frac{1}{2g}(V_2^2 - V_1^2) \qquad (20.3)$$

The change in velocity V_2 from V_1 due to constriction in venturi pipe diameter causes suction (change in pressure from P_1 to P_2) below atmospheric pressure, thereby suction of fertilizer solution. Figure 20.5 explains the principle of operation of a venturi injector. Fig. 20.6 shows use of venturi injector for application of fertilizer in banana field.

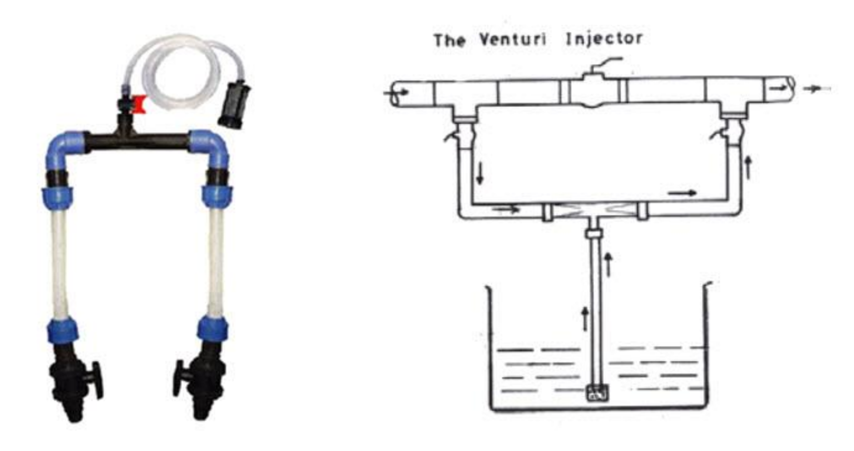


Fig. 20.5 Venturi method of fertilizer injection

(Source: ftp://ftp.fao.org/docrep/fao/010/a1336e/a1336e16.pdf)

Fig. 20.6. Venturi method of fertilizer injection
(Source: www.jains.com)

Advantages

1. Very simple to operate, no moving parts.
2. Easy to install and to maintain.
3. Suitable for very low injection rates.
4. Injection can be controlled with a metering valve.
5. Suitable for both proportional & quantitative fertilization.

Disadvantages

1. Creates considerable pressure loss in irrigation pipe line and sometimes a booster pump is required.

2. Quantitative fertigation is difficult.

3. Automation is difficult

20.3.3 Fertilizer Injection Pump

In this method a pump is used to lift the fertilizer stock solution from the storage tank and inject it under pressure in a pipe carrying irrigation water. The injection rate can be set to create a desirable mixing ratio. The fertilizer solution is normally pumped from an unpressurised storage tank.

Pumping is a common method of injecting fertilizer into a drip irrigation system. Fertilizer pumps are driven by electricity, internal combustion engines, tractor PTO or hydraulically the inherent water pressure in the irrigation system. Hydraulic pumps are versatile reliable and low operation and maintenance costs. A diaphragm or piston movement injects the fertilizer solution into the irrigation system. Positive injection pumps include single or multiple piston pumps, diaphragm pumps, gear pumps, and roller pumps. Where two or more different types of fertilizers are required, multiple pump units can be used to avoid or reduce precipitation problems. All of the injection pumps can be regulated to achieve the desired rate of application, usually by adjusting the length of stroke of the piston pump or by selecting the appropriate pulley diameter. Another means of adjusting fertilizer application is with variable-speed motors. The system should flush itself with clean water at least once after injecting the fertilizer solution. The major advantages of the system are flexibility and high discharge rate, the system does not add to the head loss in a pressurized irrigation system and that it maintains a constant concentration of nutrients throughout the period of fertilizer application. High equipment cost and high operation and maintenance costs (Michael, 2010) are the limitations of this method of fertigation.

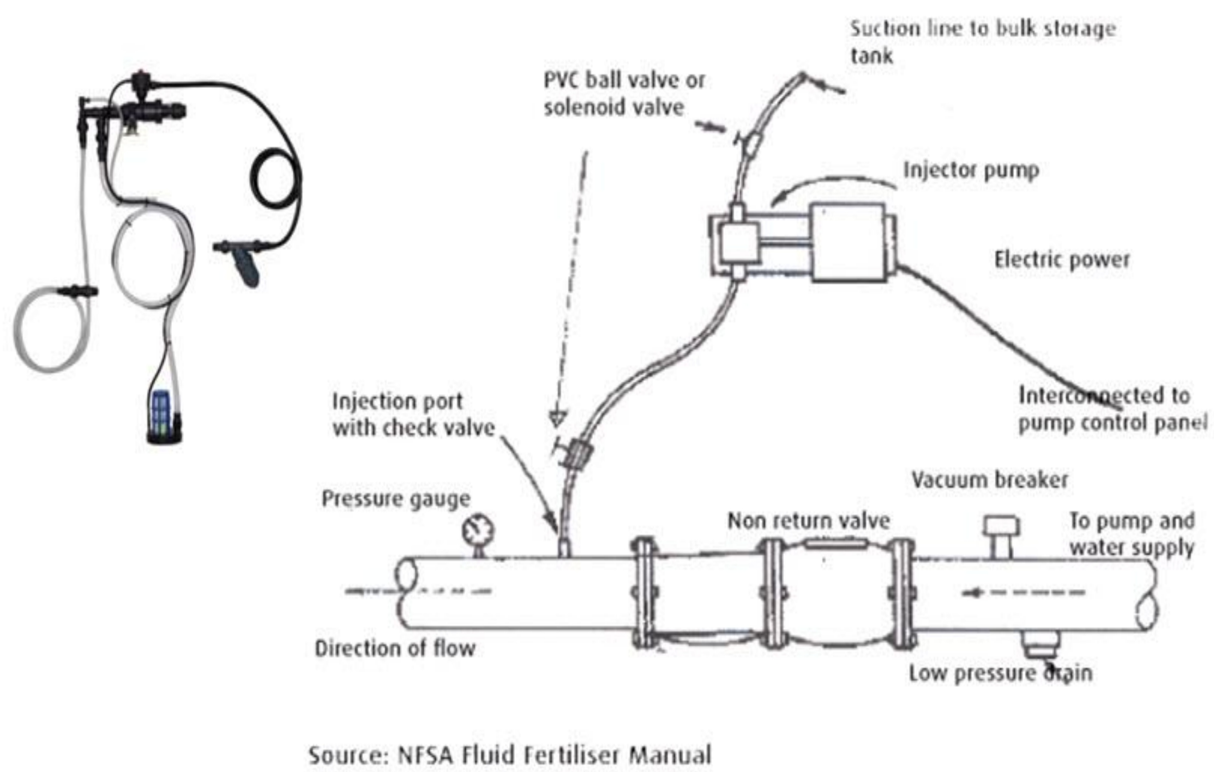


Fig 20.7: Positive displacement pump set up

(Source: ftp://ftp.fao.org/docrep/fao/010/a1336e/a1336e16.pdf)

Module 5. Quality Assurance & Economic Analysis

Lesson 21. Standardization and Quality Assurance of Micro Irrigation System Components

21.1 The Bureau of Indian Standards

Standardization of any product process or service in India is carried out by the Bureau of Indian Standards (BIS). The Government of India established Indian Standards Institution (ISI) in January 1947. With fast pace of development and industrialization the existing structure was found to be inadequate. ISI was therefore restructured with statutory authority and Bureau of Standards Act was passed in December 1986. The BIS became functional from April 1987.

Bureau has several technical divisions to look after the Indian Standards, of which one of the important divisions has been Agriculture and Food Division. This division has several technical committees. FAD-35 was one of such committees that formulated the standards for drip irrigation. This was later modified as Irrigation and Farm Drainage Equipments and System Sectional Committee FAD-54.

Institutions Framing Standards

At the international level there are several institutions formulating standards for crop irrigation. Some of these are

i) Bureau of Indian Standards (BIS)

ii) British Standards Institute (BSI)

iii) American Society of Testing Materials (ASTM)

iv) International Organization of Standards (ISO)

v) American Society of Agricultural Engineers (ASAE)

vi) American National Standards Institute (ANSI)

21.2 Testing of Micro-irrigation Components for Standards

The parameters needed for testing of micro-irrigation components are described below:

i) Melt Flow Index: This test is used to determine the right combination of materials used to manufacture laterals and other plastic materials. The melt flow indexer is used to conduct this test.

ii) Tensile Strength: This test is carried out for a special shaped piece obtained by a dumb bell and elongation is tested at 27^{o}C temperature by a universal testing machine.

iii) Environmental Stress Cracking Resistance: This test indicates the strength of material against breakage of poly-tube/lateral under various environmental conditions. The water bath with thermostatic control, vernier calipers, ball ended micro meter and forced air circulation oven maintained at 50 ^{o}C ± 3 ^{o}C capable of reestablishing that temperature in 5 minutes are required for this test.

iv) Reversion test: This test is conducted to study the internal stress during processing in the lateral. A pipe of about 200 m long is subjected to a temperature around 100 ^{o}C for about an hour and cooling to the room temperature. The changes in the dimensional should not be more than 3%. Thermostatic oven is required for this test.

v) Carbon Black Content: The concentration of carbon black is essential to ascertain that the lateral can provide appropriate UV stability. The carbon black should have specified density. The manufacturer is permitted to add carbon black to an extent of 10%. Carbon content analyzer with ultra pure nitrogen cylinder is required to determine the carbon black content.

vi) Carbon Dispersion: Proper dispersion of carbon black is essential for good UV stability of lateral pipes. A micro scope with magnifier (200 times magnification) is needed for determining carbon dispersion.

vii) Hydraulic Characteristics: Internal Pressure Creep Rupture of poly-tubes is required to conduct hydraulic characteristics of drip pipes. This essentially consists of two important tests: a) Acceptance test and b) Quality test. Acceptance test is carried out at a lower temperature for test duration of a given time (say 1 h) under an induced stress as specified by prevailing standards. The quality test is conducted to test the standard of material and procedure of pipe material and carried out at a higher temperature with longer duration (say 100 h) to stand the specified induced stress of 2.5 MPa and 20 ^{O}C for 1 h at induced stress of 6.9 MPa. Pressure Creep Rupture tester is required to conduct this test.

21.3 Indian Standards for MI Components

Indian standards published by BIS on various components of micro irrigation system are given in Table 21.1. These standards are prepared based on corresponding International standards with suitable modifications to meet Indigenous requirements.

21.3.1 Drip Laterals: Polyethylene pipes for irrigation laterals should withstand the internal pressure creep rupture test which is conducted at a temperature of 70^{0} C for 100 h at induced pressure of 2.5 MPa and 20^{0} C for 1 h at an induced stress of 6.9 MPa. Maximum longitudinal reversion of the pipe after keeping it at a temperature of 100 ± 2^{0} C for 1 h shall be in the range of ± 3%. Similarly tensile strength and elongation at break at 27 ± 2^{0} C and testing speed of 100 mm/min. ± 10 mm/ min shall not be less than 10 MPa and 350% respectively. Pipe for laterals shall also withstand the accelerated test for susceptibility to environmental stress cracking.

Melt flow index and density are two properties that control the uniformity of compounds used for the manufacture of laterals. Tensile strength and resistance to internal pressure are the major properties to be tested for laterals. Tensile strength indicates the strength of material and elongation shows extension of the material under load. The Indian standard for quality assurance of drip lateral is IS: 12786-1989.

Table 21.1. Indian standards published by BIS on various components of micro irrigation system (Source: Singh and Kumar, 2001)

1) Drip irrigation system components	Standards
i) Main and sub-main pipes a) PVC pipes b) HDPE pipes	 IS 4985 : 2000 IS 4984 : 1995
ii) Lateral: High quality PE lateral in 12 mm and 16 mm	IS 12786 : 1989
iii) Emitting pipe system	IS 13488 : 1992
iv) Emitters/drippers (Pressure and non pressure compensating types)	IS 13487 : 1992
v) Micro-tubes	IS 14482 : 1998
vi) Micro-sprayers	IS 14605 : 1998
2) Filteration system i) Strainer type filters ii) Media filters iii) Hydro-cyclone filters	 IS 12785 : 1994 IS 14606 : 1998 IS 14743 : 1999
3) Fertigation i) Fertilizer and chemical injection system part I Venturi injectors	IS 14483(Part I):1997
4) Others i) Pressurized irrigation equipments terminology ii) Design, installation and field evaluation of micro-irrigation system- code of practices iii) Recommended criteria for adoptability of different irrigation methods iv) Prevention and treatment of blockage problem in drip irrigation system- code of practice	 IS 14178 : 1994 IS 10799 : 1999 IS 11711 : 1986 IS 14791 : 2000

21.3.2 Emitting Pipe: Uniformity of emission of emission rate should not deviate from declared value by more than ± 5% for category A and ± 10% for category B pipes. Emitting pipe shall withstand the hydrostatic pressure 1.8 times the recommended working pressure at ambient temperature for 1 h and at temperature of 60 ± 2^0 C for 48 h without any leakage and any permanent deformation or damage. Emitting pipe shall also bear the tensile forces of 180 N when applied for 15 minutes at elevated temperature of 50 ± 2^0 C joint between fitting and emitting pipe shall not come out on pull of 180 N when applied for 1 hour.

21.3.3 Main and Sub-main pipe

The material used for pipe is polyvinyl chloride (PVC). The different grades of resins are available for various usages and these are selected according to the essential properties such as density, melt flow index/K-value, molecular weight distribution, etc. The BIS specifications of plastic materials in various applications are given in Table 21.2. For PVC pipe, the base material density of the resin should be between 1.40 and 1.46 g/cc, and K-value minimum 64 and other additives which may help the manufacturing process and good finish. For HDPE pipes, base material density of 0.9405 to 0.9460 g/cc and Melt Flow Index 0.4 to 1.1 g/10 min at 190^0C/5 kg/load are desired. Carbon black should be added to the tune of 2-3% and should be well dispersed for long service life of lateral. The pipe shall not have any detrimental effect on the composition of the water flowing through these pipes.

The extrusion is carried out under strict quality control conditions to ensure that the internal and external diameters remain with specified tolerances. As the strength of the plastics are stress and time dependent, the short-term hydraulic test has been specified to detect the manufacturing defect periodically and the long term hydraulic test to assess the durability of pipes. For the safe use of PVC pipe for drip irrigation it should meet all the requirements as per IS: 4985-2000. Similarly, for HDPE pipes, the applicable standard is IS: 4984-1995.

Table 21.2. BIS standards & criteria of plastic materials in various applications (Source: Kumar, 2007)

Material characteristics	Value		
	PVC pipe IS:4985-2000 IS: 12818-1992	HDPE pipe IS:4984-1995 IS:14151-1999	LDPE/LLDPE Laterals IS: 12786-1989 (Drip laterals)
Density (g/cc)	1.40 – 1.46	0.9405 - 09464	0.920 – 0.930
K-value	Min.64	--	--
MFI (G/10)	--	0.4 – 1.1	0.9 – 1.0
Carbon black content (%)	--	2 - 3	2 - 3
Carbon black dispersion	--	should be well dispersed	should be well dispersed
Mechanical Properties Tensile strength at break (kg/cm^2)	Minimum 45 Mpa	Minimum 19 Mpa	Minimum 10 Mpa
Elongation at break (%)	--	Minimum 600%	Minimum 350%

21.3.4 Emitters (IS 13487 : 1992): The smallest measured flow path dimension shall not be smaller than the dimension declared by the manufacturers. Emitters shall be tested to resistance to hydrostatic pressure and leakage at pressure twice the maximum working pressure. The mean emission rate of 25 randomly selected emitters shal not deviate from the nominal discharge rate by more than ±5% for category A and ±10% for category B emitters.

When inserted on the lateral emitter shall also bear a pull of 40 N for on-line emitters and a radial force of 500 N for inline emitters.

21.3.5 Micro-tubes (IS 14482 : 1997): Micro tubes shall conform to the requirements for longitudinal reversion, tensile strength and environmental stress cracking test for polythene laterals. In addition micro tube shall also withstand hydrostatic pressure 1.2 times the maximum operating pressure for 1 h without suffering damage and pulling out from assembly.

21.3.6 Micro-sprayers (IS 14605 : 1998): Micro-sprayers shall bear the hydrostatic pressure of 1.2 times the maximum working pressure for a period of 1h without any damage, leakage and pull out from assembly. Threaded connections shall withstand a torque of 20 Nm for metal to metal contact and 4 Nm for plastic to plastic or plastic to metal contact without showing any sign of damage. Upper and lower specification limits for uniformity of flow rate are ±10% for regulated sprayers and ±7% for non regulated sprayers. In case of regulating type micro sprayer, the maximum and minimum flow rates shall not deviate by more than ±10% from the nominal flow rate within the regulation range and average flow rate shall not deviate by more than ±2.5% from the nominal flow rate, the effective diameter of coverage shall conform to the value supplied by the manufacturer within a permissible deviation of ±10%. After operating the micro sprayer for 1500 h, the measured flow rate of test sprayer shall remain within ±10% of the initial flow rate and sprayer shall not show any visible defect.

21.3.7 Strainer type filter (IS 12785 : 1994): Strainer should withstand internal hydrostatic pressure at ambient as well as elevated temperature (60 ± 2^0 C) conditions. In addition, test for resistance of filter element to buckling or tearing or tightness of filter element should also be conducted at nominal pressure. The measured clean pressure drop should not be more than 10% greater than the pressure declared by the manufacturer.

21.3.8 Media filter (IS 14606 : 1998): Test of hydrostatic pressure are same as for strainer filter. In addition guidelines for sand media bed selection and recommended design flow rates have also been specified.is between Sand used by the media is graded by mean effective size (size of opening which will pass 10% of representative sample of sand) and uniformity coefficient (D_{60}/D_{10}). Uniformity coefficient between 1.4 to 1.6 has been recommended. Recommended design flow rates for media filter are given in Table 21.3.

Table 21.3. Recommended design flow rates for media filter (Source: Singh and Kumar, 2001)

Contaminant level	Contaminant concentration, mg/L (ppm)	Recommended design flow rate range ($m^3/hr/m^2$)
Light	0-10	63-76
Medium	11-100	50-63
Heavy	101-400	43-50

21.3.9 Venturi Injector (IS 14483(Part 1): 1997): The application of fertilizers and or chemicals with irrigation water has added advantage of improved application efficiency. Venturi injector should withstand a hydrostatic pressure equal to 1.6 times the maximum operating pressure when applied for one minute. Motive flow water suction rate of test liquid should not vary by more than ±10% from the declared values. Similarly minimum pressure drop at which the water is drawn through the suction port in relation to inlet pressure specified by the manufacturers.

21.4 Code of Practice for Design, Installation, Operation and Field Evaluation of Micro-irrigation System (IS 10799 : 1999)

This Indian Standards establishes minimum recommendations for design, installation, operation and field evaluation of micro-irrigation system. Provision of this code of practice primarily those that affect the adequacy and uniformity of water application, filtration requirement, water treatment, water amendments and field performance. As for as design installation and performance are concerned, this standard covers recommendations for system capacity, emitter discharge rate, number and spacing of emitters, operating pressures, manufactures coefficient of variation (Table 21.4), design emission uniformity (Table 21.5), allowable pressure variation, filtration system requirements (location, size and type) chemical water treatment, fertilization system, injection system, flow monitoring and safety requirements. For comparison with recommendations given in the standard it also defines field evaluation uniformity, water application efficiency and efficiency of micro irrigation system.

21.5 Code of Practices for Prevention and Treatment of Blockage Problem in Drip Irrigation System (IS 14791 : 2000)

Irrigation water may contains suspends solids, chemicals, minerals, dissolved solids and other foreign materials. If proper care is not taken during operation of drip irrigation system, severe blockage problem may occur which can cause the system failure. This standard covers recommendations for testing of quality of irrigation water, chemical treatment devices, types and causes of blockage problems, method of assessment of blockage problems, physical and chemical treatments for prevention of blockage problems. It also covers recommended doses of chlorine and acid treatment.

Table 21.4. Recommended classification of manufacture's coefficient of variation (Cv) (Source: Singh and Kumar, 2001)

Emitter type	Cv range	Classification
Point source	< 0.05	Excellent
	0.05 to 0.07	Average
	0.07 to 0.11	Marginal
	0.11 to 0.15	Poor

	> 0.15	Unacceptable
Line sourec	< 0.10	Good
	0.10 to 0.20	Average
	> 0.20	Marginal

Table 21.5. Recommended ranges of design emission uniformity (EU) (Source: Singh and Kumar, 2001)

Emitter type	Spacing (m)	Topography	Slope (%)	EU range (%)
Point source on perennial crops	> 4	Uniform steep or undulating	< 2 > 2	90 to 95 85 to 90
Point source on perennial or semi permanent crops	< 4	Uniform steep or undulating	< 2 > 2	85 to 90 80 to 90
Line source on annual or perennial crops	All	Uniform steep or undulating	< 2 > 2	80 to 90 70 to 85

Lesson 22. Terminologies in Economic Analysis

When planning any irrigation system both an economic and a financial feasibility evaluation should be carried out. The economic feasibility evaluation assesses the economic viability of the planned development and assists in selecting the farm irrigation system from among adaptable alternatives, while financial feasibility evaluation assess the financial conditions that will be encountered in developing and operating the irrigated farms.

Important part of irrigation system design is determining the expected annual cost of owning and operating each feasible alternative design. Banks, government and financial agencies evaluate the soundness of the project and make suitable repayment arrangements.

22.1 Types of Costs

In general, cost or total cost (TC) explains the total economic cost of production of particular goods and comprises of variable costs (VC), which vary according to the quantity of goods produced with inputs such as fertilizer, pesticide, labour etc. plus the fixed cost (FC) which are independent of quantity of goods produced and include inputs such as buildings, rent of land, machinery etc. which cannot be varied over short period of growing season.

i.) Fixed cost (FC)

Fixed costs are also known as annual ownership cost, as they are generally independent of the level of system use as shown in Fig 22.1. Fixed costs include annual depreciation, interest costs and yearly expenditure for taxes and insurance.

ii.) Depreciation

The depreciation means to distribute the cost of given component over the expected life. Table 22.1 gives the expected useful life of several irrigation system components, has been prepared by the researchers from numerous sources serves as a guideline for estimating depreciation (Thompson et al. 1980). The useful life value is based on 2000 hours use in a year.

Table 22.1 Annual maintenance and repairs, and depreciation guidelines for irrigation system components.

Components	Depreciation	Period (year)	Annual Maintenance and Repairs
Wells and casings	-	20-30	0.5-1.5
Pumping plant structure	-	20-30	0.5-1.5

Pump, vertical turbine			
Bowls	16000-20000	8-10	5-7
Column, etc.	32000-40000	16-20	3-5
Pump, centrifugal	32000-50000	16-25	3-5
Power transmission			
Gear head	30000-36000		5-7
V-belt	6000	3	5-7
Flat belt, rubber and fabric	10000	5	5-7
Flat belt, leather	20000	10	5-7
Prime movers			
Electric motors	50000-70000	25-35	1.5-2.5
Diesel engine	28000	14	5-8
Gasoline engine			
Air cooled	8000	4	6-9
Water cooled	18000	9	5-8
Propane engine	28000	14	4-7
Open farm ditches		20-25	1-2
Concrete structure		20-40	0.5-1.0
Pipe, asbestos-cement and PVC buried		40	0.25-0.75
Pipe, aluminium, gated surface		10-12	1.5-2.5
Pipe, steel coated buried		20-25	0.5-0.75
Pipe, steel coated surface		10-12	1.5-2.5
Pipe, steel galvanised surface		15	1.0-2.0
Pipe, wood buried		20	0.75-1.25
Pipe, plastic, trickle, surface		10	1.5-2.5
Sprinkler heads		8	5-8

Trickle emitters		8	5-8
Trickle filters		12-15	6-9
Reservoirs		none	2.0-2.0
Mechanical move sprinklers		12-16	5-8
Continuously moving sprinklers		10-15	5-8

(Source: Thompson et al. 1980)

iii.) Interest costs

Interest is the return from productivity invested capital. When money is borrowed to finance the initial cost of the irrigation system, interest is the money paid for the use of the borrowed money.

iv.)Variable cost (VC)

Variable costs are those which vary as a total cost to the farmer when the output (agricultural production) varies. In fact, variable cost will vary in exactly the same proportion as the output (Fig. 22.1). These include cost of labour, electricity charges etc.

v.)Marginal cost (MC)

Marginal cost is the increase in variable cost associated to a unit increase in production. It can be calculated using eq. 22.1.

$MC = \Delta TC/\Delta Q = \Delta VC/\Delta Q$ (for an discrete change of Q)

$MC = \delta TC/ \delta Q = \delta VC/ \delta Q$ (for an infinitesimal change of Q) (22.1)

where,

MC = Marginal cost,

Q is the total quantity of goods produced,

VC = Variable cost,

TC = Total cost

If oneimaginesincreasing production one unit at a time, then MC is the cost of last unit produced.

vi.) Average cost (AC)

Average cost is the cost associated to each unit of production, that is, it is how much it costs the average to produce one unit of output. This can be clarified in two ways as shown in Eq. 22.2:

Average variable cost (AVC) = VC / Q

Average total cost (AC) = TC / Q (22.2)

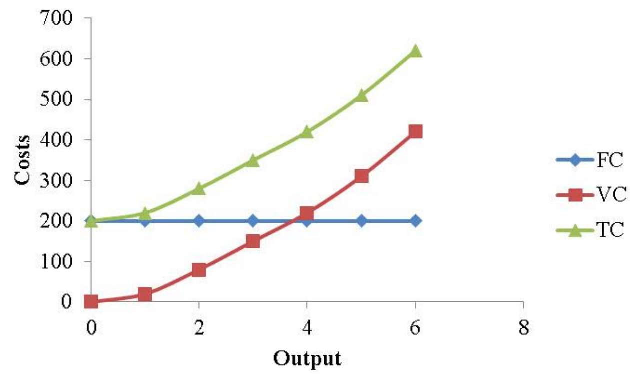


Fig. 22.1 Types of costs

vii.) Total production function

1st stage: The total production function is explained through Fig. 22.2.The output (maize yield) increases more than proportionally to the input (seed) increase. This is because the particular input combines better and better with other fixed factors.

2nd stage: The output (maize yield) increases less than proportionally to the input (seed) increase. This stage must necessarily exist, given that other factors are fixed. For instance increasing quantity of seeds increase output but not indefinitely.

3rd stage: The output (maize yield) decreases when increasing input (seed) usage (or remains at the same level): when the maximum output is reached, it is impossible to increase further the output, unless other factors are increased.

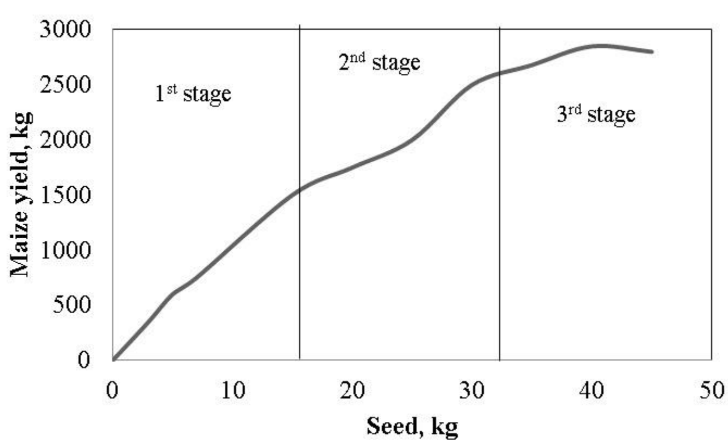


Fig. 22.2 Total production function

This is expressed as law of diminishing marginal returns: given the fixed factors, production cannot increase indefinitely unless other factors also increase/decrease.

22.2 Supply and Demand

22.2.1Supply

It is the quantity of a commodity that sellers are able and willing to offer for sale atdifferent prices per unit of time.

i)Law of supply: The law of supply states that the quantity of a good offered or willing to offer by the producer/owners for sale, increases with the increase in the market price of the good and falls if vice versa, all other things remaining unchanged.

Supply function expresses the relationship between supply and the factors affecting the producer/supplier to offer goods for sale.

The supply function given below can be expressed as shown in Eq.22.3

$$Qs = f\,(P, Prg, S) \qquad (22.3)$$

where,

P = price;

Prg = price of related goods; and

S = number of producers.

ii) Supply curve

The supply curve is the graphical representation of the supply function and it shows the quantity of a good that the seller is offering or willing to offer at various prices as shown in Fig. 22.3.

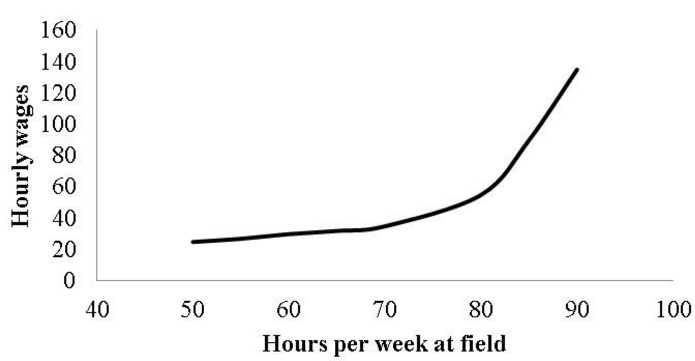


Fig. 22.3 Supply curve

22.2.2 Demand

Demand is the desire to possess and willingness and ability to pay for particular goods i.e. it's an effectiveness of desire which explains ability and willingness to pay for a particular commodity. Say, if a person has desire to buy sprinkler system, he has willingness but not the ability to pay for it. Then it becomes a want or a simply wish. So ability and willingness both are important. The major characteristics of demand are (i) ability and willingness to pay for a particular commodity (ii) the demand is always at a given price (iii) demand is always per unit of time.

i.)Law of Demand

It states that as price increases the consumer/buyer will buy less of a particular commodity and vice-versa.

In Table 22.2 the demand of buyers A, B, C and D are the individual demands. Total demand by the fourbuyers is market demand. Therefore, the total market demand is derived by summing upthe quantity demanded of a commodity by all buyers at each price.

Table 22.2 Market demand

Price, Rs.	Buyer A	Buyer B	Buyer C	Buyer D	Market demand
150	2	0	5	0	7
120	5	1	10	3	19
80	9	3	15	9	36
50	12	5	20	12	49
40	17	7	25	13	62

ii.) Demand Curve

Demand curve is a diagrammatic representation of demand schedule. It is a graphical representation of price- quantity relationship. Individual demand curve shows (Fig. 22.4) the highest price which an individual is willing to pay for different quantities of the commodity. As price falls from P_1 to P_2 the quantity demanded increases from Q_1 to Q_2. This is a negative relation between price and quantity, hence the negative slope of the demand schedule; as predicted by the law of demand.

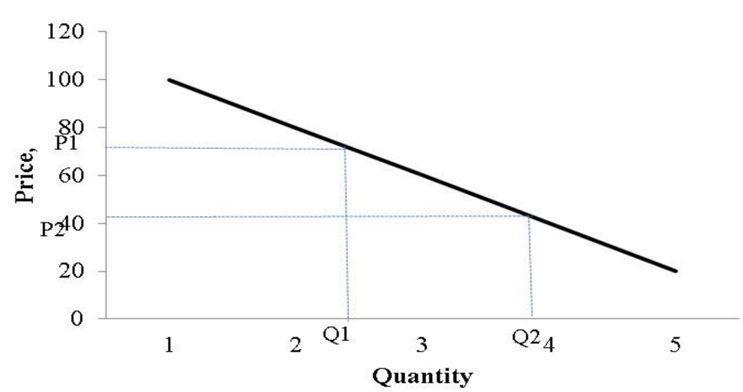


Fig. 22.4 Demand curve

22.3 Net Present Value and Benefit-Cost Ratio

Cost Benefit Analysis (CBA) provides a systematic set of procedures by which a firm or owner can assess whether to undertake a project or an irrigation system or a cropping pattern or a technology when there is choice between mutually exclusive projects or programs or crop.Cost Benefit Analysis is used to assess the value for money of large projects or adaption of new technology in agriculture or change in cropping pattern (Boardman et al. 2006).

The Net Present Value (NPV) of a project simply expresses the difference between the discounted present value of future benefits and the discounted present value of future costs, which is NPV = PV (Benefits) – PV (costs). A positive NPV for a given project signify that project benefits are greater than its costs and vice versa. The formula to calculate the present value (PV) for given future value (FV), interest rate (r), and number of accounting periods (n) is given by Eq.22.4,

$$PV = \frac{FV}{(1+r)^n} \qquad (22.4)$$

NPV decision rule:

For accept or reject decisions, if NPV ≥ 0, accept, if NPV ≤ 0, reject

Benefit cost ratio decision rule states that

BCR = PV (Benefits)/PV (costs)

Denominator of BCR includes the present value of all project costs, not just the capital costs.

Decision rules:

If BCR ≥ 1 then accept the project, if BCR ≤ 1 then reject the project. It should be clear that when,

NPV ≥ 0, then BCR ≥ 1

and NPV < 0, then BCR < 1

22.4 Internal Rate of Return (IRR)

The internal rate of return of a project is defined as the interest rate at which the net present value of that project equals zero. Let's consider a case in which cost of financing the project is 15% and IRR is 23%. Now, as the rate of return, the IRR is greater than the cost of financing the project, and thenone should accept the project. If IRR is less than the cost of finance, the project should be rejected. The decision rule for IRR can be given as

When IRR ≥ r, then accept and when IRR < r, then reject.

NPV and IRR give the identical results to accept Vs. reject decisions then considering individual project using Payback period as given in Eq.22.5

$$\text{Payback period} = \frac{\text{Initial investement}}{\text{Net cash inflow}} \qquad (22.5)$$

Example: Suppose forrice production, the initial investment is Rs. 100,000 and net cash inflow is Rs.40000, then the payback period is given by:

100000/40000 = 2.50 years

In the same manner, the payback period for wheat production with initial investment of Rs. 150,000 and net cash inflow of Rs. 58,333 then payback period will be: 150000/58333 = 2.57 years

From above data, one can decide in favour of a project with shorter payback period. Decision can be taken solely based on payback period criteria and does not involve other decision variables.

22.5 Sensitivity Analysis

In engineering economics, sensitivity analysis measures the economic impact resulting from alternative values of uncertain variables that affect the economics of the project. Sensitivity analysis is the study of how the variation in the output of a model (numerical or otherwise) can be approached qualitatively or quantitatively to different sources of variation. Sensitivity analysis can be used to determine model resemblance with the process under study, quality of model definition, factors that mostly contribute to the output variability, region in the space of input factors for which the space of factors for use in a subsequent calibration study, and interaction between factors. Possible situations where sensitivity analysis can be used;

i.) Volume of sales increase by 10%:In this case both the revenue and the labor and inputs would increase by 10%. So the corresponding increase in net income can be analyzed.

ii.) Prices increase by 10%, but nothing else changes: This may arise if one decides to increase prices and assume that one will be able to still sell the same volume. Then one can see the corresponding increase in profit/net income.

22.6 Break Even Analysis

Break-Even analysis is used to give answers to questions such as "what is the minimum level of sales that ensure the company will not experience loss" or "how much can sales be decreased and the company still continues to be profitable". Break-even analysis is the analysis of the level of sales at which a company (or a project) would make zero profit. As its name implies, this approach determines the sales needed to break even.

Break-Even point (B.E.P.) is determined as the point where total income from sales is equal to total expenses (both fixed and variable). In other words, it is the point that corresponds to this level of production capacity, under which the company operates at a loss. If all the company's expenses were variable, break-even analysis would not be relevant. But, in practice, total costs can be significantly affected by long-term investments that produce fixed costs. Therefore, a company in its effort to produce gains for its shareholders – has to estimate the level of goods (or services) sold that covers both fixed and variable costs.

Break-even analysis is based on categorizing production costs between those which are variable (costs that change when the production output changes) and those that are fixed (costs not directly related to the volume of production). The distinction between fixed costs (for example administrative costs, rent, overheads, depreciation) and variable costs (for example production wages, raw materials, sellers' commissions) can easily be made, even though in some cases, such as plant maintenance, costs of utilities and insurance associated with the factory and production manager's wages, need special treatment. Total variable and fixed costs are compared with sales revenue in order to determine the level of sales volume, sales value or production at which the business makes neither a profit nor a loss (Diewert, 1984).

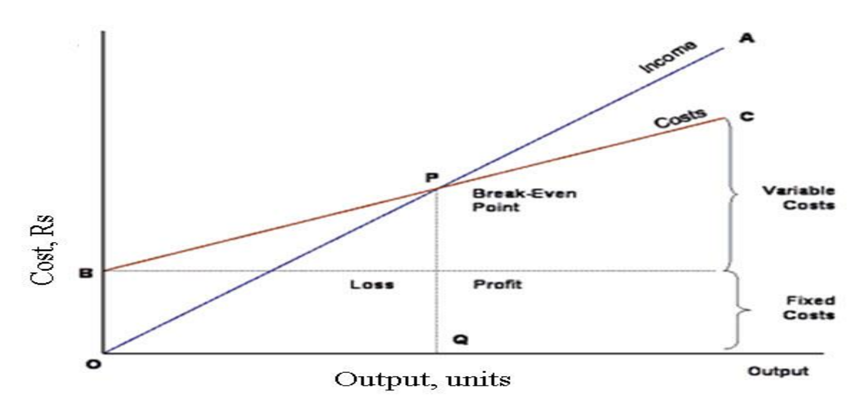


Fig. 22.5 Conceptual diagram for Break even analysis

(Source: http://www.tutor2u.net/business/production/break_even.html)

In the Fig. 22.5, the line OA represents the variation of income at varying levels of production activity. OB represents the total fixed costs in the business. As output increases, variable costs are incurred, meaning that total costs (fixed + variable) also increase. At low levels of output, Costs are greater than Income. At the point of intersection, P, costs are exactly equal to income, and hence neither profit nor loss is made i.e. Break-even point.

Breakeven point can be calculated using Eq. 22.6

Breakeven point (BEP) = TFC / (SP – VCP) (22.6)

where,

BEP = Breakeven point (units of production)

TFC = Total fixed costs

VCP = Variable costs per unit of production

SP = Selling price per unit of production

Lesson 23. Optimal Flow Criterion for Economic Drip Irrigation Pipes Selection

In pressurized irrigation systems, the selection of proper diameter of the pipeline is an important part in the design process. The logical diameter of an irrigation pipeline is the one that results in the lowest annual cost for particular operating conditions. The general layout of a drip irrigation system may include an extensive pipe network of lateral and sub mains connected to the main line. The main pipeline in the drip irrigation system is the pipe line that carries water from the source to the sub mains. Main pipelines are selected based on both economic and hydraulic considerations. Selection based on economic consideration means that the pipelines have the lowest annual cost for the entire life of the irrigation system compared with both next larger and next smaller available pipe diameters. Optimal sizing of the pipe is a key step in the optimization process that a given flow can result in minimum combined fixed and operating costs. In the past, economic chart and life cycle costing (LCC) technique have been used in the selection of the most economical pipe size for a given set of economic parameters and in the analysis and optimization of distribution pipe network (Keller, 1965 and Mohatar, 1985).

According to ASAE (1991) the hammer in irrigation pipeline can be minimized by limiting velocity of flow to 1.5 ms^{-1}. A main pipeline diameter is selected on the basic of maximum allowable velocity of 1. 5 ms^{-1} and pressure rating adequate for the normal operating pressure.

23.1 Theoretical Considerations and Development

The selection of economical pipe sizes is an engineering consideration of as much importance as the solution of the hydraulic problems involved. Life cycle costing technique is used for optimizing the pipe diameters to determine optimal flows between adjacent pipe diameters. The parameters necessary for the economic optimization are market available pipe sizes and their costs per unit length, existing interest rates, cost of energy, hours of operation of the system per year, overall system efficiency.

According to the definition of optimal flow, it is the flow rate at which the total annual costs between two adjacent pipes can be equated in order to find out optimal flow between the two pipe diameters. The criteria followed for deriving optimal flow expression presented in this lesson is taken from Reddy and Tiwari (2006).

Let D_1, D_2 be two adjacent pipe sizes and C_1, C_2 be their costs per unit length, respectively. Annual costs of these pipes can be obtained by multiplying their costs with capital recovery factor (CRF) as given in Eq. 23.1 (James and Lee, 1971)

$$\mathrm{CRF} = \frac{i\,(1+i)^n}{(1+i)^n - 1} \qquad (23.1)$$

where,

i = yearly interest rate, %

n = life period, years.

The total annual cost of a system (TAC_1), for the pipe diameter, D_1can be written as Eq. 23.2

$$TAC_1 = (AC_1)_{pipe} + (AC_1)_{pump} \qquad (23.2)$$

where,

$(AC_1)_{pipe}$ = annual cost of pipe line with pipe diameter D_1

$(AC_1)_{pump}$ = annual cost of pumping with pipe diameter D_1

Similarly, the total annual cost of the system (TAC_2), for the pipe diameter D_2can be written as Eq. 23.3

$$TAC_2 = (AC_2)_{pipe} + (AC2)_{pump} \qquad (23.3)$$

where,

$(AC_2)_{pipe}$ = annual cost of pipe line with pipe diameter D_2

$(AC_2)_{pump}$ = annual cost of pumping with pipediamter D_2

According to the optimal flow definition, the total annual cost of two adjacent pipe diameters will become equal at a particular flow rate. Hence, the optimal flow rate (Qc) exists between two diameters D1 and D2, the annual cost of two pipes can be equated as given in Eq.23.4.

$$(AC_1)_{pipe} + (AC_1)_{pump} = (AC_2)_{pipe} + (AC_2)_{pump} \qquad (23.4)$$

In the above equation (23.4), if annual costs of pipe and pump are replaced by fixed and operating costs, then above Eq. 23.4 may be written as

$$(FC_1)_{pipe} + (OC_1)_{pump} = (FC_2)_{pipe} + (OC_2)_{pump} \qquad (23.5)$$

In Eq. 23.5 the operating cost of pipe line and fixed cost of pump are not considered. The change of pipelines from D1 to D2 will have little effect on these aspects and they are considered equal in both cases.

By considering only the energy cost required towards the frictional head component of the total operating cost of the pump due to pipe diameters D1 and D2 equation 23.5 can be written as

$$(FC_1)_{pipe} + \frac{(Q_u\ H_1)}{75\times3600}\ C_{WHP} = (FC_2)_{pipe} + \frac{(Q_u\ H_2)}{75\times3600} \qquad (23.6)$$

$$C_{WHP} = \frac{H_0 C_0}{E_f} \qquad (23.7)$$

$$\frac{Q_u}{75 \times 3600}(H_1 - H_2)C_{WHP} = DF \qquad (23.8)$$

where,

H_1 and H_2 = head losses due to friction corresponding to pipessof sizes D1 and D2 respectively,

Q_u = total flow into the unit, L h^{-1}

DF = difference in annual fixed cost per unit length of pipes D_1 and D_2, Rs.

C_{WHP} = cost of water horse power

H_o = hours operating of system per year

C_o = energy cost, Rs./bhp h

E_f = overall pumping efficiency

Now,

$$(H_1 - H_2) = \frac{DF \times 75 \times 3600}{C_{WHP} Q_u} \qquad (23.9)$$

Above Eq. 23.9 can be modified further by estimating the head losses H_1 an H_2 in terms of flow taking place in the pipes by using proper friction factors for different flow regimes. Assuming the flow is in turbulent range, substitution of equation 23.10, Eq. 23.11 and Eq. 23.12 for the estimation of frictional head loss (Darcy- Weisbach formula), Reynolds number, and friction factor (Blasius formula) respectively in the above Eq. 23.9 will lead to development of Eq. 23.13.

Modified Darcy-Weisbach (DW) equation for frictional head loss is given by Eq. 23.10

$H_f = 6.3755\ f\ L\ Q^2\ D^{-5}$ (23.10)

where,

H_f = frictional head loss, m

f = Darcy's frictional factor

L = length of pipe, m

Q = flow rate, L h^{-1}

D = internal diameter of pipe, mm

The frictional head loss coefficient 'f' depends upon Reynolds number and the relative roughness of the pipe. Drip irrigation laterals have surface made of smooth. Flow in laterals is generally turbulent at its upstream end and becomes laminar at the downstream reach. The flow regime is characterized by Reynolds number (Re) and for cylindrical flow path this is given by

$$Re = \frac{4\,Q}{k\,\eta\,\pi\,D} \qquad (23.11)$$

where,

Q and D are as defined above

k = a constant equal to 3600

η = kinematic viscosity of water, $m^2\,s^{-1}$

For turbulent flow, the Blasius equation is

$$f = 0.316\,Re^{-0.25} \qquad (4000 > Re < 10000) \qquad (23.12)$$

$$0.465 \times Q_c^{1.75}\left[\frac{1}{D_1^{4.75}} - \frac{1}{D_2^{4.75}}\right] = \frac{DF \times 75 \times 3600}{Q_u\ C_{WHP}} \qquad (23.13)$$

where,

Q_C = optimal flow rate, L h^{-1}

Assuming that the flow through the unit is equal to optimal flow (Qu = Qc), the above equation can be converted in the following form for the calculating the optimal flow between adjacent diameters D1 and D2 as shown below.

$$Q_c = \left[\frac{\frac{k_1}{k_2}}{\frac{1}{D_1^{4.75}} - \frac{1}{D_2^{4.75}}}\right]^{0.3636} \qquad (23.14)$$

where,

$$k_1 = \frac{DF \times 75 \times 3600}{C_{WHP}} \qquad (23.15)$$

$$k_2\ 0.465 \qquad (23.16)$$

Hence, the optimal flow between any two adjacent pipe diameters can be obtained by using the data on available pipe sizes in the market, their costs, bank interest rate, energy cost, hours of operation per year and overall pumping efficiency.

The Eq. 23.14 can be written in generalized form for different flow regimes as shown below

$$Q_c = \left[\frac{\frac{k_1}{k_2}}{\frac{1}{D_1^a} - \frac{1}{D_2^a}}\right]^b \qquad (23.17)$$

Similar derivations are made to include friction factors for laminar range, fully turbulent range and also by using Hazen-Williams equation. The resultant constants are presented in Table 23.1.

The developed equation with coefficients makes it possible to derive optimal flows between the adjacent pipe sizes available in the market. This optimal flow criterion can be used for selection of sub main and main pipe sizes required for drip irrigation.

Table 23.1. Coefficients of optimal flow Eq. 23.17 under different flow regimes

Type of equation	Flow regime	Friction factor (Wu and Gitlin, 1973)	K_2	a	b
Darcy-Weisbach (DW)	Laminar range	$f = 64\ Re^{-1.0}$	1.157	4.000	0.2500
	Turbulent	$f = 0.316\ Re^{-0.25}$	0.465	4.750	0.3636
	Fully turbulent	$f = 0.130\ Re^{-0.172}$	0.302	4.828	0.3506
Hazen-Williams (HW)		C = 150	0.294	4.871	0.3506

23.2 Optimal Flows in Drip Pipes

In the present study, a model equation for determining optimal flows between adjacent pipe sizes by using both Darcy-Weisbach and Hazen-Williams equations was developed and shown in Eq. 23.17 along with its associated values was used in this section for deriving the optimal flows. The objective of this study was to find out suitable pipe sizes for sub main and main lines for drip system.

Based on available pipe sizes suitable for sub main and main lines for irrigation purpose the economical analysis has been carried out using the required input values for economical model. The input data required for deriving optimal flows between adjacent pipe sizes, annual interest rate, and life period of pipe, annual operating hours, overall pumping efficiency and energy cost. Life period of pipes vary based on pipe material. Hence, suitable value for life period should be taken considering the type of pipes used in the analysis.

The details of pipe sizes and their costs per meter length are as follows:

Pipe size, mm	Unit cost, Rs. m^{-1}
40	13.0
50	20.5
63	25.5
75	36.5
90	53.5

Optimal flows are derived using following assumptions:

Life period of pipe lines: 10; Annual operating hours: 2000 h; Annual interest rate :12%; Overall pumping efficiency: 65% and Energy cost is Rs. 1 bhp h (1 US$ = Rs. 55 approx.).

The optimal flows are derived for the successive sizes of the pipes under turbulent and fully turbulent range with DW equation and also with HW equation with C = 50 and shown in Fig. 23.1.

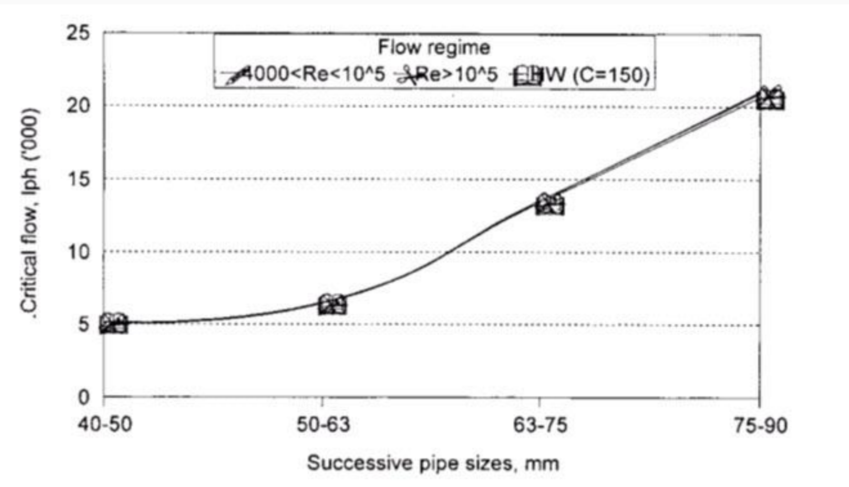


Fig. 23.1. Optimal flows for different pipe size combinations

Fig. 23.1 indicates the optimal flows estimated under the three cases for turbulent range, fully turbulent range and with HW equation for C= 150 gave almost same values. With DW equation the temperature of water was considered 20^0C. With other temperatures, incorporating suitable correction in formula will result in different optimal flows. Fig. 23.1 shows for the given criteria, the flow rate in the pipeline at which the pipe size has to be changed from one to other. By using DW equation for turbulent flow, the optimal flows for the pipe size combinations of 40-50 mm, 50-64 mm, 63-75 mm and 75-90 mm are found to be 5085, 6406, 13521 and 21049 L h^{-1},respectively. These values indicate the flow rates at which pipe size has to be changed. For example, if the flow rate is expected in pipe line in between 13521 L h^{-1} to 21049 L h^{-1}, use of 75 mm size pipe is advisable. But when, flow rate exceeds

21049 use of 90 mm pipe size will prove to be economical. This means the annual cost of 90 mm pipe size will be lower than 75 mm pipe size when flow in the pipeline is beyond 21049

L h^{-1}.

Hence, the optimal flow criteria will provide useful tool for making pipe size selection in the pressurized irrigation system.

23.3 Model application

The proposed theoretical developments were used for the analysis of optimal flow criteria for the pipe size selection and design of economic layouts of drip irrigation system.

23.3.1 Design of economical layouts

In this section, suitable design layouts are proposed using the computer program (Tricad) developed using optimal flow criteria for the design of drip irrigation system for a 6 ha area banana crop. Details of data used design are as follows:

Crop: banana; Spacing:2 m x 2 m; Area:6 ha (400 m x 150 m); Slope of the field:flat terrain; Soil texture: medium textured; Peak evaporation rate:9.75 mm day^{-1};Source of water:well and Static head:8 m.

Emission uniformity (EU) of greater than 90% and maximum limiting velocity in pipeline of 1.5 m s^{-1} are considered as criteria for designing the drip irrigation layouts.

23.3.2 Pipe sizes for the drip system

The following pipe diameters available in the market were considered for design purpose. Data on pipe diameters and their costs are as shown in the Table 23.2. Each pipe size is designated suitably indicating its size and suitability for lateral, sub main and main.

The pipe diameters of 10 mm, 12 mm and 16 mm were considered for lateral and designated as D_{l10}, D_{l12} and D_{l16}, respectively. The pipe diameters of 40 mm, 50 mm and 63 mm were considered for sub main pipes and designated as D_{s40}, D_{s50} and D_{s63}, respectively. The pipe diameters of 63 mm, 75 mm and 90 mm are considered for main and designated as D_{m63}, D_{m75} and D_{m90}, respectively.

Table 23.2 Pipe sizes for drip irrigation lateral, sub main and main and their respective costs

Diameter, mm	10	12	16	40	50	63	75	90
Cost, Rs. m^{-1}	3.0	4.5	6.3	13.0	20.5	25.5	36.5	53.2
Lateral	D_{l10}	D_{l12}	D_{l16}					
Sub main				D_{s40}	D_{s50}	D_{s63}		
Main							D_{m75}	D_{m90}

23.3.3 Planning Layout

The field size was considered as 400 m x 150 m with well located outside the boundary on the width side of the field as shown in the layout (Fig. 23.2).

Based on water requirement estimates for the crop, it was considered to provide one 4 l h^{-1} emitter for each plant. The total number of plants in 6 ha field is estimated to be 14,800 by leaving one row space at the centre along the length for easy operation of subunits. Based on emitter discharge and number of plants in the field, the pump discharge requirement is computed to be 59,200 L h^{-1}. This flow in the main line of D_{m90} will cause the flow velocity of 2.59 m s^{-1}, which was considered to be high for irrigation pipe lines,and also it would cause the requirement of bigger size prime mover for operating the pump. In order to use specified pipe diameter to D_{m90}, D_{m75} and D_{m63} for the main and also to reduce the pump capacity and prime mover requirement, it is desired to irrigate field in two shifts. For this reason, the field needs to be divided into two halves for irrigation purpose. This aspect has been considered while planning irrigation layouts.

The proposed layout consists of subunits with laterals on one side of the sub main. The field is divided into eight subunits with four on each side of main line. The length of sub main is 75 m with 37 rows and with 50 emission points on each row. The subunits are numbered serially from 1 to 8 as shown in Fig 23.2.

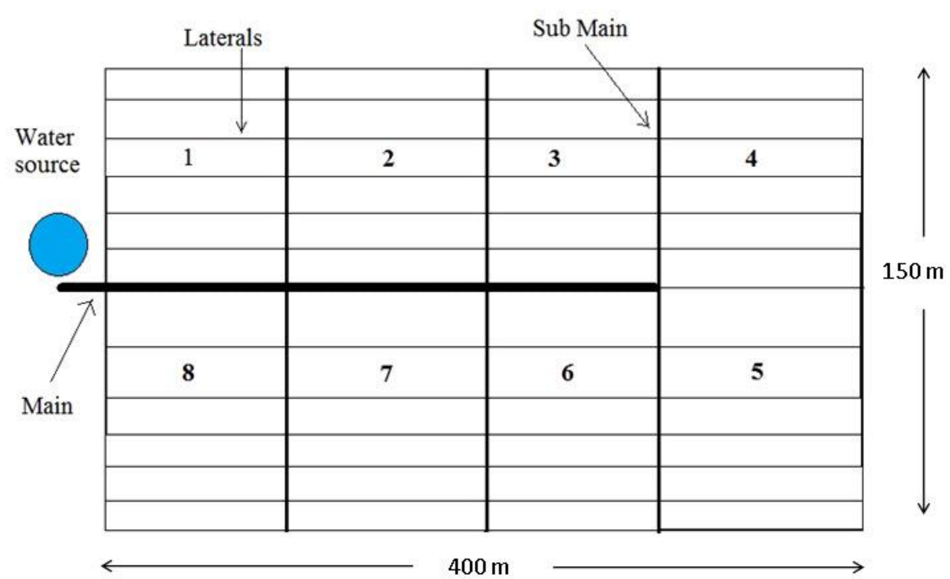


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Fig. 23.2 Layout of the field (not to scale)

23.3.4 Irrigation Plans

The field shown in layout (Fig 23.2) can be irrigated in through two different plans as shown in Table 23.3.

Table 23.3 irrigation plants for layout proposed

Irrigation plan	Description
I_1	Irrigating subunits 1,2,3, and 4 in one shift and 5,6,7, and 8 in another shift
I_2	Irrigating subunits 1, 2, 7 and 8 in one shift and 3, 4, 5 and 6 in another shift

23.3.5 Design of Main Pipe Lines

Design of main pipes was made based on both optimal flow criteria and velocity limit in the main line.

23.3.5.1 Based on optimal flow criteria

In order to design main line pipe sizes for laying in field the optimal flow rates were computed for the successive pipe sizes to be considered for main line sizes. In estimating the optimal flows, the following assumptions were made.

Life period of pipes, n:10 years; Interest rate, i:12%; Energy cost/bhp h:Rs. 1.00; Operating hours per annum:2000 h and Overall pumping efficiency: 65%

In order to study the effect of time of operation on optimal flows, the analysis was made for the operating hours from 500 to 2500 at an interval of 500 hours. The optimal flows estimated are shown in Table 23.4.

Table 23.4 indicates the flow rates at which the pipe diameters are to be changed from lower to higher sizes for the consequent pipe sizes of 63-75 mm and 75-90 mm for different annual hours of operation. For, example at 2000 hours of operation, the pipe size required to be changed from 63 mm to 75 mm when the flow in the network exceeds 13,520 L h^{-1} and similarly, the pipe size need to be changed from 75 mm to 90 mm at 21,048 L h^{-1}.

Table 23.4 Optimal flows for pipe size combinations of 63-75 mm and 75-90 mm for different operating hours in a year

Operating hours	63-75 mm		75-90 mm	
	Lh^{-1}	L s^{-1}	L h^{-1}	L s^{-1}
500	22382	6.217	34843	9.678
1000	17396	4.832	27081	7.522
1500	15011	4.120	23369	6.491
2000	13520	3.756	21048	5.847
2500	12467	3.463	19408	5.391

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23.3.5.2 Velocity Limit in the Main Pipe

An attempt has also been made to design the size of main pipe keeping the velocity limit as 1.5 m s^{-1} (ASAE, 1991). In order to select suitable pipe size for the expected flow rates and corresponding velocity is worked (Table 23.5). Table 23.5 is referred while applying the velocity criteria in selection of main pipe.

Table 23.5. Flow velocities in the main pipeline for different diameters at various flow rates

Expected flow, L h^{-1}	Velocity in different main line pipe sizes, m s-1		
	63 mm	75 mm	90 mm
7400	0.66	0.47	0.32
14800	1.32	0.93	0.65
22200	1.98	1.40	0.97
29600	2.64	1.86	1.29
59200	5.28	3.72	2.59

23.3.6 Estimation of Main Line Pipes

With the help of Tables 23.4 and 23.5 and considering the layout and expected flows in the main line in different zones, the requirement of the main pipelines was worked out and presented in Table 23.6 for different irrigation plans.

In calculating the pipe sizes the maximum flow expected in each zone was considered. It was also assumed that the water source was 10 m away from the field boundary. Hence, 10 m length of the pipe was added to the segment at the beginning to arrive at the final estimates of length of pipe and cost.

It is clear from the Table 23.6 that there are significant differences in the estimates of pipe lines in the two irrigation plans. With optimal flow criteria in case of irrigation plan $\mathbf{I_1}$, the requirement of the pipe were 100 m of 63 mm size, 100 m of 75 mm size and 110 m of 90 mm size. With $\mathbf{I_2}$ plan, the requirement of the pipes was 100 m of 75 mm and 210 m of 90 mm. The estimates were obtained based on the flow expected in each segment of the pipe. For example, in case of $\mathbf{I_1}$, considering the subunits 1, 2, 3 and 4 are irrigated in one shift, the main pipeline feeding the subunit 4 should carry the flow of 7,400L h^{-1} and accordingly 63 mm pipe size was found suitable. Similarly, the segment supplying water to 3 and 4 subunits will carry 14,800 L h^{-1} and need 75 mm pipe size of 100 m length, then the pipe segment carrying flow to 2, 3 and 4 sub units should carry 22,200 l h^{-1} and require 90 mm size of 100 m length. Then the segment, which has to carry flow for all the subunits at the rate of 29,600 L h^{-1}, will be of 90 mm size and 10 m length. In the similar way estimates were made for **I_1** assuming that 3, 4, 5 and 6 subunits are to be irrigated in one shift. The segment of pipe carrying water to the subunits 4 and 5 should carry 14,800 L h^{-1} and should be of 75 mm and 100 m length. Then for entire area under subunits 3, 4, 5 and 6 the total flow; requirement was 29,600 L h^{-1} and the pipe size should be of 90 mm of 210 m lengths. The cost of the main line under 11 and 12 were found to be Rs. 12,052 and Rs. 14822 respectively. It shows net saving of Rs. 2,770 was possible by adopting **I_1** over **I_2**. This indicates that the selection of irrigation pipe is an important aspect to optimize the pipe requirement. Similarly, main lines estimates were made by considering the velocity criteria. Estimates were also made based on the assumption that uniform size pipes could be used as main lines. By considering the initial investment on the pipeline, the pipe sizes selected based on velocity criteria were found to be less expensive than those selected under optimal flow criteria.

Table 23.6 Estimates of length of pipe line (m) required for main based on optimal flow criteria and velocity limit

Irrigation plan	Optimal flow criteria				Velocity limit criteria			
	63 mm	75 mm	90 mm	Total cost, Rs.	63 mm	75 mm	90 mm	Total cost, Rs.
I_1	100	100	110	12052	200	100	10	9282
I_2		100	210	14822	100		210	13722

23.3.7 Comparison of Irrigation plans in terms of Main Pipe Selection

In order to compare the economics of pipe size selection for main line, the pipes sizes D_{m63}, D_{m75} and D_{m90} were also considered for mainlines separately without any sizing. The frictional head loss in the mainline for different pipe sizes is estimated by considering the amount of flow taking place in each zone. The details of the comparisons on frictional head loss and annual costs are presented in the Table 23.7.

Table 23.7 furnishes the detailed calculations of the frictional head loss in the main, energy cost to overcome friction, annual fixed costs and the horsepower requirement for the prime mover for all the criteria under which the main size was selected. The annual fixed cost on the main line was more for larger pipe sizes. However, the annual operating cost in order to overcome the friction was less. The total annual costs are considered for purpose of comparisons. The pipe size combinations with lower annual cost are better for selection. In all irrigation plans the optimal flow criteria proves to be more economical. In calculating the hp requirement, a constant loss of 2 m of head in accessories and 8 m static suction head were considered. Considering the pressure head at the inlet of the subunit as 10 m, the total head requirement estimated to be 20 m plus the frictional head loss in the main line as presented in the Table 23.7.

In all the cases the optimal flow criteria proves to be requiring less horsepower to operate the prime mover than with uniform sizes of D_{s63} and D_{s75}. However use of uniform size of D_{s90}would need less prime mover size, but the annual cost of the pipeline would be much higher than those selected with optimal flow criteria. This shows the optimal flow criteria should be the basis for pipe size selection in selection of the main line in drip irrigation systems design.

Table 23.7 Comparison of different irrigation plans based on mainline pipes Selection.

Irrigation plan	Pipe sizes for main as per	Frictional head loss, (H_f), m	Energy cost due to H_f, Rs	Annual fixed cost of the main, Rs.	Total annual cost, Rs.	hp of the prime mover
I_1	Optimal flow	3.06	560.3	2401.2	2961.5	3.89
	Velocity	5.88	1150.2	1849.3	2999.5	4.36
	63 mm	9.61	2152.8	1575	3727.8	4.99
	75 mm	4.19	939.3	2254.4	3193.7	4.08
	90 mm	1.77	395.6	3285.9	3681.5	3.67
I_2	Optimal flow	4.54	1139.6	2953.1	4292.7	4.14
	Velocity	6.02	1588.8	2734	4322.8	4.39
	63 mm	21.12	6682.7	1575	8257.8	6.94
	75 mm	9.23	2919.5	2254.4	5173.9	4.93
	90 mm	3.88	1228.6	3285.9	4487.4	4.03

23.4 Summary

Optimal flow criterion and Life Cycle Costing (LCC) techniques were used for development of an equation for economic pipe size selection. The model equation developed was based on both economic and as well as hydraulic considerations. It estimates the flow rate at which the designer should change from one size to another size pipes. The main line selection made for 6 ha banana plot was compared with other methods of pipe selection. Application of the optimal flow method resulted in lowest annual cost of mainlines in comparison to the selection on velocity basis and uniform size pipes. In all irrigation plans the optimal flow criteria proved to be more economical.

Lesson 24. Economic Viability of Micro Irrigation in Different Crops

Micro irrigation (MI) includes drip and micro sprinklers. Since micro irrigation is effective method for conserving water resources, the Government of India considered all the water emitting devices used for irrigation, such as overhead sprinklers, mini and micro sprinklers, drip emitters, sprayers, water jets, bubblers, foggers, spitters, etc. under micro irrigation system for providing financial supports to Indian farmers. The high cost of installation, operation and maintenance of micro irrigation systems remains a major constraint to micro irrigation expansion. Only crops with highest return are considered implementation of micro irrigation.

International Committee on Irrigation and Drainage (ICID) conducted a survey in 1991 and reported that an average installation cost for micro irrigation system was USD $ 2000-4000 (Bucks, 1995). Estimates of operation and maintenance cost of MI ranged from USD $ 100-800 per hectare per year. This large range of variation was due to variable labor cost, large variation in crop types, and difference in age of MI system.

The estimated cost of installing drip irrigation system as per government of India guidelines prepared for different lateral spacings for calculation of subsidy is given in Table 24.1 (NMMI, 2010) for different crops.

The relative cost of drip installation decreases with increase in area, since certain essential components remain the same irrespective of the area covered. Further, the cost of installation will reduce for close growing vegetable crops by using laterals in paired row system. The life of materials and accessories of the system is normally considered as 5 to 10 years.

Table 24.1. Estimated cost of drip system for various crops with different spacing

Sl. No.	Fruit crops	Lateral for crop spacing, m x m	Estimated cost, Rs.		
	Wide spacing		0.4 ha	1 ha	5 ha
1.	Mango/Sapota	i) 12 x 12	13785	18820	73611
		ii) 10 x 10	14277	20041	79831
2.	*Moderate spacing*				
	Mango / Sapota	i) 6 x 6	16605	26551	109129
		ii) 5 x 5	17977	30143	126925
	Orange and citrus species				
3.	Pomogranate	4 x 4	18621	31793	135459

	Grapes	3 x 3	20048	36551	153441
	Ber	3 x 3	20048	36551	153441
4.	Banana	2 x 2	31616	63598	305797
	Papaya	2 x 2	31616	63598	305797
5.	Closed spaced vegetable crops				
	Brinjal	1.5 x 1.5	35973	74737	360002
	Tomato	1.2 x 0.6	43816	97548	474070
	Chilli	1.2 x 0.6	43816	97548	474070

(Source: National Mission of Micro Irrigation Operational Guidelines, GoI, Ministry of Agriculture, Deptt. of Agri. and cooperation, New Delhi 2010)

24.1 Economic Evaluation of Drip Irrigation

To evaluate the economic viability of drip investment both the Net Present Value (NPV) and Benefit Cost Ratio (BCR) are computed by utilizing discounted cash flow technique. The net present value (NPV) is the difference between sum of present value of benefits and that of costs covering items like capital and depreciation costs of drip system. In terms of the NPV criteria, the investment on drip set can be treated as economically viable, if the present value of benefits is greater than present value of costs. The BCR is also related to NPV as it is obtained just by dividing the present value of benefit stream with that of cost stream. Generally, if the BCR is more than one then, the investment of that project can be considered as economically viable.A BCR greater than one obviously implies that the NPV of the benefit stream is higher than that of cost stream. The NPV and BCR can be defined as follows:

$$NPV = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad (24.1)$$

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \quad (24.2)$$

where, B_t= benefit in year, t

C_t= cost in year, t

t = 1, 2, 3…, n

n = project life, years

i = rate of discount (or opportunity cost of investment)

Since, the drip irrigation involves fixed capital, it is necessary to take into account the income stream for the whole life span of drip investment. It is difficult to generate the cash flows for the entire life span of drip investment in the absence of observed temporal information on benefits and cost, we need to make few assumptions so as to estimate both cash inflows and outflows for drip investment. These assumptions are:

i) The life period of drip set is considered as 5 to 10 years depending upon type of crop. Considering 5 years for banana, papaya and 10 years for Mango, Sapota etc.

ii) The income stream from drip set is uniform and constant over its entire life for the crops. However, this assumption is relaxed at later stage by considering alternative scenarios; where in cash out flows are allowed to increase by 2% and 5% per annum over the corresponding cash inflows.

iii) Differential rates of discount (interest rate) are considered to undertake sensitivity of investment to change in capital cost. These are assumed at 10, 12 and 15% as alternatives representing various opportunity costs of capital.

iv) Finally, the crop cultivation technology is to be assumed constant for considering same group of crops.

24.2 Economic Analysis Considering Optimal Spacing of Laterals

The major limiting factor in large scale adoption of drip irrigation is its high initial investment. Physical factors such as field dimensions, shape and topography will influence the layout of pipe networks. Cost of the lateral and drippers are the main factors that influence the system cost. Any effort made to reduce the length of lateral and number of drippers in a drip system will cause reduction in the system cost.

a.) Water front advance studies for optimizing the spacing of laterals

Water front advance under a point source dripper depends on soil type, dripper discharge and the operation time of the drip system. Larger operation time results into larger lateral spacing but may simultaneously result into deep percolation losses because of *consequential* larger vertical movement of water into soil. Horizontal advance corresponding to the operation duration of the system that results into vertical advance equal to the root zone depth should therefore be considered as maximum allowable lateral spacing. Patel and Rajput (2001) determined the optimal spacing of laterals and appropriate number of drippers for irrigating Okra crop in sandy loam soil. They obtained optimal operation durations of drip system with dripper discharges of 2, 4 and 6 Lh^{-1} as 720, 480 and 240 minutes, respectively based on the horizontal and vertical advance of soil moisture. They also reported drip system with 4 $L\ h^{-1}$ dripper discharge capacity for a lateral spacing of 92.5 cm apart is most economical system for a irrigating Okra crop.

Jaiswal et al. (2001) conducted experimental study to determine the optimal length of lateral for various emitter discharge and emitter spacing. They reported optimal length of lateral 28.76, 59.7 and 171.1 m for the dripper capacity of 4 Lh^{-1} at 0.6, 1.2, 1.8 and 2.4 m emitter spacing, respectively. For 8 $l\ h^{-1}$ emitter at 0.6, 1.2 and 2.4 m emitter spacing optimal length of lateral were 20.2, 33.6, and 49.8 and 63.8 m,respectively. They concluded that 4 Lh^{-1} emitters resulted in more optimal length of lateral as compared to 8 lh^{-1}emitter capacity.

b.) Economic studies considering planting geometry

Tiwari et al. (1997) conducted field experiment to study the effect of crop geometry on biometric growth and yield of banana considering groups of 1 plant, 2 plants, 3 plants and 4 plants nearer to each other by placing each plant in a separate pit and adjusting their row to row and plant to plant spacing such that area under each plant is 4 m^2. The required amount of water estimated using modified Penman method was applied to the banana crop. Standard agronomic practices were followed to carryout experiment. The biometric response and yield data were observed for two crop seasons. The cost of cultivation as per prevailing rate during experimental period (1994-95 and 1995-96) was worked out as Rs. 26,300 per hectare. The planting geometry (2 m x 2 m) responded highest yield. This planting geometry requires total length of laterals as 4900 m and results in B.C. ratio as 2.97 for one hectare area. Among all the planting geometry, the planting geometry 1.33 m x 3 m requires lateral length 3290 m resulted in highest B.C. ratio as 3.09. Hence, plant to plant spacing of 1.33 m with one plant in each pit and row to row spacing of 3 m (lateral to lateral spacing) recommended for dwarf Cavendish variety of banana cultivation to minimize the cost of drip irrigation system.

24.3 Economic Analysis of Experimental Field Trials under Drip Irrigation

Large numbers of field experiments were conducted in Precision Farming Development Centre projects sponsored by National Committee on Plasticulture applications in Horticulture (NCPAH), Ministry of Agriculture, Government of India to evaluate the benefit cost analysis of drip/micro irrigation on various fruits, vegetables and other horticultural crops. The biometric and yield responses of these horticultural crops were recorded for different amount of water application through drip and conventional irrigation (ring basin, check basin or furrow) methods. The amount of water to be given to the crop was estimated by FAO56 (Penman Montieth) or using USWB open pan evaporation method. The economic analysis of the data recorded from long term field experiments 3 years for seasonal vegetables and fruit crop such as Banana, Papaya and Pine apple and 5-6 years for perennial fruit crops (Mango, Sapota, Guava crops) were analyzed. The steps followed to carry out economic analysis are stated below:

1. Determine the fixed cost of drip system

a) Use life of drip/micro irrigation system (i.e. 7 to 10 years).

b) Determine the depreciation cost.

c) Determine the interest (use prevailing bank interest rates for agriculture).

d) Determine the annual repair and maintenance cost (1% of annual cost).

e) Determine the total cost (b+ c +d).

1. Determine the cost of cultivation, Rs.

The cost of cultivation includes field preparation, seedlings, planting, intercultural operations, cost of fertilizers and manures and their application, plant protection chemicals and their application, harvesting and other relevant operations.

1. Determine the seasonal total cost (1(e) + 2.

2. Determine the amount of water applied through drip system and by conventional methods. This is the water estimated by FAO56 or Pan evaporimeter and, considering the wetting factor for drip system.

3. Estimate the yield response under drip (micro irrigation) and conventional method of irrigation.

4. Determine the prevailing market selling price.

5. Estimate the income from production (5 x 6) due to drip/micro irrigation or conventional irrigation.

6. Estimate the net seasonal income due to drip/micro irrigation and conventional irrigation (7-3).

7. Estimate the additional area cultivated due to saving of water.

8. 10. Estimate the additional expenditure due to additional area (3 X 9).

9. 11. Estimate the additional income due to additional area (7X 9).

10. 12. Estimate the additional net income (11-10).

11. 13. Determine the gross cost of production (3+10).

12. 14. Determine the gross income (7+11).

13. 15. Determine the gross B.C. Ratio, (14/13)

14. 16. Determine the net extra income due to drip irrigation system over conventional irrigation (12+8 (drip)-8(conventional).

15. 17. Determine the net profit per mm of water used (8/4).

16. 18. Determine the yield per mm of water used, (kg/ha/mm).

Precision Farming Development Centre located at Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, India conducted research experiments on fruits and vegetable crops under drip/ micro sprinkler irrigation. The salient results in terms of amount of water applied, yield, water use efficiency and B. C. ratio of some of the crops are presented in Table 24.2

Table 24.2. Salient findings of experimental trials of fruits and vegetable crops under drip irrigation.

Sl. No	Fruit crop	Yield, t/ha	Water applied, mm	Fixed cost, Rs.	WUE, kg/ha mm	B. C. Ratio	Source
1.	Banana (2 m X 2 m)	39.53	1059	45000	37.32	4.49	Tiwari et al., 1998
2.	Guava (5 m X 5 m)	37.70	206.0	30200	183.0	4.40	Singh and Tiwari, 2007
3.	Pine apple	70.00	1085.0	84000	64.5	6.85	Tiwari et al., 2005
4.	Mango (5 m X 5m)	20.9	512.0	28210	54.42	7.01	Anonymous, 2004
5.	Sapota (5 m X 5 m)	15.6	232.5	10929	6.71	3.55	Anonymous, 2012
	Vegetable crops						
6.	Turmeric (Intercrop to Sapota) 0.5 m X 0.25 m	14.10	483.5	86674	29.16	2.25	PFDC, Annual Report, 2013
7.	Potato 0.3 m X 0.5 m	250.86	220.0	118320	114.02	1.75	Tiwari et al., 2009
8.	Okra 0.6 m X 0.3 m	13.06	665.0	65666	19.64	1.77	Tiwari et al., 1998
9.	Tomato (0.6 m X 0.6 m)	70.28	560.0	65000	125.5	6.79	Tiwari et al., 1998
10.	Cabbage	106.68	400.0	95279	266.7	6.99	Tiwari et al., 2003
11.	Capsicum	13.57			282.71	6.38	Tiwari et al., 1998
12.	Brocolli	19.63			48.05	2.79	Tiwari et al., 2003

Rao and Singh (1998) conducted field experiments on tomato crop under drip and check basin irrigation to evaluate the economic feasibility of drip irrigation. Drip method consisted of two treatments. i) one emitter in the center of 4 plants (double pair wise) ii) one emitter between two plants (single pair wise) iii) one micro tube for each plant. The present worth of total cash inflows, out flows, payback period and benefit cost ratio were estimated for all these treatments. The least payback period of 13.28 years and maximum benefit cost ratio of 1.882 was obtained for double pairwise followed by micro tube drip treatment as 13.68 years and 1.826, respectively. They recommended using pair wise drip system layout for irrigating tomato.

Singh (2008) studied economic viability of drip irrigation for growing capsicum based on discounted cash flow technique (NPV and BCR). The experiment was conducted with different amount of water application through drip system to capsicum crop. Highest yield of 14.5 t ha^{-1} was found under full amount of water applied through drip with plastic mulch. The net present value was highest under drip with full amount of water application and with B.C. ratio of 3.12.

Summary

The micro irrigation has its advantages and limitations. Its advantages are in terms of saving of water (50-60%) of that for conventional irrigation, effective use of fertilizers, less labour and energy cost. Based on the economic analysis carried out, the micro irrigation system is highly remunerative for high value crops. The limitation of this method is its high initial cost, which is beyond purchasing capacity of small and marginal farmers, that's why it is normally adopted by large land holdings farmers. As a policy to encourage the use of such system, the Ministry of Agriculture, Government of India, provides subsidy to the tune of 50% to small and marginal farmers under National Mission on Micro Irrigation.

Module 6. Automation of Micro Irrigation System

Lesson 25. Automation

25.1 Introduction

Automation of micro irrigation system refers to operation of the irrigation system with minimum or without manual intervention. A well-controlled irrigation system is one which controls the spatial and temporal distribution of soil moisture to achieve maximum crop yield and benefit cost ratio. The adoption of automated new micro irrigation makes possible to grow advanced high value cropping system with new technologies which are difficult to grow by conventional means. Using automation one can control the irrigation valves, pump and fertigation equipment.

Some of the specific features of automation irrigation are stated below:

i) It eliminates the manual opening and closing of valves.

ii) It starts and stops pump exactly as and when required thus optimizing the

energy requirement.

iii) Irrigation system can be started at any desired time. One need not worry to visit farm during odd time (night). This is specially in Indian condition, where power supply is available for agricultural operation during night time.

iv) Possibility to change frequency of irrigation and fertilizer application as per the crop need.

v) Use of water from different sources and increased water and fertilizer use efficiency.

25.2 The Need for Automation of Irrigation

The consumption of energy and water is quite high for agricultural production. Both of these are scare national resources. It is therefore in the national interest to adopt newer technologies to reduce their wastage. Automation of irrigation system is one way of doing it as the same helps in optimal utilization of energy and water resources. The micro irrigation system possesses all qualities to introduce automation in this irrigation system. Micro irrigation includes drip surface and sub-surface, bubblers, mini and micro sprinklers and jet that offers the means to maintain soil water nearly at constant levels and minimizes the water stress. However, with frequent irrigation the control of the soil water root environment is critically dependent upon the irrigation regardless whether it is manually or computer controlled. Any disturbance is the irrigation schedule quickly creates detrimental water or oxygen stress on the crop. On the control of high frequency micro-irrigation systems must be automatic, redundant and capable of responding to small and rapid changes in soil water. Hence automation of micro irrigation meets these requirements. To meet the increasing food demand for growing population it is the need of the hour to increase agricultural production with minimum expenditure and loss of resources. Automation of drip and micro irrigation will serve as basic tool to achieve this. Although initial cost of drip and along with automation unit is high. However, the long term benefits in saving water, labour, energy, and fertilizer and also increase in agricultural produce as well as quality definitely covers up the high initial cost in a less pay back period.

25.3 Merits and Demerits of Automation

A) Merits

An automated micro irrigation system increases crop yield, save water and energy and labor costs as compared with the manual system. The automated irrigation system starts watering just at the predetermined level of moisture content and stops irrigation as the desired soil moisture content or field capacity is attained. The system accounts for effective rainfall to schedule irrigation, eliminates the need to visit the farm frequently and ensures optimum soil water condition in the root zone. This prevents leaching of minerals and nutrients vital for the plant's healthy growth and eliminates the long term ill-effects of over irrigation that leads to development of the salinity. The system is useful for both arid and humid areas where unpredictable and unevenly distributed rainfall disrupts a fixed irrigation schedule. This system also facilitates high frequency and low volume irrigation.

Automation results in higher production, increased productivity, better quality, improved safety, shorter workweeks for labour. Higher output and increased productivity. Automated systems typically perform the irrigation process with less variability than human workers, resulting in greater control and consistency. Also, increased process control makes more efficient use of irrigation water, resulting in less water consumption or high water use efficiency.

i) Reduced labour

As the irrigator is not required to constantly monitor the progress of irrigation, the irrigator is available to perform other tasks uninterrupted.

ii) Improved life style

The irrigator is not required to constantly check the progress of water down the bays being irrigated. The irrigator is able to be away from the farm, relax with the family and sleep during night.

iii) More timely irrigation

Irrigators with automation are more inclined to irrigate when the plants need water, not when it suits the irrigator.

iv) Assists in the management of higher flow rates

Many irrigators are looking to increase the irrigation flow rates they receive through installing bigger channels and bay outlets. Such flow rates generally require an increase in labour as the time taken to irrigate a bay is reduced thus requiring more frequent change over. Automation allows for these higher flows to be managed without an increase in the amount of labour.

v) More accurate cut-off

Automation of the irrigation system allows cut-off of water at the appropriate point in the bay. This is usually more accurate than manual checking because mistakes can occur if the operator is too late or too early in making a change of water flow.

vi) Reduced runoff of water and nutrients

Automation can help keep fertiliser on farm by effectively reducing runoff from the farm. Retaining fertiliser on farm has both economic and environmental benefits.

vii) Reduced costs for vehicles used for irrigation

As the irrigator is not required to constantly check progress of irrigation, motor bikes, four wheelers and other vehicles are used less. This reduces the running costs of these vehicles and they require less frequent replacement.

B) Demerits

Automated irrigation system requires high capital expenditure to invest in automation.

i) Cost

There are costs in purchasing, installing and maintaining automatic equipment.

ii) Reliability

Can the irrigator trust an automatic system to work correctly every time? Sometimes failure will occur. Often these failures are because of human error in setting and maintaining the systems. A reuse system is good insurance to collect any excess runoff when failures occur.

ii) Increased channel maintenance

There is a need to increase maintenance of channels and equipment to ensure the system works correctly. Channels should be fenced to protect the automatic units from stock damage.

25.4 Semiautomatic and Fully Automatic Systems of Automation

i) Semiautomatic

Semiautomatic systems and controls require manual attention at each irrigation and are usually simpler and less costlier than the fully automatic systems. Most semi-automated systems use mechanical or electronic timers to activate control structures at predetermined times. The irrigator usually determines when to begin irrigation and its duration and manually resets or returns the devices to their original positions or moves them from one location to another before the next irrigation. The parts of given system may be automatic while other parts are semiautomatic or manually operated. Such systems require communication between the controller and system components located in the field. Communication may be by direct interconnecting electrical wires, by hydraulic or pneumatic conduits or by radio telemetry.

ii) Fully Automatic

Fully automatic systems normally operate without operator attention except for periodic inspections and routine maintenance. The irrigator may determine when and how long to irrigate and turn water into the system or start programmed controllers to initiate the automated functions. Fully automatic systems may use soil moisture sensors, such as tensiometers or electrical resistance blocks to activate electrical controls when soil water is depleted to predetermined levels. Meteorological data using climate based sensors can also be used to predict when to irrigate and the output from a microprocessor controller can automatically begin irrigation. Once irrigation has been started water is diverted into the farm distribution system and irrigation is completed without operator intervention. Irrigation duration may be controlled by programmed timers, soil moisture sensors or surface water sensors. Fully automatic systems require a water supply available on demand such as from wells or farm reservoirs. Most farm systems however do not have the flexibility required for complete automation (Hart et al., 1980).

25.5 Automatic Controllers

Micro irrigation system use automatic controller, which can be simply mechanical clocks that open/close a single valve on a pre-set time schedule to microcomputers. These can be programmed to interrogate with soil moisture and/or climate sensors, decide when to start and stop irrigation, start/stop pumps and open/close valves to accomplish the irrigation and to apply exact amount of water and fertilizer to each block within the field.

A timer type controller uses a clock (either solid state or motor driven electric) and programmed for starting and to sequence the irrigation. The controller's supplies electrical or hydraulic power to activate remote solenoid valves located on individual laterals or sub-mains (manifolds). Electrical cables wires, hydraulic or pneumatic conduit or radio telemetry are used for communication between controller and valves.

Microprocessor/microcomputer-based controllers can be programmed to control pumps, fertilizer injection equipment, filters, etc., as well as activate/deactivate solenoid valves using data from tensiometers, pyranometers, evaporation pans, thermocouple, humidity meters, anemometers, flow meters, pressure transducers, and other sensors. These controllers pull soil and/or climate sensors data according to a schedule specified by the irrigator. The controller is programmed to use these data to determine the need for irrigation in each field and block. It then operates the pumps, filters, injection equipment, and valves needed to accomplish the irrigation. Data from flow meters and pressure sensors are used to determine the need for such things as flushing and to detect system malfunctions.

Some controllers are also able to diagnose system malfunctions and take corrective action. Some even turn the system off during rain storms and then restarts the system when the storm ends (James, 1988).

Lesson 26. Components of Automation System

26.1 Introduction

Automation in micro-irrigation system is typically achieved by a centralized decision making control device supported with a set of hardware (control valves, relays etc.) to carry out irrigation commands and sensors to input environmental measurements for making irrigation decision.

The basic structure and components of a relatively comprehensive irrigation control system are shown in Figure 26.1.

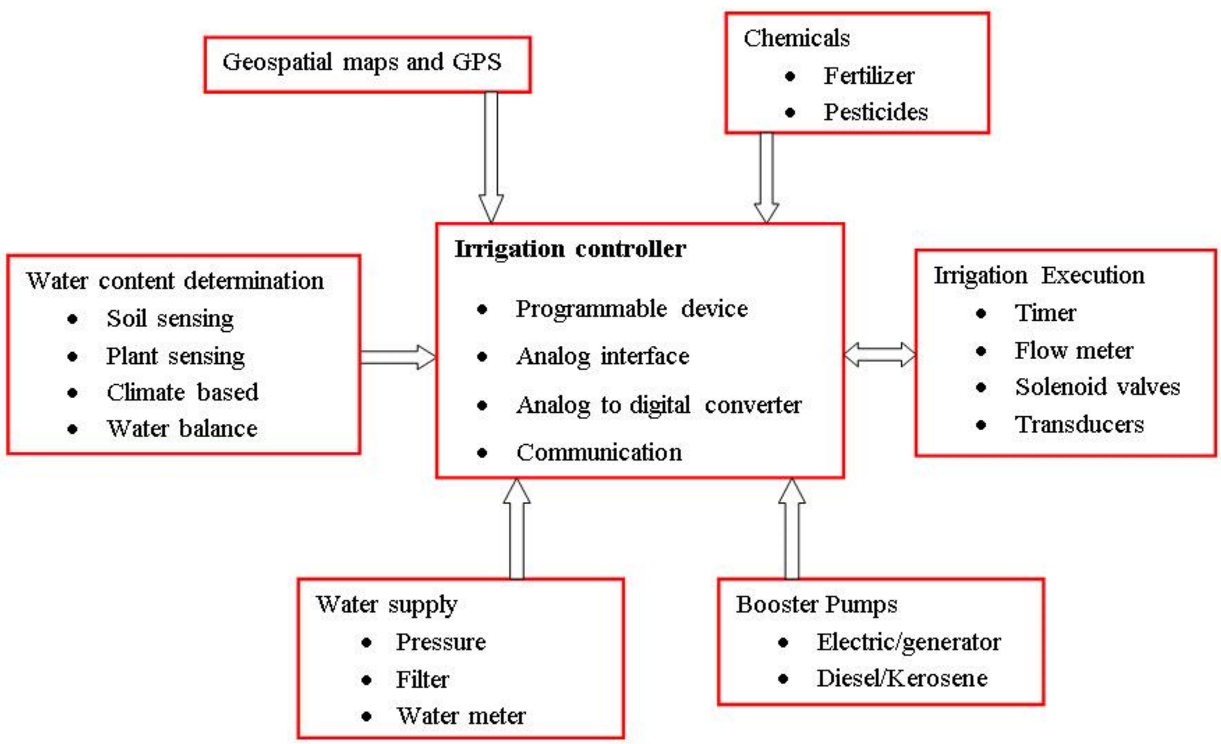

Fig. 26.1. Basic structure of irrigation control system with different functional model (Source: Wang et al. 2013)

For automation of irrigation, the irrigation controller is used. The irrigation controller is an electronic device to store and execute irrigation scheduling program based on soil/plant water content and using criteria of when and how much water to supply. The following are the decision making steps to execute irrigation.

i) Geospatial data are provided to the controller to generate site specific water assessment or demand for water to irrigate field crops.

ii) Assessment of water demand using a) soil moisture/plant water status sensors in-situ or remotely located, b) meteorological based soil-water balance estimation and c) calendar based soil-water balance.

iii) Direct continuous communication between these sensors and irrigation controllers is essential, which can be achieved by directly connecting the sensors output to the analog interface panel for wired system or through wireless transmitters/receivers.

iv) If irrigation is to be given after knowing soil-water status, the irrigation is given using a pump attached with source of water and network of pressurized irrigation pipe lines. In case of additional pressure requirement the booster pump can be operated electrically or fossil fuel.

v) The set of control and monitoring devices are deployed to execute irrigation command to complete the irrigation. Solenoid valves are used to turn on/off water flow with the amount of water monitored by water meter. Sometimes timer is used to apply water for set time.

vi) Fertigation or chemigation is important process in micro-irrigation. This may be with or without automation.

vii) Sometimes filters cleaning and backwashing are automated/manually operated. The last step involves system monitoring to ensure system maintenance. This is accomplished by supervisory control and remote monitoring to ensure optimal irrigation.

26.2 Automation Equipments and Their Application

The devices used for automation of micro-irrigation (MI) system are: controller, control valves, metering pumps, flow transducers, sequencers sensors, master relay etc. The brief description of these hardware equipments are presented in this section. Fig. 26.2 shows different components of computer controlled automated irrigation system developed at IIT Kharagpur, India.

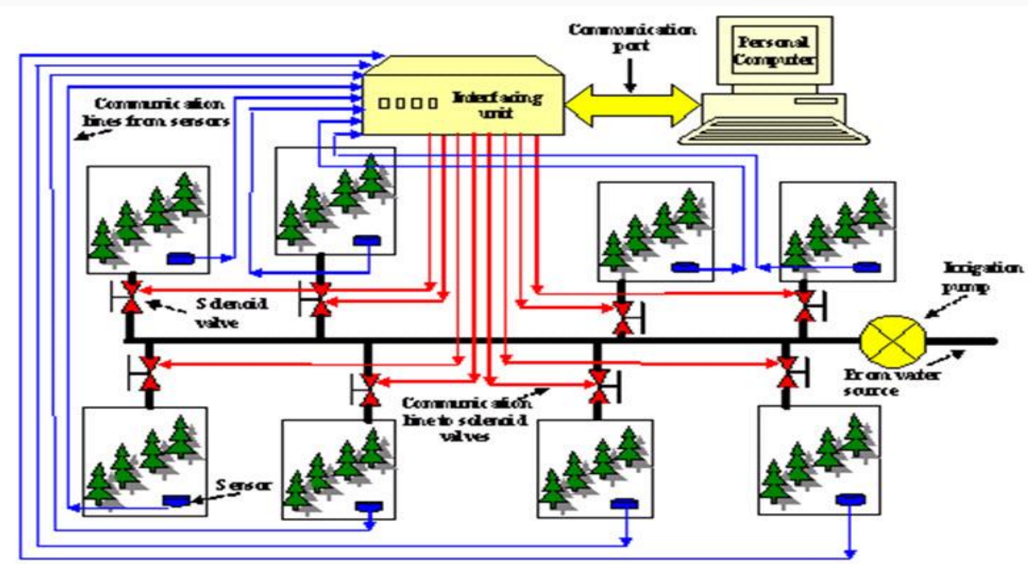

Fig. 26.2. Components of automated irrigation system

(Source: Joshi et al., (2002))

26.2.1 Controller

The PLC (Programmable Logic Controllers) is used extensively for various industrial applications including irrigation. These are available for inputs/outputs varying from 6 to 512. The analog input/output modules enable interfacing of base unit of PLC with many sensors, transducers and output devices. These systems can be programmed to issue command for operation of solenoid valves, pumps, booster, fertilizer injectors, backwashing of filters etc. according to irrigation cycle (Dhingra & Kumar, 2001). Micro-processor, personal computers, laptops, palmtops are also used as controllers.

The controller is heart of the automation, which co-ordinates operation of the entire system. The controller is programmed to run various zones of an area for their required duration. In some cases moisture sensors is used with it which gives feed back to the controller about field moisture level.

The controller has in-built 24-hr clock. There is an option to have different irrigation schedule for different days of the week. These are mostly multistation controller i.e. they can control 4/6/8/12 and even more number of solenoid valves are connected through them. Other facilities available with the controllers are multi programme facility to suit different weather conditions, weekly/fortnightly calendar or skip days interval option and option to connect moisture sensors, temperature sensor, or other sensors having analog output (Joshi 2001). The different types of controller are: cyclic controller, stand alone battery operated controller, light commercial controller, coded signal controller and satellite based computerized control system. The cyclic controller can be used for one station where as satellite based controller can be used for as maximum as 999 stations.

26.2.2 Control Valves

Control valves are activated electrically, hydraulically or pneumatically and used to switch on or off water supply, filter flushing, mains and laterals, sequence water from one field or segment to another.

a) Solenoid valve: Controllers are connected electrically operated valves (solenoid valve). These valves are fitted in place of manual gate valve in an automatic system. One valve controls one section. As soon as the signal is received from the controller the solenoid gets activated and valve is turned on which allows passing of water through it. After the signal is stopped the valve shuts off. These are normally two way open and close valves and operate on 24 volt DC or 220 volt AC motor.

b) Hydraulic valves: These valves are operated on hydraulic pressure. The operation of a hydraulic valve depends on the type of valve and whether it is NC (Normally closed) or NO (Normally open) in principle.

A command can be transmitted to these hydraulic valves by means of control tubes and solenoid coil. These solenoid coils are mounted on the main line and connected to the valve by control tubing.

c) Solenoid coil: Solenoid coil is used to translate electric pulses into hydraulic pulses which enable opening and closing of specific hydraulic valve. These solenoid coils require 24V AC input for its operation. Solenoid coils mounted on the valves are connected to controller electrically. The size of the cable is the function of the distance between solenoid valve and the controller. The solenoid coil has a metal plunger inside the electromagnetic coil. The coil gets actuated after receiving required voltage. It pulls up the plunger and water passes from the lower orifice port to control tubing towards the hydraulic valve. When operation time is over, the controller stops sending signals to the solenoid coil to deactuate. Thus the plunger again seals the orifice port to close.

d) Automatic metering valves: These valves are used in volume based irrigation system. The volume of water required for the irrigation can be adjusted in these automatic metering valves. It shuts itself off after a preset quantity of water has flown through. These valves are available with different capacity (10 L h^{-1} to 10 m^3 h^{-1}).

The sequential arrangement of these valves in the system is also possible. All automatic metering valves are interconnected in series with the help of control tube. During the sequential operation next valve in the series opens after the first valve closes. Shut down of the irrigation pump can be made automatic after closure of the last valve in series by connecting to a micro switch.

26.2.3 Metering pumps

These pumps are suitable for feeding of known quantity of fertilizers/chemicals. The capacity of pumps varies from 1.5 to 3.5 L h^{-1}. These pumps are micro-processor based solenoid driven diaphragm type. The control can be manual or remote.

Peristaltic pumps: These are ideal system for accurate pumping of fluids at low flow rates. These can be used for accurate dosing of chemicals as and when desired. The flow rate is directly proportional to rotor speed and thus dependent on motor drive voltage.

26.2.4 Flow transducers

These can be used for measuring flow rate and totalizing the flow. The fluid passes through internal fluid flow straightners, to stabilize turbulence, before impacting on the vaned turbine rotor, which rotates at speed proportional to the flow rate. Each rotor blade has a stainless steel tip which is detected by a sensor mounted externally to the glass tube. The pulse output which is proportional of flow rate, is measured by the counter. Flow measuring feedback devices allow the computer to determine the rate and volume of water applied for estimating whether the irrigation scheduling algorithm and recommendations are followed.

26.2.5 Sequencer systems

Electromechanical and electronic time driven sequencer systems are available for use in automatic micro-irrigation system. The electromechanical system consists of cam sequencer assembly frame, gear box, gears and synchronous motor. The cam shaft contains 2,4,6 or more adjustable cams, to operate switches and SPDT contacts. The gears can be used to provide a variety of time periods for a single revolution of cam shaft. This type of system is cheaper compared to electronic sequencer.

26.2.6 Master relay

This relay controls function of pump whenever any of the solenoid valve is switched on, one pulse is sent to activate master relay which in turn starts the pump through Pump Starter.

26.2.7 Sensors

Sensor is defined as an element that senses a variation in input energy to produce a variation in another or same form of energy. Different types of sensors used to monitor soil and plant parameters are as follows:

i) Electromagnetic

ii) Optical

iii) Mechanical

iv) Electrochemical

v) Airflow

vi) Infrared sensors for plants temperature and

vii) Climatological parameters monitoring

Brief description of sensors used for soil and plant water monitoring and irrigation execution is discussed in this section.

26.2.7.1 Soil-plant water monitoring sensors: Different types of devices used to monitor soil-plant water status and to automate irrigation system are listed below:

a) Tensiometer

b) Resistance block

c) Gypsum block

d) Granular matrix sensor

e) TDR based soil moisture sensor

f) Infrared sensors for leaf air temperature

g) High frequency capacitance type soil moisture sensor

a) Tensiometer: The tensiometer is a device, which provides direct measure of tenacity with which water is held by the soil. Any change in soil water causes corresponding change in soil moisture tension. In automated irrigation controller, the tensiometer is modified to read change in soil moisture tension in terms of change in voltage or resistance, it consists of electro tensiometer, an electronic switching unit and a solenoid valve. Fig. 26.3 shows a typical automated irrigation controller using a tensiometer to trigger irrigation based on soil-water potential (Joshi et al. 1999).

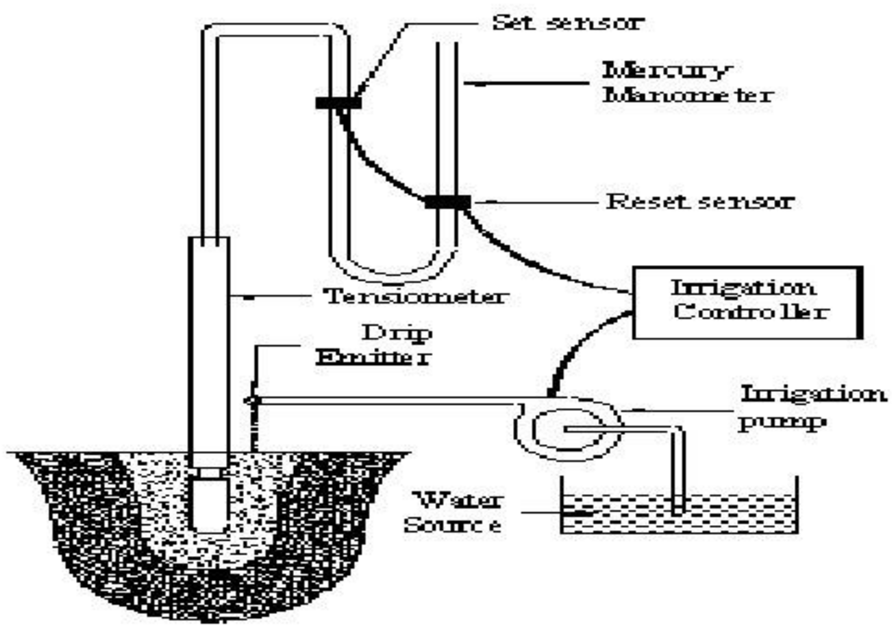

Fig. 26.3. Automated irrigation controller
(Source: Joshi et al. (1999))

b) Resistance Blocks: In this type of sensor, the electrical resistance between the electrodes varies with moisture content of resistance block. The moisture of resistance block is in equilibrium with the soil moisture. The presence of salt or salinity in irrigation water or soil affects the observations. The gypsum block and granular matrix type sensors are commonly used for soil moisture sensing and irrigation automation.

c) Gypsum Block: It consists of two electrodes inserted in a solid block of gypsum. Gypsum neutralizes the affect of salt content. Gypsum blocks are easy to use and economical. The limitation of this type of sensor is gypsum gets dissolved with water. Therefore, the calibration changes with the passage of time.

d) Granular Matrix: The granular matrix sensor uses granular matrix of standard size with uniform pore size. Two electrodes are inserted in granular matrix fill material, above which gypsum wafer supported with metallic or plastic screen. The gypsum wafer slowly neutralizes the salinity of the soil solution hence electrical resistance between the electrodes is unaffected. Particle size of the granular fill material and its compression determines the pore size distribution in sensor and their response characteristics. Such sensors require little maintenance during the growing season and suited for sensing soil water potential and automatic control of irrigation systems. They have advantages of low unit cost and simple installation procedures similar to those used for tensiometer. A granular matrix type soil moisture sensor developed at IIT Kharagpur is shown through Figure 26.4. These electrodes are connected to controllers. As the soil moisture replaces the air present in the voids of granular material thus results in reduction of electrical resistance between the electrodes and vice versa. The developed sensor is calibrated in terms of impedance versus soil moisture content. The sensor gives feedback to the central processing unit of the personal computer to automate micro-irrigation system (Joshi et al., 2007).

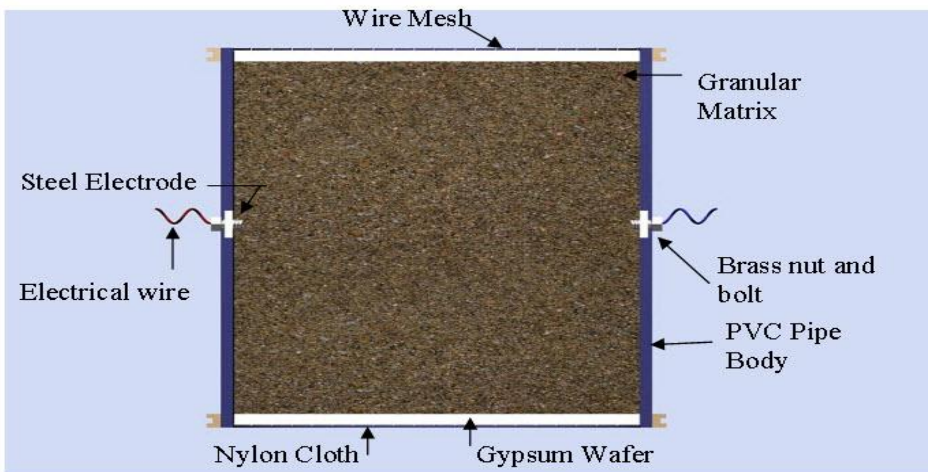

Fig. 26.4. Granular matrix soil moisture sensor developed at IIT Kharagpur (Source: Joshi et al., 2007)

e) TDR based soil moisture sensor: Time Domain Reflectometry (TDR) is a reliable soil moisture measurement compared to other methods stated above because of their frequent calibration. This device has been recommended for automation of irrigation. This device determines dielectric constant of the soil by measuring the transit time of an electro-magnetic pulse created along the pair of parallel metallic rods of known length inserted in the soil. The empirical relationship between dielectric constant (K) and volumetric moisture content given by Topp et al. (1980) is

$$Q_v = 0.053 + 0.0292K - 5.5 \text{ X } 10^{-4} K^2 + 4.3 \text{ X } 10^{-6} K^3 \qquad \text{……… (26.1)}$$

Where

K = Dielectric constant ($Ct\, l^{-2}$)

C = Velocity of light in free space (3 X 10^8)

t = Travel time of voltage pulse measured by TDR

l = Length of probe, m

Such sensors have been evaluated in light soils both in laboratory and field conditions and it resulted in closer matching with the observed volumetric content.

f) Infrared sensors for leaf air temperature: Plant canopy temperature measured from a distance with an infrared thermometer can be used to detect plant water stress and signal irrigation needs before the crop exhibits any visual symptoms of drought. This is because water-stressed plants have a tough time in obtaining enough water from the soil to meet atmospheric demand, and this reduces evaporative cooling of their leaves. The Crop Water

Stress Index (CWSI) method uses plant and air temperature and vapor pressure deficit of the air to determine whether a crop has adequate water (CWSI=0) or under severe water stress (CWSI= 1).

Infrared thermometers can be hand held or mounted on booms for continuous operation. Thermal scanners on board satellites or aeroplanes, map crop temperatures across an entire field or farm. Thermal data are used for irrigation scheduling (Gontia and Tiwari, 2008).

g) High frequency capacitance type soil moisture sensor: The capacitance of electrodes inserted in to soil operating at oscillation frequency (80-150 MHz) is dependent on the dielectric properties of the soil. The probes consists of two stainless steel rods of 100 mm long 6 mm diameter placed at 20 mm apart inserted in to the soil. The relative permittivity of such sensors is related to soil moisture content. Closer agreement between the observed soil water content and estimated volumetric content by gravimetric method for all types of soil has been reported for this type of sensor. However, difference in bulk density affects the performance of sensors.

26.2.7.2 Sensors for Climatological Parameters: Sensors for measuring various climatological parameters such as solar radiation, maximum and minimum temperature, wind speed, relative humidity, pan evaporation etc. are interfaced with the microprocessor computer to estimate evapotranspiration of crop and irrigation is commissioned based on evapotranspiration demand.

Lesson 27. Types of Controls and Automation in Micro Irrigation

Automatic micro irrigation/drip irrigation ensures optimum soil moisture at root zone of the crop and throughout crop growth season for healthiest growth. This involves complete understanding of irrigation of irrigation scheduling, which is a function of soil plant and weather parameters. The control systems are designed to accomplish automation using these parameters. In this lesson basic control theory relevant to micro irrigation and types of automating micro irrigation are dealt

27.1 Automation Controls

The control theory or system analysis of mathematical techniques used to model how one component controls the activity of another component is an inter linked system. The control systems are divided in to two categories:

i) Open loop control (OLC)

ii) Closed loop control (CLC)

27.1.1 Open loop control (OLC)

In an open loop control system, the operation is pre-set and independent of any sensor input with an operator making the decision. In irrigation scheduling program, two decisions are used: i) When to irrigate and ii) how much to irrigate. The operation of an open loop control for operating irrigation system is shown through Fig. 27.1.

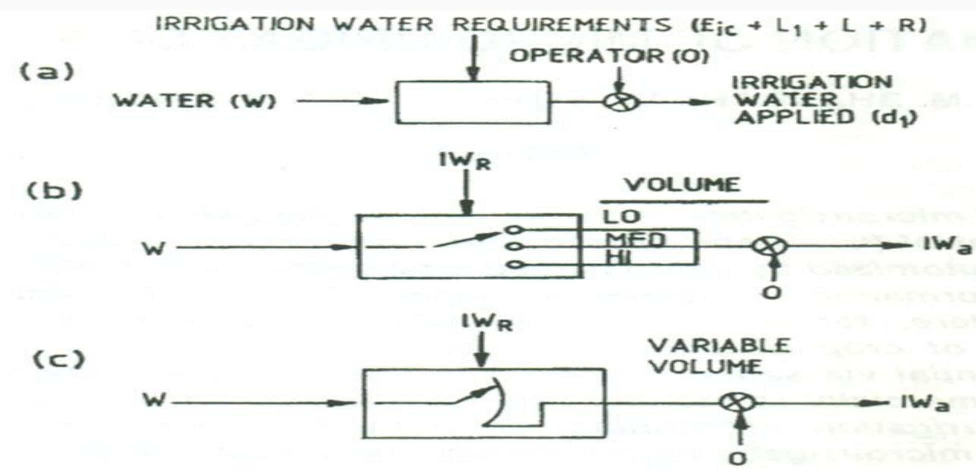

Fig.27.1. (a) Open loop on-off irrigation control system (time is set by operator that is only one variable), (b) open loop step-wise irrigation control system (3 pre-set irrigation volumes are variable available) and (c) open loop continuous irrigation system (an infinite number of irrigation variables are available) (Source : James & Phene, 2007).

27.1.2 Closed loop control (CLC)

In this system, the input is directly dependent on the output through a feedback mechanism from the output to the input. By having closed to compare the output with some reference input signal (pre-set value) so that the precise control can be achieved. The closed loop control operation installed for controlling irrigation system is given in Fig.27.2. The crop evaporation (ETc) is measured directly by using lysimeter using a sensor and this information is used to adjust the irrigation volume or time so that the depth of irrigation water (d_i) is proportional to Et_c such that

$$d_i = Et_c/E_a \qquad (27.1)$$

where, E_a = application efficiency of irrigation system

Within OLC and CLC, three control modes used are: i) On- off control; ii) Step- wise control and iii) continuous control. Brief description of these control modes are presented below:

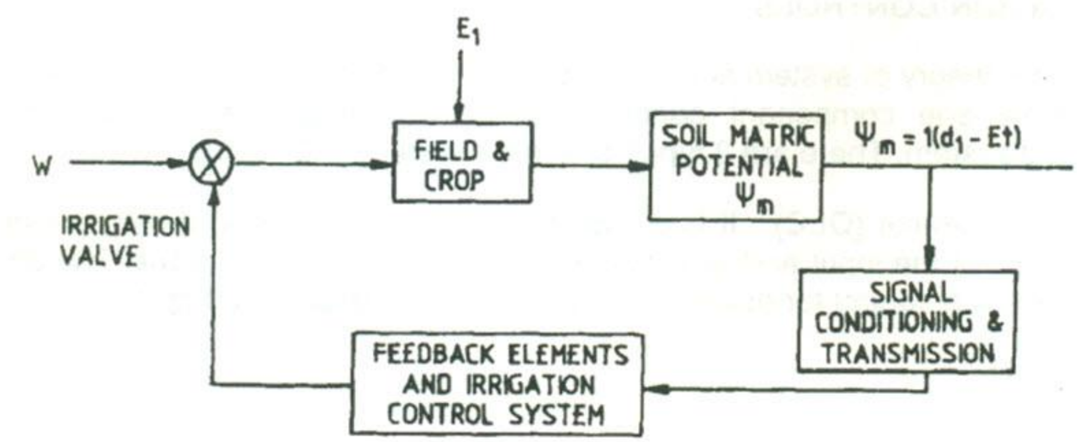

Fig. 27.2. Close loop feedback irrigation system using soil matric potential as the control variable, time variable is used to adjust the amount of water being applied (Source: James and Phene, 2007)

i) On-off control: The on-off control makes the irrigation system on or off, and the control condition is independent of the system. Fig. 27.1(a) shows a block diagram of this control system where the valve is on or off. Most of the irrigation systems are controlled by this mode. In some cases, the operator is replaced by the timer switch or more sophisticated electronic devices. However, the control condition remains independent of the system.

ii) Step-wise control: In step-wise control 27.1(b), di may be varied by selecting different positions on a valve, a flow meter, or a timer to give different irrigation volumes. For example, early in season where Et_c is low, position L_o could be used. As Et_c increases, position Med and HI could be selected to increase di and progressively apply more water with each irrigation.

The application of step-wise control in irrigation is sometimes implemented by a time clock with fixed intervals of time control, but operates exactly like the on-off control. The irrigation time (Ti) can be calculated from the relation

$$T_i = 100\ (Et_c \times I_f)\ /\ (E_i \times l_a) \qquad (27.2)$$

Where, T_i = irrigation time, h

l_f = irrigation frequency, days / irrigation

l_a = application rate of irrigation system, mm h^{-1}

Et_c can be adjusted for both leaching and percolation losses by multiplying Et_c with appropriate correction factor.

iii) Continuous control: In continuous control (Fig. 27.1. c) can be selected from minimum to maximum values by adjusting time or volume of water in a continuous manner. Any value of time or volume can be set in the flow meter.

27.2 Volume-Based Automated Irrigation System

In volume-based system, the preset amount of water can be applied in the field segments by using automatic volume controlled metering valves. Automation using volume-based systems are of two types. In first type of system, automatic metering valve with pulse output provides one pulse after completing one dial of the automatic metering valve. The dial capacity may vary. The volume-based controller accepts the pulse input from the valve and counts the volume per pulse. The volume of water required for each segment can be programmed in the controller. Thus by counting the number of pulse received by the controller, it can count the volume of water passed through. After providing required volume of water through first valve, the first valve, it closes down controller, then switch on the next valve in the sequence. In second type of system, no controller is required. Automatic metering valves are positioned near each field segment. All automatic metering valves are interconnected in series with the help of control tube. For automatic closing and opening of the metering valves with the help of water pressure signal, components like T- connector, shuttle valve and a 3 way relay (called shastomit) are also installed along the circuit. During sequential operation only one automatic metering valve remains open. The next valve in the series opens after the first valve closes.

27.3 Time Based Automated Irrigation System

In time based system, time is the basis of irrigation. Time of operation is calculated according to volume of water required and the average flow rate of water. The first thing to perform before programming for time-based system is to determine the duration of irrigation required for each section. The duration of individual valves has to be fed in the controller along with system start time, also the controller clock is to be set with the current day and time. As the clock of the controller knocks the start time of programme, it starts sending signals to the first automatic valve in the programme sequence, the pump also starts up at the same time. As soon as duration of first valve is over the controller either stops or switches on to next valve. When the operation of last valve is over, controller stops sending signals to valves and pump. The same process is repeated at next run time.

27.4 Real Time Feedback System

Real time feedback is the application of irrigation based on actual dynamics demand of the plant itself, plant root zone effectively reflecting all environmental factors acting upon the plant. Operating within controlled parameters, the plant itself determines the degree of irrigation required. Various sensors, viz. tensiometers, relative humidity sensors, rain sensors, temperature sensors etc. control the irrigation scheduling. These sensors provide feedback to the controller to control its operation.

27.5 Sequential and Non Sequential Automated Irrigation System

27.5.1 Sequential System

On the basis of type of control, the automated irrigation systems can be classified in to two categories: sequential and non- sequential type. In sequential systems the field in divided in to different sub-units, which is irrigated one after the other in particular sequence. Whereas in the non-sequential systems the sub-units are irrigated randomly based on the plant water needs and operated electrically with or without programming with possibility of utilizing feedback information from the field for remote control.

A sequential system can be operated

i) Hydraulically operated

ii) Electrically operated

iii) Combination of both hydraulically or electrically operated.

i) Sequential hydraulically operated automated irrigation system

The sequential system is particularly suited for low discharge rates irrigation through small diameter tubing. At each connection to the main line (except at the end last connection) a water metering valve unit and a hydraulic valve are installed. At the beginning of the irrigation cycle the metering valves are set for the required volume of water to be supplied to the field. The amount of water is set based on the type of the crop, soil and climatic conditions. Such type of automation is suitable for greenhouse nurseries irrigation.

ii) Sequential electrically operated system (Time based)

Sequential electrically operated systems operate the remotely placed solenoid valves in sequence using electricity. In this system, the water delivered to different plots is regulated by a timer clock, which is programmed to start and stop at desired time by the user. These types of controllers are usually designed with calendar programs so that the watering cycle can be automatically started on the desired day of the week. The controllers have seven or fourteen days calendar program. This type of system is used for irrigation of irrigation of domestic gardens.

27.5.2 Non-Sequential Systems: Hydraulic/Electric valves

Electrically controlled non-sequential systems are fully automatic to a greater extent as compared to that of sequential systems. Water in each unit can be supplied in different quantity and valve opens at a different time in response to a predetermined program or to soil water content. The control panel consists of programmed electrical circuits to operate the pump or main valve, to add fertilizer according to a pre-set schedule and or to apply irrigation as per crop need and soil moisture. Such systems are also remote-controlled, and are designed for feedback of the data received from the field so that automatic regulation can be done and adjustments for changes in the pressure and discharge rate of the supply line can be made. This type of system is used for high pressure discharge. Solenoid valves serve only as control to activate hydraulic valves and the overall operation is hydraulic electric. Rest of its operation is similar to sequential electrically operated systems.

Non-sequential systems are further classified into three categories:

(i) Feedback control

(ii) Inferential control

(iii) Combination of above two methods with time based control

27.5.2.1 Feedback control system (Soil moisture based)

The main components of the feedback control system are sensors for soil moisture, weather monitoring parameters, electronic control unit (comparators /microprocessor/computer) and solenoid valves. A farm is divided in to different sub-units. Each sub-unit has one soil moisture sensor. The sensors are connected through interfacing circuit to the central control unit, which could be a microprocessor or a computer with a program to schedule irrigation a or comparator circuit. Based on the soil moisture status (measured by soil moisture sensor) of a sub-unit the decision to start and stop irrigation is taken by the controller. The electronic controller actuates and de-actuates solenoid valves to start and stop the irrigation respectively through proper interfacing circuit and relay switches (Joshi et al., 2002).

Soil moisture based Automated Irrigation Controller developed at IIT Kharagpur (Joshi et al., 1999) uses a tensiometer connected with a U-tube manometer to activate/deactivate irrigation pump. In this system irrigation is given to unit area considering homogeneous soil condition.

Luthra et al. (1996) developed an automatic valve for irrigation operation. The soil water tension is sensed through modified tensiometer which generates electrical signal. The output of tensiometer is processed for operation of D.C. operated bidirectional motor at present values of soil water tension which is coupled to the gate valve. This valve can be fitted with mains, sub-mains or individual laterals of drip irrigation setup. Through automatic operation of valve, required amount of irrigation is applied which maximizes the water use efficiency of the system. After meeting the irrigation requirement of crop a signal is generated through a preprogrammed timer (designed suitably for this purpose) for closing the valve.

Testezlaf et al. (1997) developed automated irrigation computer control system for management of greenhouse container plants. The system consisted of soil moisture sensors, a hardware input/output interface (A/D card), a computer with a software interface, and actuators. The evaluation results show that the control system is reliable in applying water responding to the plant demands.

27.5.2.2 Inferential control system

The main parts of inferential control system are sensors for measuring various climatological parameters such as solar radiation, maximum and minimum temperature, wind speed, relative humidity, pan evaporation etc.

This system makes use of various evapotranspiration models to estimate evapotranspiration of crop using different climatological parameters. The estimated evapotranspiration is used to schedule irrigation. The solenoid valves are operated using interfacing circuit and relay switches to put on or to put off the irrigation system.

Koe et al. (2000) developed and tested an automated cycled over tree sprinkler irrigation system in a 0.4 ha (1 acre) dwarf apple orchard to protect apple buds from cold temperatures. The control system hardware components used in the experiment included sensor for measuring air temperature, wind speed, wind direction, relative humidity data, a microcomputer, data acquisition system, control boards and the irrigation system.

27.5.2.3 Combination of Both

Noble et al. (2000) developed and tested two automated drip irrigation systems: one based on soil electrical conductivity and the other based on leaf-air temperature difference of Okra (Abelmosolus esculentus) crop. Sensors were evaluated for monitoring the soil moisture content based on electrical resistance variation with moisture content. The sensor with washed sand as porous medium was found to be the most efficient one among the other materials. A low cost, commercially available button type thermistor was used as the leaf and air temperature sensors. Variation of moisture in soil causes variation in electrical resistance across the electrode of the sensor. The electrical signal obtained by variation in the electrical resistance is processed by the circuit and operates the relay contacts connected to a 12 volt DC operated normally closed solenoid valve. When the soil gets dry and its resistivity increases, the circuit opens the valve and water flows to the plants. As water content in soil reaches the required level set by a variable resistance, the solenoid valve closes. The difference of voltage between the two thermistors (one attached to plant leaf and other exposed to atmosphere) was used for starting irrigation through the solenoid valve for a fixed duration using IC 555 and 12 volt relay. The amount of water applied per day, leaf-air temperature and soil moisture content can be monitored. The system maintained the designed soil moisture content and air-leaf temperature differential of the crop.

Module 7. Greenhouse/Polyhouse Technology

Lesson 28. Overview of Greenhouse and Basic Concept

28.1 Advantages, Importance, World Scenario and Status in India

A greenhouse is a framed or an inflated structure covered with a transparent or translucent material in which crops could be grown under the conditions of at least partially controlled environment and which is large enough to permit persons to work within it to carry out cultural operations. After the advent of green revolution, more emphasis is laid on the quality of the product along with the quantity of production to meet the ever- growing food requirements. Both these demands can be met when the environment for the plant growth is suitably controlled. The need to protect the crops against unfavorable environmental conditions led to the development of protected agriculture. Greenhouse is the most practical method of achieving the objectives of protected agriculture, where the natural environment is modified by using sound engineering principles to achieve optimum plant growth and yields.

The following are the advantages of using the greenhouse for growing crops under controlled environment:

1. Throughout the year four to five crops can be grown in a greenhouse due to availability of required plant environmental conditions.

2. The productivity of the crop is increased considerably.

3. Superior quality produce can be obtained as they are grown under suitably controlled environment.

4. Gadgets for efficient use of various inputs like water, fertilizers, seeds and plant protection chemicals can be well maintained in a green house.

5. Effective control of pests and diseases is possible as the growing area is enclosed.

6. Percentage of germination of seeds is high in greenhouses.

7. The acclimatization of plantlets of tissue culture technique can be carried out in a greenhouse.

8. Agricultural and horticultural crop production schedules can be planned to take advantage of the market needs.

9. Different types of growing medium like peat mass, vermiculate, rice hulls and compost that are used in intensive agriculture can be effectively utilized in the greenhouse.

10. Export quality produce of international standards can be produced in a greenhouse.

11. When the crops are not grown, drying and related operations of the harvested produce can be taken up utilizing the entrapped heat.

12. Greenhouses are suitable for automation of irrigation, application of other inputs and environmental controls by using computers and artificial intelligence techniques.

13. Self-employment for educated youth on farm can be increased.

Greenhouses – World Scenario

There are more than 50 countries now in the world where cultivation of crops in the greenhouse is undertaken on a commercial scale. United States of America has a total area of about 4000 ha under greenhouses mostly used for floriculture with a turnover of more than 2.8 billion US $ per annum and the area under greenhouses is expected to go up considerably, if the cost of transportation of vegetables from neighboring countries continues to rise. The area under greenhouses in Spain has been estimated to be around 25,000 ha and Italy 18,500 ha used mostly for growing vegetable crops like watermelon, capsicum, strawberries, beans, cucumbers and tomatoes. In Spain simple tunnel type greenhouses are generally used without any elaborate environmental control equipments mostly using UV stabilized polyethylene film as cladding material.

In Canada the greenhouse industry caters both to the flower and off-season vegetable markets. The main vegetable crops grown in Canadian greenhouses are tomato, cucumbers and capsicum. Hydroponically grown greenhouse vegetables in Canada find greater preference with the consumers and could be priced as much as twice the regular greenhouse produce. The Netherlands is the traditional exporter of greenhouse grown flowers and vegetables all over the world. With about 89,600 ha under cover, the Dutch greenhouse industry is probably the most advanced in the world. Dutch greenhouse industry, however, relies heavily on glass framed greenhouses, in order to cope up with very cloudy conditions prevalent all the year round. A very strong research and development component has kept the Dutch industry in the forefront. The development of greenhouses in Gulf countries is primarily due to the extremity in the prevailing climatic conditions.

Israel is the largest exporter of cut flowers and has wide range of crops under greenhouses (15,000 ha) and Turkey has an area of 10,000 ha under cover for cultivation of cut flowers and vegetables. In Saudi Arabia cucumbers and tomatoes are the most important crops contributing more than 94% of the total production. The most common cooling method employed in these areas is evaporative cooling.

Egypt has about 1000 ha greenhouses consisting mainly of plastic covered tunnel type structures. Arrangements for natural ventilation are made for regulation of temperature and humidity conditions. The main crops grown in these greenhouses are tomatoes, cucumbers, peppers, melons and nursery plant material.

In Asia, China and Japan are the largest users of greenhouses. The development of greenhouse technology in China has been faster than in any other country in the world. With a modest beginning in late seventies, the area under greenhouses in China has increased to 48,000 ha in recent years. Out of this 11,000 ha is under fruits like grapes, cherry, Japanese persimon, fig, loquot, lemon and mango. The majority of greenhouses use local materials for the frame and flexible plastic films for glazing. Most of the greenhouses in China are reported to be unheated and use straw mats to improve the heat retention characteristics.

Japan has more than 40,000 ha under greenhouse cultivation of which nearly 7500 ha is devoted to only fruit orchards. Greenhouses in Japan are used to grow wide range of vegetables and flowers with a considerable share of vegetable demand being met from greenhouse production. Even a country like South Korea has more than 21,000 ha under greenhouses for production of flowers and fruits. Thus, greenhouses permit crop production in areas where winters are severe and extremely cold as in Canada and USSR, and also permit production even in areas where summers are extremely intolerable as in Israel, UAE, and Kuwait. Greenhouses in Philippines make it possible to grow crops inspite of excessive rains and also in moderate climates of several other countries. Thus, in essence greenhouse cultivation is being practiced and possible in all types of climatic conditions.

Status in India

While greenhouses have existed for more than one and a half centuries in various parts of the world, in India use of greenhouse technology started only during 1980's and it was mainly used for research activities. This may be because of our emphasis, so far had been on achieving self-sufficiency in food grain production. However, in recent years in view of the globalization of international market and tremendous boost and fillip that is being given for export of agricultural produce, there has been a spurt in the demand for greenhouse technology. The National Committee on the use of Plastics in Agriculture (NCPA-1982) has recommended location specific trials of greenhouse technology for adoption in various regions of the country. Greenhouses are being built in the Ladakh region for extending the growing season of vegetables from 3 to 8 months. In the North-East, greenhouses are being constructed essentially as rain shelters to permit off-season vegetable production. In the Northern plains, seedlings of vegetables and flowers are being raised in the greenhouses either for capturing the early markets or to improve the quality of the seedlings. Propagation of difficult-to-root tree species has also been found to be very encouraging. Several commercial floriculture ventures are coming up in Maharashtra, Tamil Nadu and Karnataka states to meet the demands of both domestic and export markets. The commercial utilization of greenhouses started from 1988 onwards and now with the introduction of Government's liberalization policies and developmental initiatives, several corporate houses have entered to set up 100% export oriented units. In just four years, since implementation of the new policies in 1991, 103 projects with foreign investment of more than Rs.80 crores have been approved to be set up in the country at an estimated cost of more than Rs.1000 crores around Pune, Bangalore, Hyderabad and Delhi. Thus the area under climatically controlled greenhouses of these projects is estimated to be around 300 ha. Out of which many have already commenced exports and have received very encouraging results in terms of the acceptance of the quality in major markets abroad and the price obtained.

Source: http://en.wikipedia.org/wiki/Greenhouse

http://www.vedamsbooks.in/no105062/cart.php

28.2 Constituents of Environment in Greenhouse- Natural Light, Artificial Source of Light, Solar Radiation, Temperature, Humidity, Carbon Dioxide

The productivity of a crop is influenced not only by its heredity but also by the microclimate around it. The components of crop microclimate are light, temperature, air compositions and the nature of the root medium. In open fields, only manipulation of nature of the root medium by tillage, irrigation and fertilizer application is possible. The closed boundaries in greenhouse permit control of any one or more of the components of the micro climate.

Light

The visible light of the solar radiation is a source of energy for plants. Light energy, carbon dioxide (CO_2) and water all enter in to the process of photosynthesis through which carbohydrates are formed. The production of carbohydrates from carbon dioxide and water in the presence of chlorophyll, using light energy is responsible for plant growth and reproduction. The rate of photosynthesis is governed by available fertilizer elements, water, carbon dioxide, light and temperature. Considerable energy is required to reduce the carbon that is combined with oxygen in CO_2 gas to the state in which it exists in the carbohydrate. The light energy thus utilized is trapped in the carbohydrate. If the light intensity is diminished, photosynthesis slows down and hence the growth. If higher than optimal light intensities are provided, growth again slows down because of the injury to the chloroplasts. The light intensity is measured by the international unit known as Lux. It is direct illumination on the surrounding surface that is one meter from a uniform point source of 1 international candle. Greenhouse crops are subjected to light intensities varying from 129.6 klux on clear summer days to 3.2 klux on cloudy winter days. For most crops, neither condition is ideal. Many crops become light saturated, in other words, photosynthesis does not increase at light intensities higher than 32.2 klux. Rose and carnation plants will grow well under summer light intensities. In general, for most other crops foliage is deeper green if the greenhouse is shaded to the extent of about 40% from mid spring (May) to mid fall (August and September). Thus, it is apparent that light intensity requirements of photosynthesis are vary considerably from crop to crop.

Light is classified according to its wave length in nanometers (nm). Not all light is useful in photosynthesis process. UV light is available in the shorter wavelength range, i.e. less than 400nm. A large quantity of it is harmful to the plants. Glass screens are opaque to the most UV light and light below the range of 325nm. Visible and white light has wavelength of 400 to 700nm. Far red light (700 to 750nm) affects plants, besides causing photosynthesis. Infrared rays of longer wavelengths are not involved in the plant process. It is primarily, the visible spectrum of light that is used in photosynthesis. In the blue and red bands, the photosynthesis activity is higher, when the blue light (shorter wavelength) alone is supplied to plants, the growth is retarded, and the plant becomes hard and dark in colour. When the plants are grown under red light (longer wavelength), growth is soft and internodes are long, resulting in tall plants. Visible light of all wavelengths is readily utilized in photosynthesis. The intensity of sunlight required by different plants is different. If plant requires shade, a shade net can be used which allows around 30 to 50% of sunlight to pass through it. UV stabilized polythene sheets have transmittance value of 88% (single layer), 77% for double layer.

Temperature

Incoming solar radiation has shorter wavelength and hence greater energy. After penetrating through the polythene sheet this radiation strikes the earth. Earth absorbs some energy thus converting radiation of shorter wavelength to longer wavelength radiation. Hence the outgoing radiation has longer wavelength. Longer wavelengths are trapped inside the Greenhouse that causes increase in the temperature. This is beneficial during winter month.

To reduce temperature during summer months, polyethylene can be removed or shade net is used to allow only some percentage of sunlight to pass through. Misters and micro sprinklers are also used to reduce inside temperature. In sub-humid climate temperature maintained inside a Greenhouse is between 30 and 37^0 C.

Temperature is a measure of level of the heat present. All crops have temperature range in which they can grow well. Below this range, the plant life process stop due to ice formation within the tissue and cells are possibly punctured by ice crystals. At the upper extreme, enzymes become inactive, and again process essential for life cease. Enzymes are biological reaction catalyst and are heat sensitive. All biochemical reactions in the plant are controlled by the enzymes. The rate of reactions controlled by the enzyme often double or triple for each rise of temperature by 10^0C, until optimum temperature is reached. Further, increase in temperature begins to suppress the reaction and finally stop it. As a general rule, greenhouse crops are grown at a day temperature, which are 3 to 6^0C higher than the night temperature on cloudy days and 8^0C higher on clear days. The night temperature of greenhouse crops is generally in the range of 7 to 21^0C.

Humidity

As the greenhouse is a closed space, the relative humidity of the greenhouse air will be more when compared to the ambient air, due to the moisture added by the evapo-transpiration process. Some of this moisture is taken away by the air leaving from the greenhouse due to ventilation. Sensible heat inputs also lower the relative humidity of the air to some extent. In order to maintain the desirable relative humidity levels in the green houses, processes like humidification or dehumidification are carried out. For most crops, the acceptable range of relative humidity is between 50 to 80%. However for plant propagation work, relative humidity up to 90% may be desirable. In summer, due to sensible heat addition in the daytime, and in winters for increasing the night time temperatures of the greenhouse air, more sensible heat is added causing a reduction in the relative humidity of the air. For this purpose, evaporative cooling pads and fogging system of humidification are employed. When the relative humidity is on the higher side, ventilators, chemical dehumidifiers and cooling coils are used for de- humidification. Inside a Greenhouse humidity should always be greater than 50%. To increase the humidity various accessories are used like, sprinklers, misters, water coolers with fans. Hygrometer is fixed inside the greenhouse to check the humidity inside.

Air Circulation

A greenhouse is ventilated for either reducing the temperature of the greenhouse air or for replenishing carbon dioxide supply or for moderating the relative humidity of the air. Air temperatures above 35^0C are generally not suited for the crops in green house. It is quite possible to bring the greenhouse air temperature below this upper limit during spring and autumn seasons simply by providing adequate ventilation in the green house. The ventilation in a greenhouse can either be natural or forced. In case of small green houses (less than 6m wide) natural ventilation can be quite effective during spring and autumn seasons. However, fan ventilation is essential to have precise control of the air temperature, humidity and carbon dioxide levels. Air circulation inside a Greenhouse can be controlled either natural ventilation or by forced ventilation. The temperature difference between inside and outside air causes natural air movements. The warmer air inside is replaced by outside air through natural ventilation with the help of vents provided at the top of the roof. In forced ventilation fans are used for forced air circulation.

Greenhouse ventilation

Ventilation is the process of allowing the fresh air to enter into the enclosed area by driving out the air with undesirable properties. In the greenhouse context, ventilation is essential for reducing temperature, replenishing CO_2 and controlling relative humidity. Ventilation requirements for green houses vary greatly, depending on the crop grown and the season of production. The ventilation system can be either a passive system (natural ventilation) or an active system (forced ventilation) using fans. Usually greenhouses that are used seasonally employ natural ventilation only. The plant response to specific environment factor is related to the physiological processes and hence affects the yield and quality. Hence, controlling of environment is of great importance to realize the complete benefit of CEA. Manual maintenance of uniform environmental condition inside the greenhouse is very difficult and cumbersome. A poor maintenance results in less crop production, low quality and low income. For effective control of automatic control systems like micro processor and computer are used to maintain the environment.

Natural ventilation

In the tropics, the sides of greenhouse structures are often left open for natural ventilation. Tropical greenhouse is primarily a rain shelter, a cover of polyethylene over the crop to prevent rainfall from entering the growing area. This mitigates the problem of foliage diseases. Ventilators were located on both roof slopes adjacent to the ridge and also on both side walls of the greenhouse. The ventilators on the roof as well as those on the side wall accounts, each about 10% of the total roof area. During winter cooling phase, the south roof ventilator was opened in stages to meet cooling needs. When greater cooling was required, the north ventilator was opened in addition to the south ventilator. In summer cooling phase, the south ventilator was opened first, followed by the north ventilator. As the incoming air moved across the greenhouse, it was warmed by sunlight and by mixing with the warmer greenhouse air. With the increase in temperature, the incoming air becomes lighter and rises up and flows out through the roof ventilators. This sets up a chimney effect, which in turn draws in more air from the side ventilators creating a continuous cycle. This system did not adequately cool the greenhouse. On hot days, the interior walls and floor were frequently injected with water to help cooling.

Forced Ventilation

In forced or active ventilation, mechanical devices such as fans are used to expel the air. This type of ventilation can achieve uniform cooling. These include summer fan-and-pad and fog cooling systems and the winter convection tube and horizontal airflow systems. For mechanical ventilation, low pressure, medium volume propeller blade fans, both directly connected and belt driven are used for greenhouse ventilation. They are placed at the end of the greenhouse opposite to the air intake, which is normally covered by gravity or motorized louvers. The fans vents, or louvers, should be motorized, with their action controlled by fan operation. Motorized louvers prevent the wind from opening the louvers, especially when heat is being supplied to the green house. Wall vents should be placed continuously across the end of the greenhouse to avoid hot areas in the crop zone. Evaporative cooling in combination with the fans is called as fan-and-pad cooling system. The fans and pads are usually arranged on opposite walls of the greenhouse. The common types of cooling pads are made of excelsior (wood fiber), aluminum fiber, glass fiber, plastic fiber and cross-fluted cellulose material. Evaporative cooling systems are especially efficient in low humidity environments. There is growing interest in building greenhouses combining both passive (natural) and active (forced) systems of ventilation. Passive ventilation is utilized as the first stage of cooling, and the fan-pad evaporative cooling takes over when the passive system is not providing the needed cooling. At this stage, the vents for natural ventilation are closed. When both options for cooling are designed in greenhouse construction, initial costs of installation will be more. But the operational costs are minimized in the long run, since natural ventilation will, most often meet the needed ventilation requirements. Fogging systems is an alternative to evaporative pad cooling. They depend on absolutely clean water, Free of any soluble salts, in order to prevent plugging of the mist nozzles. Such cooling systems are not as common as evaporative cooling pads, but when they become more cost competitive, they will be adopted widely. Fogging systems are the second stage of cooling when passive systems are inadequate.

Carbon Dioxide

Carbon is an essential plant nutrient and is present in the plant in greater quantity than any other nutrient. About 40% of the dry matter of the plant is composed of carbon. Under normal conditions, carbon dioxide (CO_2) exits as a gas in the atmosphere slightly above 0.03% or 345ppm. During the day, when photosynthesis occurs under natural light, the plants in a greenhouse draw down the level of CO_2 to below 200ppm. Under these circumstances, infiltration or ventilation increases carbon dioxide levels, when the outside air is brought in, to maintain the ambient levels of CO_2. If the level of CO_2 is less than ambient levels, CO_2 may retard the plant growth. In cold climates, maintaining ambient levels of CO_2 by providing ventilation may be un- economical, due to the necessity of heating the incoming air in order to maintain proper growing temperatures. In such regions, enrichment of the greenhouse with CO_2 is followed. The exact CO_2 level needed for a given crop will vary, since it must be correlated with other variables in greenhouse production such as light, temperature, nutrient levels, cultivar and degree of maturity. Most crops will respond favorably to CO_2 at 1000 to 1200 ppm.

28.3 Working principle

A greenhouse uses a special kind of covering material that acts as a medium which selectively transmits spectral frequencies. The covering material of the greenhouse traps energy within the greenhouse and the heat in turn provides for the plants and the ground inside the greenhouse. It warms the air near the ground, preventing it from rising and leaving the confines of the structure. The sun shines enters in the greenhouse through the covering material as short waves. These waves strike objects in the greenhouse and are reradiated as long waves, the long waves do not readily return through the covering material. This is known as the greenhouse effect. The greenhouse effect is similar to hot air trapped in a car on a sunny day with the windows closed. The inside air becomes warmer than the outside air. Objects in the greenhouse such as absorb heat during the day and return it to the ambient at night.

Lesson 29. Classification of Greenhouse

Greenhouses are frames of inflated structure covered with a transparent material in which crops are grown under controlled environment conditions. Greenhouse cultivation as well as other modes of controlled environment cultivation has been evolved to create favorable micro-climates, which favours the crop production could be possible all through the year or part of the year as required. Greenhouses and other technologies for controlled environment plant production are associated with the off-season production of ornamentals and foods of high value in cold climate areas where outdoor production is not possible. The primary environmental parameter traditionally controlled is temperature, usually providing heat to overcome extreme cold conditions. However, environmental control can also include cooling to mitigate excessive temperatures, light control either shading or adding supplemental light, carbon dioxide levels, relative humidity, water, plant nutrients and pest control.

29.1 Types of Greenhouse

Greenhouses are a technology based investment. The higher the level of technology used the greater potential for achieving tightly controlled growing conditions. This capacity to tightly control the conditions in which the crop is grown is strongly related to the health and productivity of the crop. The following three categories of greenhouse have been defined to assist people in selecting the most appropriate investment for their needs and budget.

Low technology greenhouses

These greenhouses are less than 3 m in total height. Tunnel houses, are the most common type. They do not have vertical walls. They have poor ventilation. This type of structure is relatively inexpensive and easy to erect. Little or no automation is used. While this sort of structure provides basic advantages over field production, crop potential is still limited by the growing environment and crop management is relatively difficult. Low level greenhouses generally result in a suboptimal growing environment which restricts yields and does little to reduce the incidence of pests and diseases. Pest and disease control, as a result, is normally structured around a chemical spray program.

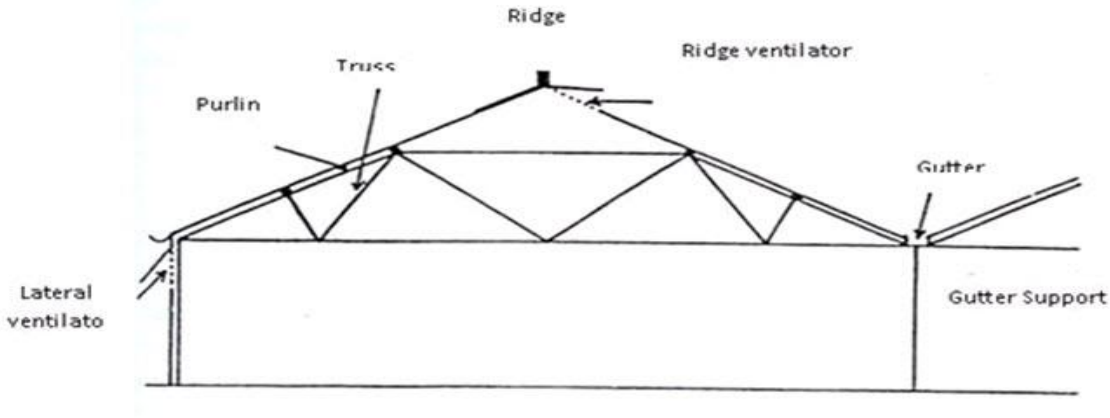

Fig. 29.1 Components of a greenhouse

(Source: http://www.agritech.tnau.ac.in/horticulture/horti_Greenhouse%20cultivation_clip_image002_0000.jpg)

Low technology greenhouses have significant production and environmental limitations, but they offer a cost effective entry to the industry.

Medium technology greenhouses

Medium level greenhouses are typically characterized by vertical walls more than 2m but less than 4 m tall and a total height usually less than 5.5 m. They may have roof or side wall ventilation or both. Medium level greenhouses are usually clad with either single or double skin plastic film or glass and use varying degrees of automation.

Medium level greenhouses offer a compromise between cost and productivity and represent a reasonable economic and environmental basis for the industry. Production in medium level greenhouses can be more efficient than field production. Hydroponic systems increase the efficiency of water use. There is greater opportunity to use non-chemical pest and disease management strategies but overall the full potential of greenhouse horticulture is difficult to attain.

High technology greenhouses

High level greenhouses have a wall height of at least 4 m with the roof peak being up to 8 m above ground level. These structures offer superior crop and environmental performance. High technology structures will have roof ventilation and may also have side wall vents. Cladding may be plastic film (single or double), polycarbonate sheeting or glass. Environmental controls are almost always automated. These structures offer enormous opportunities for economic and environmental sustainability. Use of pesticides can be significantly reduced. High technology structures provide a generally impressive sight and, internationally, are increasingly being involved in agribusiness opportunities. Although these greenhouses are capital intensive, they offer a highly productive, environmentally sustainable opportunity for an advanced fresh produce industry. Investment decisions should, wherever possible, look to install high technology greenhouses.

Greenhouses vary in style, size and materials that are used to build it in order to fulfill any requirements and to suit any type of crop. The materials used to build the main structure of a greenhouse are timber, aluminum or steel. Timber frames are the traditional choice for garden greenhouses and hardwoods require low maintenance. Aluminum alloy frames are more lightly, need only minimum maintenance but are extremely sturdy. Steel frames are very strong but must be treated regularly to prevent them from rust, but they are also cheaper than timber or aluminum frames. For glazing you can use glass or plastic panels. Size may also vary according to your necessities.

Many styles of greenhouses are available on the market, every one of them with specific qualities: some provide optimum ventilation, or best use of space, or conserve heat well or allow better light penetration but all of them are made in order to fulfill your personal preferences.

Greenhouses types can be split into two main categories: conventional greenhouses and specialist greenhouses. Conventional greenhouses include: traditional span, Dutch light, three-quarter span, lean-to and mansard or curvilinear greenhouses. Specialist greenhouses include: Dome-shaped, polygonal, alpine house, conservation, mini and poly-tunnel greenhouses.

In the next lines we will try to describe every of those types and see what are their main qualities to help you choose the most suitable greenhouse for your garden.

Traditional span

This type of greenhouse is practical in terms of growing space and headroom by its vertical sides and even span roof. It provides the best use of space for the least cost for raising seedlings and growing border crops. Its lower part stop the heat lost over the winter.

Dutch light

This type of greenhouse is designed in order to allow in maximum light through the sloping sides. It is suitable to grow border crops, preferably low-growing ones. The panes of glass on the roof overlap slightly to keep out rain but also to increase the rigidity of the structure.

Three-quarter span

This type of greenhouse is positioned with one of its sides against a wall, preferably beside a sunny wall because the light is a little more restricted than in a free-standing greenhouse, but this also mean that it will need some extra shading in the summer. If you will choose a house wall to position your greenhouse you will also benefit from extra warmth and insulation from this.

Lean-to Lean

One can use this type of greenhouse in a garden with insufficient space for a free-standing structure. Like the three-quarter span, this type of greenhouse will benefit from the warmth and insulation of the house wall. Many of those greenhouses are similar in appearance to conservatories and may be used as garden rooms. In this type of greenhouse installation of electricity, gas or water supply easier and cheaper than that of a greenhouse located at some distance from the house.

Mansard or curvilinear

This greenhouse has slanting sides and roof panels designed to allow in maximum light available so a best place for this type of greenhouse is an open site with no shade from the surrounding trees or buildings. This greenhouse is suitable for plants that need maximum light over the winter.

Dome-shaped

This type of greenhouse is offering an elegant design that is mostly useful in exposed positions. It is stable and offers less wind resistance than traditional greenhouses. It allows maximum light transmission because of its multi-angled glass panels. It might offer limited headroom around the edge.

Polygonal

For a focal point in the garden or for gardens where appearance is important those greenhouses are the most used. Any octagonal or polygonal greenhouse is a good choice, but they may be more expensive than traditional greenhouses of similar sizes.

Alpine house

Traditionally those greenhouses have timber-frame with louvre vents all along the sides. This help for most effective ventilation. Usually, these types of greenhouses are not heated and they are not closed unless the winter is too cold, so the insulation is not needed. They are used mostly for plants that just need some protection from dampness and rain and require a bright and well-ventilated place.

Conservation

This type of greenhouse is designed to save as much energy as possible using special features. The roof panels are angled to permit optimum light penetration. Mirrored surfaces are also used to reflect light within the greenhouse itself. With all those special features, this type of greenhouse is usually more expensive than others of the same size.

Mini

For a limited space in your garden, or if you only have a small number of plants to grow, this useful, low-cost greenhouse is available in different sizes and also as free-standing or wheeled versions. Made from aluminum frame and covered with plastic or glass, this greenhouse is best to be placed face SE or SW in order to get the maximum light penetration. Access may be a problem as all the work has to be done from the outside. Venting and shading in the summer are essential.

Poly-tunnel

For a low-cost protection, for the vegetable plot for example, a plastic poly-tunnel greenhouse is the choice. It covers a large area, is covered with heavy-duty transparent plastic sheets and offers protection from cold and wind, is easy to move where needed, so is the perfect choice for your crops, either you choose to plant them directly into the soil, in pots or in growing bags. Ventilation may be a problem and the sheets may need to be replaced every few years as they gradually become opaque.

Source: http://www.greenzonelife.com/greenhouses/greenhouses-types.html

29.2 Basis for Classification of Greenhouse

Greenhouse structures of various types are used for crop production. Although there are advantages in each type for a particular application, in general there is no single type greenhouse, which can be said as the best. Different types of greenhouses are designed to meet the specific needs. The different types of greenhouses are classified based on shape, utility, material and construction are given below:

1. Greenhouse type based on shape:

The types of greenhouses based on shape are:

a) Lean to type greenhouse

b) Even span type greenhouse

c) Uneven span type greenhouse

d) Ridge and furrow type

e) Saw tooth type

f) Quonset greenhouse

g) Interlocking ridges and furrow type Quonset greenhouse

h) Ground to ground greenhouse.

2. Greenhouse type based on utility

Greenhouse classification can be made depending on the functions or utilities. Among the different utilities, artificial cooling and heating are more expensive and elaborate. Hence based on this, they are classified into two types.

a) Greenhouses for active heating

b) Greenhouses for active cooling

3. Greenhouse type based on construction

The type of construction predominantly is influenced by structural material, though the covering material also influences the type. Higher the span, stronger should be the material and more structural members are used to make sturdy tissues. For smaller spans, simple designs like hoops can be followed. So based on construction, greenhouses can be classified as

a) Wooden framed structure

b) Pipe framed structure

c) Truss framed structure

4. Greenhouse type based on covering material

Covering materials are the important component of the greenhouse structure. They have direct influence on greenhouse effect, inside the structure and they alter the air temperature inside. The types of frames and method of fixing also varies with covering material. Hence based on the type of covering material they may be classified as

a) Glass glazing

b) Fibre glass reinforced plastic (FRP) glazing

i) Plain sheet

ii) Corrugated sheet.

c) Plastic film

i) UV stabilized LDPE film.

ii) Silpaulin type sheet.

iii) Net house.

d) Based on the cost of construction involved

i) High cost greenhouse

ii) Medium cost greenhouse

iii) Low cost greenhouse

Lesson 30. General Criteria for Construction

30.1 Site Selection

A greenhouse is designed to withstand local wind, snow and crop loads for a specific cropping activity. In this way, the structure becomes location and crop specific. The building site should be as level as possible to reduce the cost of grading, and the site should be well aerated and should receive good solar radiation. Provision of a drainage system is always possible. It is also advisable to select a site with a natural windbreak. In regions, where snow is expected, trees should be 30.5 m away in order to keep drifts back from the greenhouses. To prevent shadows on the crop, trees located on the east, south, or west sides should be at a distance of 2.5 times their height.

A good site can make a difference in the functional and environmental operations of greenhouses.

1) Ground slope for drainage is an important factor. Adequate provision should be made to divert surface water away from the greenhouse.

2) A greenhouse needs a dependable source of energy in the form of electricity and /or other fuel for environmental control. An electric power distribution line adjacent to the site will reduce the investment on cable laying.

3) A short access to all weather public roads will facilitate material handling to and from greenhouse. Nearness to market is another added advantage.

4) A dependable supply of good quality of water is needed for a greenhouse.

5) Greenhouse should be located away from other buildings and trees to avoid obstruction of sunlight.

6) Orientation of the greenhouse is another important factor. An East-West oriented free standing greenhouse maintains better winter light as compare to a North-South oriented greenhouse. Therefore in north India a free standing greenhouse should be oriented in East-West direction. Gutter connected greenhouse be oriented North-South to avoid continuous shading of certain portions of the greenhouse due to structural members.

7) The greenhouse frame is the most important component of the greenhouse system. It provides support for glazing material and a place for fitting of environmental control equipment. Commonly used structural shapes are gable, quonset and gothic arch with minor changes to suit local conditions.

30.2 Standards for Construction

The Bureau of Indian Standards (BIS) has formulated the following standards with respect to greenhouse technology:

1) IS 14462: 1997- Recommendations for layout, design and construction of greenhouse structures.

2) IS 14485: 1998- Recommendations for heating, ventilating and cooling of greenhouse.

3) IS 15827: 2009- Plastic films for greenhouses – specifications.

30.3 Methods of Construction

For locating the greenhouse, a piece of land larger than the grower's immediate need should be acquired. The ultimate size of the greenhouse range should be estimated. Area should then be added to this estimated figure to accommodate service buildings, storage, access drives and a parking lot. The floor area of service buildings required for small farms is about 13% of the greenhouse floor area, and it decreases with the increase in size of the farm. On an average, service buildings occupy 10% of the growing area. The service building is centrally located in a nearly square design of the farm, which minimizes distance of movement of plants and materials. Doors between the service buildings and the greenhouse should be wide enough to facilitate full use of the corridor width. Doors at least 3.1 m wide and 2.7 m high are common. It is good to have the greenhouse gutter at least 3.7 m above the floor to accommodate automation and thermal blanket and still leave the room for future innovations.

Construction of Glass Greenhouses

Glass greenhouses have an advantage of greater interior light intensity over plastic panel and film plastic covered greenhouses. Glass greenhouses tend to have a higher air infiltration rate, which leads to lower interior humidity, which is advantageous for disease prevention. On the other hand, glass greenhouses have a higher initial cost than double-layer film plastic greenhouses. While comparing the price of a glass greenhouse to a film plastic greenhouse, one needs to take into account the initial purchase price of each as well as the cost of re-covering the film plastic greenhouse every three to four years.

Several types of glass greenhouses are designed to meet specific needs. A lean-to-type design is used when a greenhouse is placed against the side of an existing building. This design makes the best use of sunlight and minimizes the requirements for roof supports. It is found mostly in the retail industry. An even-span greenhouse is one in which the two roof slopes are of equal pitch and width. By comparison, a un-even-span greenhouse has roofs of unequal width, which makes the structure adaptable to the side of a hill. This style is seldom used today because such greenhouses are not adaptable to automation. The sidewall is eliminated between greenhouses, which results in a structure with a single large interior. Basically, three frame types are used in glass greenhouses, which are wood frames (6.1 m in width), pipe frames (12.2 m in width) and truss frames (15.2 m in width). Latest glass greenhouses are primarily of the truss frame type. Truss frame greenhouses are best suited for prefabrication. All-metal greenhouses proved cheaper to maintain since they required no painting. At present, virtually all glass greenhouse construction is of the metal type. The structural members of the glass greenhouse cast shadows that reduce plant growth during the dark months of the year. Aluminum sash bars are stronger than wooden ones; hence wider panels of glass can be used with aluminum bars. The reduction in materials and the reflectance of aluminum have given these metal greenhouses a great advantage over wooden greenhouses in terms of higher interior light intensity. Glass greenhouse construction of today can be categorized as high profile or low profile. The low profile greenhouse is most popular in the Netherlands and is known as the Venlo greenhouse. The low profile greenhouses uses single panels of glass extend from eave to ridge. The low profile greenhouse slightly reduces exposed surface area, thereby reducing the heating cost, but more expensive to cool. The high profile greenhouses require more than single panel to cover the eave to ridge. A problem with this design is the unsealed junction between pieces of glass in the inner layer. Moisture and dust may enter between the layers and reduce light transmission.

Construction of pipe framed greenhouses

Fig. 1 Greenhouse construction

Image source:http://agritech.tnau.ac.in/horticulture/horti_Greenhouse%20cultivation.html

The choice of construction of pipe framed greenhouses often favours low initial investment and relatively long life. Galvanized mild steel pipe as a structural member in association with wide width UV- stabilized low density polyethylene (LDPE) film is a common option of greenhouse designers.

Material requirement

The structural members of greenhouse are

(a) Hoops

(b) Foundation

(c) Lateral supports

(d) Poly-grip assembly

(e) End frame

The materials requirement of (20m x 4.0m x 4.0m) floor area greenhouse is given:

i) GI pipe class 'A' (25 mm diameter, 85 cm long, 30 m total length)

ii) GI pipe class 'B' (15 mm diameter, 6.0 m long, 21 Nos.)

iii) GI sheet (20 gauges, size 90 x 24 cm, 4 sheets)

iv) MS flat (25x3 mm size, 4 m length)

v) Lateral support to end frames (10 mm diameter rod, 10 m length)

vi) Cement concrete (1: 3: 6 mix, 1.0 m^3)

vii) UV- stabilized LDPE film (single layer 800 gauge, 5.4 m^2/kg, 154 m^2)

viii) Poly-grip (channel 2000 x 3.5 x 4 cm, 2 Nos.; Angle 2000 x 2 x 2 cm, 2 Nos.; both made from the procured 20 gauge GI sheet, key 6 mm diameter, 56 mm length)

ix) Wooden end frames (5x5 cm wood, 0.15 m^3)

x) Nuts and bolts 96 mm diameter, 35 mm long, 70 sets)

xi) Miscellaneous items like nails, hinges and latches as per requirement

Materials for Construction of Greenhouses

The following materials are commonly used to build frames of greenhouse

i) Wood

ii) Bamboo

iii) Steel

iv) Galvanized iron pipe

v) Aluminum and

vi) Reinforced Cement Concrete (RCC).

The selection of above materials was based on their specific physical properties, requirements of design strength, life expectancy and cost of construction materials.

Wood

Fig. 2 Wooden greenhouse

Image Source:http://agritech.tnau.ac.in/horticulture/horti_Greenhouse%20cultivation.html

Wood and bamboo are generally used for low cost poly-houses. In low cost poly-houses, the wood is used for making frames consisting of side posts and columns, over which the polythene sheet is fixed. The commonly used woods are pine and casuarinas, which are strong and less expensive. In pipe-framed poly-houses, wooden battens can be used as end frames for fixing the covering material. In tropical areas, bamboo is often used to form the gable roof of a greenhouse structure. Wood must be painted with white colour paint to improve light conditions within the greenhouse. Care should be taken to select a paint that will prevent the growth of mold. Wood must be treated for protection against decay. Chromated copper arsenate and ammonical copper arsenate are water based preservatives that are applied to the wood that may come into contact with the soil. Red wood or cypress (natural decay resistance woods) can be used in desert or tropical regions, but they are expensive.

Galvanized iron (GI), aluminum, steel and reinforced cement concrete

GI pipes, tubular steel and angle iron are generally used for side posts, columns and purlins in greenhouse structure, as wood is becoming scarce and more expensive. In galvanizing operation, the surface of iron or steel is coated with a thin layer of zinc to protect it against corrosion. The commonly followed processes to protect against corrosion are: (i) Hot dip galvanizing (hot process) process: The cleaned member is dipped in molten zinc, which produces a skin of zinc alloy to the steel. (ii) Electro-galvanizing (cold process) process: The cleaned member is zinc plated similar to other forms of electro-plating. The galvanizing process makes the iron rust proof, to eliminate the problem of rusting of structural members. Aluminum and hot dipped GI are comparatively maintenance free. In tropical areas, double dipping of steel is required, as single dip galvanizing process does not give a complete cover of even thickness to the steel. Aluminum and steel must be protected by painting with bitumen tar, to protect these materials from corrosion, while these materials contact with the ground. Now-a-days, the greenhouse construction is of metal type, which is more permanent. RCC is generally limited to foundations and low walls. In permanent bigger greenhouses, floors and benches for growing the crops are made of concrete.

Glass

Glass has been traditional glazing material all over the world. Widely used glasses for greenhouse are: (i) Single drawn or float glass and (ii) Hammered and tempered glass. Single drawn or float glass has the uniform thickness of 3 to 4 mm. Hammered and tempered glass has a thickness of 4 mm. Single drawn glass is made in the traditional way by simply pulling the molten glass either by hand or by mechanical equipment. Float glass is made in modern way by allowing the molten glass to float on the molten tin. Coating with metal oxide with a low emissivity is used for saving energy with adequate light transmittance. Hammered glass is a cast glass with one face (exterior) smooth and the other one (interior) rough. It is designed to enhance light diffusion. This glass is not transparent, but translucent. Tempered glass is the glass, which is quickly cooled after manufacture, adopting a procedure similar to that used for steel. This kind of processing gives higher impact resistance to the glass, which is generally caused by hail. Glass used as a covering material of greenhouses, is expected to be subjected to rather severe wind loading, snow and hail loading conditions. The strength mainly depends on the length/width ratio of the panel and on the thickness of the panel, but the most widely used thickness is 4 mm.

Polyethylene film

Polyethylene is principally used today for two reasons - (i) Plastic film greenhouses with permanent metal frames cost less than glass greenhouses and (ii) plastic film greenhouses are popular because the cost of heating them is approximately 40% lower compared to single-layer glass or fiberglass-reinforced plastic greenhouses. The disadvantages are: these covering materials are short lived compared to glass and plastic panels. UV light from the sun causes the plastic to darken, thereby lowering transmission of light, also making it brittle, which leads to its breakage due to wind. A thermal screen is installed inside a glass greenhouse that will lower the heat requirement to approximately that of a double-layer plastic film greenhouse, but this increases the cost of the glass greenhouse. Polyethylene film was developed in the late 1930s in England and spread around the middle of this century. Commonly used plastic for greenhouse coverings are thermoplastics. Basic characteristics of thermoplastics are: (i) thermoplastics consists of long chain molecules, soften with heating and harden with cooling and this process is reversible and (ii) thermoplastics constitute a group of material that are attractive to the designer for two main reasons: (a) Thermoplastics have the following specific physical properties- stiffness, robustness and resilience to resist loads and deformations imposed during normal use and (b) It can readily be processed using efficient mass production techniques, result in low labor charge. The main reason to use polyethylene year round for greenhouse covering is due to presence of UV-inhibitor in it. Otherwise it lasts for only one heating season. UV-inhibited plastic cover may last for a period of 4 to 5 years. UV-grade polyethylene is available in widths up to 15.2 m in flat sheets and up to 7.6 m in tubes. Standard lengths include 30.5, 33.5, 45.7, 61 and 67 m. Some companies provide custom lengths up to a max. of 91.5 m. Condensation on polythene film is a big problem. Condensation causes disease development, development of water logged condition and oxygen deficient inside the greenhouse. Condensation reduces light intensity within the greenhouse. To avoid this problem, anti-fog surfactant, which discourages condensation, is built into the film or panel. Warm objects, such as plants, the greenhouse frame and soil radiate IR energy to colder bodies at night, which results in loss of heat in greenhouse. Since polyethylene is a poor barrier to radiant heat, it is formulated with IR-blocking chemicals into it during manufacture, will stop about half of the radiant heat loss. On cold and clear nights, as much as 25% of the total heat loss of a greenhouse can be prevented in this way and on cloudy nights only 15% is prevented. UV-stabilized polyethylene, on an average, transmits about 87% of photo-synthetically active radiation (PAR) into the greenhouse. IR absorbing polyethylene, reduces radiant heat loss, transmits about 82% of photo-synthetically active radiation (PAR) into the greenhouse. The amount of light passing through two layers of a greenhouse covering is approximately the square of the decimal fraction of the amount passing through one layer (e.g. when 87% passes through one layer of UV-inhibited polyethylene, only 76% (0.87 x 0.87) passes through two layers**.** Similarly, when 82% passes through one layer of IR-absorbing polyethylene, only 67% (0.82 x 0.82) passes through two layers.

Polyvinyl chloride film (PVC films)

PVC films are UV light resistant vinyl films of 0.2 to 0.3 mm and are guaranteed for 4 to 5 years respectively. The cost of 0.3 mm vinyl film is three times that of 0.15 mm polyethylene. Vinyl film is produced in rolls upto 1.27 m wide. Vinyl films tend to hold a static electrical charge, which attracts and holds dust. This in turn reduces light transmittance unless the dust is washed off. Vinyl films are seldom used in the United States. In Japan, 95% of greenhouses are covered with plastic film, out of which 90% are covered with vinyl film.

Tefzel T^2 film

The most recent addition of greenhouse film plastic covering is Tefzel T^2 film (ethylene tetra-fluoro ethylene). Earlier, this film was used as covering on solar collectors. Anticipated life expectancy is 20 years. The light transmission is 95% and is greater than that of any other greenhouse covering material. A double layer has a light transmission of 90% (0.95 x 0.95). Tefzel T^2 film is more transparent to IR radiation than other film plastics. Hence, less heat is trapped inside the greenhouse during hot weather. As a result, less cooling energy is required. Disadvantage is that, the film is available only in 1.27 m wide rolls. This requires clamping rails on the greenhouse for every 1.2 m. If reasonable width strips become available, the price is not a problem, because a double layer covering will still cost less than a polycarbonate panel covering with its aluminum extrusions, and will last longer, and will have much higher light intensity inside the greenhouse.

Polyvinyl chloride rigid-panel

Initially, PVC rigid panels showed much promise as an inexpensive covering material (almost 40% of cost of long lasting fiberglass reinforced plastics), has the life of 5 years. After commercial application, these panels indicated that the life expectancy was much shorter, less than 2 years. This is undesirable factor, because the cost of PVC panels was 4 to 5 times that of polyethylene film and they required much more time to install. Now-a-days, PVC rigid panels are not in use.

Fiberglass-reinforced plastic (FRP) rigid panel

FRP was more popular as a greenhouse covering material in the recent past. Advantage of FRP is that it is more resistant to breakage by factors, such as hail or vandals. Sunlight passing through FRP is scattered by the fibers in the panels, as a result the light intensity is rather uniform throughout the greenhouse in comparison with a glass covering. Disadvantages with these are the panels subjected to etching and pitting by dust abrasion and chemical pollution. Based on the grade, the usable life period of FRP panel varies. Some grades give 5 to 10 years, while better grades can last up to 20 years. FRP panels are flexible enough to conform to the shape of quonset greenhouses, which make FRP a very versatile covering material. FRP can be applied to the inexpensive frames of plastic film greenhouses or to the more elaborate frames of glass type greenhouses. The price of FRP greenhouse lies between that of a plastic film greenhouse and that of a glass greenhouse. But the cost is compensated by the elimination of the need for replacement of film plastic in every year or alternate years. Corrugated panels were used because of their greater strength. Flat panels are used occasionally for the end and side walls, where the load is not great. It is available in 1.3 m width, length up to 7.3 m and in a variety of colours. The total quantity of light transmitted through clear FRP is approximately equivalent to that transmitted through glass, but diminishes in relation its colour. For greenhouse crops in general, only clear FRP permits a satisfactory level of light transmission (88 to 90%). Coloured FRP has found a limited use in greenhouses intended for growing houseplants that require low light intensity and in display greenhouses for holding plants during the sales period. FRP has advantage over glass is that, it cools easily. FRP greenhouses require fewer structural members since sash bars are not needed.

Acrylic and polycarbonate rigid-panel

These panels have been available for about 15 years for greenhouse use. The panels have been used for glazing the side and end walls of plastic film greenhouses and retrofitting old glass greenhouse. Acrylic panels are highly inflammable, where as polycarbonate panels are non-flammable. Acrylic panels are popular due to their higher light transmission and longer life. Acrylic panels are available in thickness of 16 and 18 mm, and have 83% of PAR light transmission. Acrylic panels cannot be bent, but the thinner panels can be bent to fit curved-proof greenhouses. These panels are also available with a coating to prevent condensation drip. Polycarbonate panels are preferred for commercial greenhouses due to lower price, flame resistance and greater resistance to hail damage. Polycarbonate panels are available in thickness of 4, 6, 8, 10 and 16 mm. These panels are also available with a coating to prevent condensation drip and also with an acrylic coating for extra protection from UV light.

Procedure of erection

(1) A 4m by 20m rectangular area is marked on the site, preferably orienting the longer dimension in east-west direction. This rectangle will act as the floor plan of the greenhouse.

(2) Mark four points on the four corners of the rectangle.

(3) Start from one corner point and move along the length of marked rectangle, marking a point every 1.25 m distance until reaching the other corner (16 bays; 17 points). The same procedure is repeated on the other side of the rectangle.

(4) Dig 10 cm diameter holes upto 70 cm depth on all marked points with the help of bucket auger (or) a crowbar. This way a total of 34 holes on both the parallel sides of the greenhouse floor are obtained.

(5) Poly-grip sections formed according to the drawing into two 20m length.

(6) Fix the prefabricated poly-grip channels to the foundation pipes on 1.25 m spacing with the help of 6 mm diameter bolts.

(7) Set these assemblies on temporary supports between the holes with the foundation pipes hanging vertically in the holes.

(8) Pour cement concrete mix of 1: 3 : 6 around foundation pipes in such a way that the lower 15 cm to 20 cm ends are covered in concrete. The concrete is compacted around the foundation pipes with the help of the crowbar and is allowed to cure for 2-3 days.

(9) After curing, fill the soil around the foundation pipes to the ground level and compact it well.

(10) Position end frames on the two ends. Mark the position of legs and dug holes for fixing of legs. Now install both the end frames.

(11) Put the ringside of lateral support members on adjacent foundation pipe to the corner, and other side is hooked to the end frame.

(12) Put all the hoops in the foundation pipes in such a way that straight portion of hoop is inserted into the foundation and rests on the bolt used for fixing of poly-grip channel.

(13) Take a 20 m long ridge line by spacing 15 mm diameter pipes together. Put the 20m long pipe at the ridge line of the hoops.

(14) Use cross connectors on the ridge line pipe, in such a way that one half of it remains on the one side of the hoop and the other half on the other side.

(15) Put two bolts of 6 mm diameter in the holes provided in the ends of cross-connector. Tie a few of them with the help of nuts.

(16) Repeat the same procedure for joining all the hoops with ridge line pipe.

(17)While forming cross-connectors, the distance between the cross-connectors or hoops should be maintained 1.25 m center to center. This poly grip mechanism will provide a firm grip of the ridge line pipe and hoops at right angles without allowing for slippage.

(18) Spread polyethylene film over the structure from one end to the other end without wrinkles and keeping the edges together.

(19) Place polyethylene film between the poly-grip channel and right angle strip and secure them under pressure with the help of iron rods. The film is stretched gently and fixed on the other parallel side by poly-grip. This way the polyethylene is secured on both the longer sides.

(20) On the other two remaining ends, polyethylene is nailed to the end frames using wooden battens and nails.

(21) The remaining portion of the end frames is covered with polyethylene film, which is secured with wooden battens and nails.

(22) Mechanical ventilation, heating and cooling equipment is installed on the frames as per the crop requirement.

Lesson 31. Facilities and Instruments Required in Greenhouse

31.1 Lamps, exhaust fans, CO_2 cylinders, Micro irrigation system, fertigation equipment,

31.1.1 Lamps

Plants respond to the relative lengths to light and dark periods as well as to the intensity and quality of light. Artificial light has been used extensively to control plant growth processes under various conditions. Plants differ in the need for light; some thrive on sunshine, others grow best in the shade. Most plants will grow in either natural or artificial light. Artificial light can be used in the following ways:

- To provide high intensity light when increased plant growth is desired.
- To extend the hours of natural daylight or to provide a night interruption to maintain the plants on long-day conditions.

Keep growing throughout the year with outdoor fixtures and greenhouse lights that offer outstanding uniformity and superior light levels. Growers Supply has energy-efficient lighting fixtures, replacement light bulbs, high pressure sodium fixtures and outdoor lighting for your nursery or greenhouse. We offer LED bulbs, energy-saving fluorescent lights, tube lamps, metal halide lamps, heat lamps, high bay fixtures, low bay fixtures and more. Switch to light bulbs that give you the power to save money and energy in your greenhouse, cold frame, high tunnel or home.

Proper lighting not only extends the gardening day by enabling the gardener to work in the greenhouse during the dark evenings of winter and early spring, but it aids plant growth. Three basic types of lamps used in greenhouse lighting are:

Fluorescent lamps - Fluorescent bulbs are the most commonly used light source for the home gardener. Fluorescent bulbs produce a linear light that gives off more efficient and uniform lighting than incandescent types. Fluorescent bulbs are available in 28–225 watt configurations and can be stacked in banks to enhance coverage areas. In late winter/early spring, most gardeners who start plants from seed utilize some type of inexpensive fluorescent shop light system as their light source. These have the advantage of higher light efficiency with low heat. This type of lamp is the most widely used for supplemental light. It is available in a variety of colors but cool-white lamps are the most common. High intensity (1500 ma) fluorescent tubes that require higher wattage are also commonly used to reach 2000 foot candles. - These have the advantage of higher light efficiency with low heat. This type of lamp is the most widely used for supplemental light. It is available in a variety of colors but cool-white lamps are the most common. High intensity (1500 ma) fluorescent tubes that require higher wattage are also commonly used to reach 2000 foot candles. The 28–40 watt bulbs work great for germinating seeds and growing seedlings, which do not require the more expensive, higher intensity, full spectrum "grow lights." The key in the use of these low-output lights is that you must orient them to within an inch of the top of the plants to capture all the light intensity (lumens) they have to offer. If they are not placed close to the plants, inter-nodal elongation will occur, producing weak, spindly plants that will generally not perform well. While houseplants, seedlings and low-light flowering plants can flourish under fluorescent lights, they fall far short of the light requirements needed to produce most mature flowering and fruiting plants. White reflectors or reflectors made from aluminum foil may aid in maximizing what little light is available from these low-intensity bulbs.

Fluorescent lighting is rarely used in commercial greenhouses for producing mature flowering or fruiting plants because of their low-intensity output and the sunlight-shading effects that their fixtures and reflectors create. Their primary use in commercial operations is in providing light for germination benches. Under these conditions the lamps are hung very close to the seedlings. Because seedlings require much lower light levels than mature plants, several fluorescent lamps alone are capable of meeting their light requirements. As the seedlings enter their vegetative growth stage, their light requirements rapidly outpace the fluorescent lamps' capability of providing enough light intensity and quality to meet their demands. To sustain this rapid growth past the seedling stage, plants need to be moved into a greenhouse where direct sunlight or high-output artificial lighting is available.

Incandescent lamps - The incandescent "light bulb" type of light source may be useful in controlling day length, but it offers little help as a grow light. Since the major portion of energy going into incandescent bulbs is released as heat rather than as light, conventional light bulbs are primarily used to manipulate photoperiod rather than as supplemental lighting to enhance growth. These vary in size from 60 watts to 500 watts. They are used to extend day- length in greenhouses. The grower can vary foot- candle levels by adjusting the spacing and mounting height above the plants.

High-intensity discharge (HID) lamps - High-intensity discharge bulbs are the most costly to purchase and operate but offer the highest quality light output of all grow-light bulbs. Where plant appearance is critical and natural sunlight limited, metal halide bulbs should be used. Due to their energy efficiency and the general quality of the light spectrum emitted (yellowish light), high-pressure sodium (HP sodium) lights are the most commonly used types found in commercial greenhouses. These have a long life (5000 hours or more). With improvements made possible by the addition of sodium and metal-halides, the lamp has a high emission of light in the regions utilized by plants. These have a long life (5000 hours or more). With improvements made possible by the addition of sodium and metal-halides, the lamp has a high emission of light in the regions utilized by plants. Depending on the crop needs, natural light availability and greenhouse design, there are several wattages of HID lamps available. These range from 150–1000 watts. While the crop light requirements are normally documented and the natural lighting duration measurable, how the greenhouse design impacts the choice of lamp wattage is not readily apparent. An efficient greenhouse operation will maximize its lighting by assuring a uniform level of light across all of its growing benches. If there are sections that receive less light, the plants in these areas will become etiolated ("leggy") and the crop will not develop the uniform height that the market desires. In a greenhouse with a low roof it may be challenging to achieve uniform light with 1000-watt fixtures since the distance that they can be moved above the crop is limited. Although it is more costly to purchase several smaller lights than one large one, multiple lights allow additional flexibility in achieving uniform light dispersal.

Quartz-Halogen (Spotlights)-The quartz-halogen “spotlight” type bulbs produce a whiter light and are more electricity-efficient than the incandescent bulb, but because they, too, deliver a point-source type of illumination they are far less efficient than other available bulbs.

31.1.2 Exhaust fans

Greenhouse ventilation involves removing air from inside the greenhouse and replacing it with outside air. The ventilation may be (1) natural-caused by wind and temperature forces and (2) mechanical--accomplished by using fans. The purposes of ventilation are to control high temperatures during the summer caused by the influx of solar radiation, to maintain relative humidity at acceptable levels during winter, to provide uniform air flow throughout the entire greenhouse, and to maintain acceptable levels of gas concentration in the greenhouse. Ventilation systems for greenhouses must be considered for three climatic conditions that occur during the year--winter, summer, and spring-fall. **Winter Ventilation**

A heating system with adequate capacity is needed in the winter to maintain environmental conditions inside the greenhouse conducive for plant growth and development. Even during the coldest part of the winter, when the heating system is running at full capacity, some ventilation is still required in the greenhouse. Fresh, outside air must be ventilated into the greenhouse to remove the warm, moisture-laden air from within the greenhouse. If moist air within the greenhouse is not removed, high humidity and excessive condensation will occur. Studies have shown that humidity over 90% foster rapid development of leaf mold and fruit and stem rot. Problems with infection of tomatoes with leaf mold start occurring when humidity exceed 80%, but below 70%, problems with infection are slight. Economic problems associated with condensation in greenhouses are fungus diseases, difficulty in maintaining a clean greenhouse, more rapid deterioration of structural components, and damp, uncomfortable environmental conditions for the workers. Exhausting moist air and replacing it with heated outside air is effective in eliminating condensation and other problems resulting from high humidity. Whenever ventilation rates are increased in the winter, the heating requirements also increase. Consequently, it is necessary to determine a ventilation rate that will maintain humidity below the damaging level and, at the same time, keep the heating requirements as low as possible. Ventilation requirements of greenhouses in winter are generally on the order of two to three air exchanges per hour. The higher the inside temperature in the greenhouse, the lower the air exchange rate is required to maintain humidity below the damaging level. However, in no circumstances should a ventilation rate of less than two air changes per hour be used. Besides controlling humidity, this minimum ventilation rate is required to remove any gases of combustion that may be present as a result of leakages around the heater and ducting when a direct-fired heating system is used.

Summer Ventilation

The main purpose of a ventilation system in a greenhouse during the summer is to prevent the air temperature inside the greenhouse from rising too high above the outside air temperature. The reason for the higher air temperature inside the greenhouse is because of the large influx of solar radiation through the greenhouse glazing material. The ventilation system must effectively move air directly through the crop and over the soil to prevent excessive temperature buildups around the plants. A generally accepted minimum ventilation rate for temperature control in the summer is one air change per minute. The ventilation rates range from one air change every three minutes to three air changes per minute. As ventilation rates increase, the temperature difference between inside and outside air decreases. But the disadvantage of increased ventilation rate is the increased cost for fans and accessories, as well as increased operating costs. Regardless of how high the ventilation rate in a greenhouse is in the summer, the inside air temperature during the day will never be as low as the outside air temperature. If one is interested in maintaining an inside air temperature below outside air temperature, then evaporative cooling or some other means of conditioning the air must be used.

Spring-Fall Ventilation

The recommended ventilation rates for the spring-fall seasonal periods will be somewhere between rates required for summer temperature control and those required for winter-humidity control. The spring-fall periods are characterized by some times that is relatively cool and cloudy and other times that are warm and sunny. No special provisions are necessary for maintaining ventilation rates during this period except for the temperature and humidity controls that will determine the amount of ventilation necessary.

31.1.3 Carbon di-oxide

The benefits of carbon dioxide supplementation on plant growth and production within the greenhouse environment have been well understood for many years. Carbon dioxide can be obtained by burning carbon-based fuels such as natural gas, propane, and kerosene, or directly from tanks of pure CO_2. Carbon dioxide (CO_2) is an essential component of photosynthesis (also called carbon assimilation). Photosynthesis is a chemical process that uses light energy to convert CO_2 and water into sugars in green plants. These sugars are then used for growth within the plant, through respiration. The difference between the rate of photosynthesis and the rate of respiration is the basis for dry-matter accumulation (growth) in the plant. In greenhouse production the aim of all growers is to increase dry-matter content and economically optimize crop yield. CO_2 increases productivity through improved plant growth and vigour. Some ways in which productivity is increased by CO_2 include earlier flowering, higher fruit yields, reduced bud abortion in roses, improved stem strength and flower size. Growers should regard CO_2 as a nutrient.

For the majority of greenhouse crops, net photosynthesis increases as CO_2 levels increase from 340–1,000 ppm (parts per million). Most crops show that for any given level of photo synthetically active radiation (PAR), increasing the CO2 level to 1,000 ppm will increase the photosynthesis by about 50% over ambient CO_2 levels. For some crops the economics may not warrant supplementing to 1,000 ppm CO_2 at low light levels. For others such as tulips, and Easter lilies, no response has been observed.

Carbon dioxide enters into the plant through the stomata openings by the process of diffusion. Stomata are specialized cells located mainly on the underside of the leaves in the epidermal layer. The cells open and close allowing gas exchange to occur. The concentration of CO_2 outside the leaf strongly influences the rate of CO_2 uptake by the plant. The higher the CO_2 concentration outside the leaf, the greater the uptake of CO_2 by the plant. Light levels, leaf and ambient air temperatures, relative humidity, water stress and the CO_2 and oxygen

(O_2) concentration in the air and the leaf, are many of the key factors that determine the opening and closing of the stomata.

Ambient CO_2 level in outside air is about 340 ppm by volume. All plants grow well at this level but as CO_2 levels are raised by 1,000 ppm photosynthesis increases proportionately resulting in more sugars and carbohydrates available for plant growth. Any actively growing crop in a tightly clad greenhouse with little or no ventilation can readily reduce the CO_2 level during the day to as low as 200 ppm. The decrease in photosynthesis when CO_2 level drops from 340 ppm to 200 ppm is similar to the increase when the CO_2 levels are raised from 340 to about 1,300 ppm. During particular times of the year in new greenhouses, and especially in double-glazed structures that have reduced air exchange rates, the carbon dioxide levels can easily drop below 340 ppm which has a significant negative effect on the crop. Ventilation during the day can raise the CO_2 levels closer to ambient but never back to ambient levels of 340 ppm. Supplementation of CO_2 is seen as the only method to overcome this deficiency and increasing the level above 340 ppm is beneficial for most crops. The level to which the CO_2 concentration should be raised depends on the crop, light intensity, temperature, ventilation, stage of the crop growth and the economics of the crop. For most crops the saturation point will be reached at about 1,000–1,300 ppm under ideal circumstances. A lower level (800–1,000 ppm) is recommended for raising seedlings (tomatoes, cucumbers and peppers) as well as for lettuce production. Even lower levels (500–800 ppm) are recommended for African violets and some Gerbera varieties. Increased CO_2 levels will shorten the growing period (5%–10%), improve crop quality and yield, as well as, increase leaf size and leaf thickness. The increase in yield of tomato, cucumber and pepper crops is a result of increased numbers and faster flowering per plant.

31.1.4 Micro irrigation system

Drip irrigation, also known as trickle irrigation or micro irrigation or localized irrigation, is an irrigation method that saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. It delivers required and measured quantity of water in relatively small amounts slowly to the individual or groups of plants. Water is applied as continuous drops, tiny streams, or fine spray through emitters placed along a low-pressure delivery system. Such system provides water precisely to plant root zones and maintains ideal moisture conditions for plant growths.

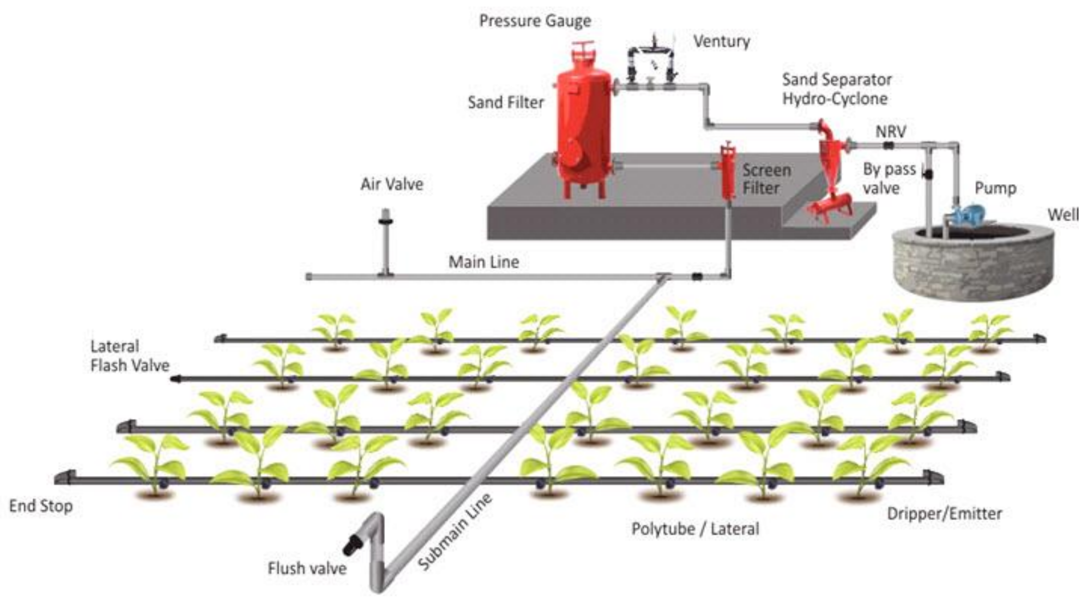

Fig. Layout of drip irrigation system

(Source: http://www.tulsigroup.com/Drip.html**)**

Components of Drip Irrigation System:

1. Control Head: This includes pump or over head tank, fertilizers or chemical application device and filters.

a) Water Source: Well, reservoir or streams

b) Pump: A centrifugal or other suitable pump to achieve required head in the pipe line.

c) By-Pass Line: A line is provided so that pumped water can be used for other activities when irrigation is not going on.

d) Fertilizer Applicator: To add fertilizer to the water directly in the pipeline.

e) Pressure Gauge: To measure head in the pipe line.

f) Sand Filter: To remove coarse impurity of water coming from water source or clogs from fertilizer.

g) Gate Valve: To regulate the flow of water in the main pipe line.

h) Screen Filter: A line filter is placed at the end of control head to avoid clogging in drippers.

2. Distribution Network*:* This part is responsible for distributing the water to the crop received by control head.

a) Main Line: It is made of HDPE or PVC having diameter in the range of 50-75mm and is able to withstand a pressure head of atleast 4-6kg/cm^2.

b) Sub main: It is made of HDPE/PVD having diameter in the range of 37-63mm and can withstand 2-5 kg/ cm^2 pressure.

c) Ball Valve: To engage or disengage a specific sub-main.

d) Flush Valve: These are provided at the end of sub mains and are used to flush the extra water if required.

e) Laterals: These are made of LDPE/ LLDPE and having diameter in the range of 12-16mm. It has an ability to withstand 2 kg/ cm^2 pressure.

f) Drippers: These are small emission devices having small flow rates and are made of poly propylene. These are provided at individual plant and have specific distance between each dripper.

31.1.5 Fertigation

Fertigation is method of applying fertilizers, soil amendments and other water soluble products required by the plants during its growth stages through drip/sprinkler irrigation system. Crops are grown intensively in the greenhouse. Hence the nutrient status maintained in the root environment is usually higher than the open field because of the greater up-take by greenhouse crops. As the mineral uptake is proportional to the total yield, the high physical production level involves high fertilizer inputs. In this respect the amount and combination of the fertilizers is critical for both, yield production and crop protection. Soluble fertilizers or liquid fertilizers are used in fertigation, they should not precipitate as insoluble salts by reacting with other fertilizers or ions present in the irrigation water. Apart from the high crop demand, the high fertilizer inputs are also believed to be necessary to maintain high osmotic pressure level in the root environment, in order to prevent lush growth and to enhance product quality. The fertigation allows us to apply the nutrients exactly and uniformly only to the wetted root volume, where the active roots are concentrated. This remarkably increases the efficiency in the application of the fertilizer, which allows reducing the amount of applied fertilizer. This not only reduces the production costs but also lessens the potential of groundwater pollution caused by the fertilizer leaching. Fertigation allows to adapt the amount and concentration of the applied nutrients in order to meet the actual nutritional requirement of the crop throughout the growing season. In order to make a correct planning of the nutrients supply to the crop according to its physiological stage, we must know the optimal daily nutrient consumption rate during the growing cycle that results in maximum yield and production quality. These functions are specific for each crop and climate, and were determined in different experiments for the main crops.

Other advantages of the fertigation are: (1) the saving of energy and labor, (2) the flexibility of the moment of the application (nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment), (3) convenient use of compound and ready-mix nutrient solutions containing also small concentrations of micronutrients which are otherwise very difficult to apply accurately to the soil, and (4) the supply of nutrients can be more carefully regulated and monitored. When fertigation is applied through the drip irrigation system, crop foliage can be kept dry thus avoiding leaf burn and delaying the development of plant pathogens.

Equipments used for fertigation

1) Venturi injector:

This is very simple and low cost device. A partial vacuum is created in the system which allows suction of the fertilizers in to the irrigation system.

Fig. 3 Venturi injector

Image Source: http://www.ncpahindia.com/articles/article17.pdf

The vacuum is created by diverting a percentage of water flow from the main and passes it through a constriction which increases the velocity of flow thus creating a drop in the pressure. When the pressure drops the fertilizer solution is sucked in to the venturi through a suction pipe from the tank and from there enters in to irrigation stream. The suction rate of the venturi is 30 to 120 l/hr.

1) Fertilizer tank:

In this system part of the irrigation water diverted from the main of the flow through a tank containing fertilizer in fluid or soluble solid form, before returning to the main line, the pressure in the tank and main line is the same but a slight drop in the pressure is created between the off take and return pipes from the tank by means of a pressure reducing valve. This causes water from main line to flow through the tank causing dilution and flow of the diluted fertilizer in to the irrigation stream. With this system the concentration of the fertilizer entering the irrigation water charges continuously with the time, starting at high concentration. As a result uniformity of the fertilizer distribution can be a problem. Fertilizer tanks are available in 90, 120, 160 liters capacity.

Fig. 4 Fertigation tank

Image Source: http://www.ncpahindia.com/articles/article17.pdf

2) Fertilizer injector pump:

These are piston or diaphragm pumps which are driven by the water pressure of the irrigation system and such as the injection rate is proportional to the flow of water in the system. A high degree of control over the fertilizer injection rate is possible, no serious head losses are incurred and operating costs are low. Another advantage is that, if the flow of water stops, fertilizer injection also automatically stops. This is perfect equipment for accurate fertigation. Suction rates of pumps vary from 40 lit to 160 lit/hr.

Fig. 5 Fertilizer injector pump

Image Source: http://www.ncpahindia.com/articles/article17.pdf

31.2 Instruments for Greenhouse Heating

Having a greenhouse is a must when you want to grow plants that are frost tender or you want to start early seedlings. Maintaining a correct temperature in your greenhouse for the plants that you have chosen to grow is an important thing. There are some options from which you can choose in order to heat your greenhouse: electric heaters, gas heaters, paraffin heaters, solid fuel hot water systems. If the heater does not have a thermostat is better to use a min/max thermometer and a frost alarm. Always choose a heater which is powerful enough to maintain the required temperature efficiently and is also convenient as cost of installation and running costs.

Electric heaters - are most reliable, efficient and convenient to use in your greenhouse. Most of them are thermostatically controlled, so there will be no waist of energy. They don't need regular refueling or special maintenance, do not produce fumes or water vapors. There are some types of electric heaters that can be used to heat your greenhouse: fan heaters, water-proof tubular heaters or convector heaters. Fan heaters are the most effective because they can be moved, promote good air circulation and also can be used in warm weather to cool the greenhouse. Tubular heaters need to be fitted to the sides of the greenhouse, just above floor level.

Gas heaters - connected to the mains supplies or from bottled gas. Their thermostats are not so efficient as to the electric heaters and if used with bottled gas they need to be regularly replaced. Propane gas releases fumes and water vapors as it burns, so proper ventilation is required in this case. Always have two bottles connected by an automatic switch-over valve in case one bottle runs out. Keep the gas cylinders in a safe place and have them checked regularly.

Paraffin heaters: These types of heaters are not as efficient as electric or gas heaters in their use of fuel because they are not thermostatically controlled. They may be expensive to run because some of energy is wasted if you need to maintain a high temperature in your greenhouse but they are inexpensive to buy and no installation cost is required. Proper ventilation is necessary in this case also because it produce plant-toxic fumes and water vapors. Another disadvantage is that you need to transport and store the fuel and check its level every day to make sure that it is burning cleanly.

Solid fuel hot water systems: it is being rarely used now. Oil- and gas-fired circulated hot water systems are still sometimes used but only on a small scale. They need regular stoking and cleaning out of the fire.

Thermometers and frost alarms: it is must if your heater is not thermostatically controlled. Use a min/max thermometer to check that the right temperatures are maintained overnight. In regions with extremely low temperatures you should use a frost alarm also. It will allow you time to protect plants if temperatures drop unexpectedly because of a power failure or heater breakdown. An alarm bell will sound remotely to announce you that temperature has drop to near freezing.

31.3 Instruments for Greenhouse Cooling

Overheating of the greenhouse during the summer months is a common but unnecessary problem. Your greenhouse can and should be a comfortable and refreshing place for you and your plants to enjoy on those hot summer days. Keeping the greenhouse cool is accomplished by obtaining a proper balance of shading, ventilation and humidity. Following are some guidelines.

Greenhouse Ventilation

Traditional ventilation systems of ridge or end vents work well if large enough and oriented to take advantage of prevailing winds. The upper vents should be equal in size to 20% of the floor area. In addition, there should be vents in the lower walls equal to 10% of the greenhouse floor area. A typical 8' x 12' greenhouse would have 15 sq feet of roof vents and 10 sq feet of lower vents. The roof vent should open 45° above horizontal. These vents can be operated by hand, or by non-electric solar powered pistons. Thermostatically controlled exhaust fan systems are a popular alternative to traditional roof vents. The fan uses very little electricity, and the thermostat makes the system automatic and easily adjustable to various operating temperatures. The thermostat is usually set at 75° to 80° F. The proper size fan will change the air in the greenhouse in about 1½ to 2 minutes. Determine the volume of your greenhouse (Length x Width x Average Height) and multiply by 0.75 to obtain the ventilation rate in Cubic Feet per Minute (CFM). (For Average Height, measure halfway up a roof rafter and then measure straight down to the floor. This vertical measurement is the Average Height). To enable the exhaust fan to operate effectively, fresh air intake shutters must be provided in the opposite end of the greenhouse. The shutters are opened by the flow of air drawn into a greenhouse by the fan, or they can be opened and closed by a shutter motor. Determine shutter size by dividing the fan CFM by 250. This gives you shutter size in square feet. If more than one shutter is to be used, divide this figure by the number of shutters to obtain the area of each shutter. (Two shutters are recommended for greenhouses over 100 sq. ft. or wider than 8 feet).

In a greenhouse good ventilation is essential, even over the winter, to avoid a built-up of stuffy or damp, stale air and to control temperature levels. The area covered by ventilations should be equal to at least one sixth of the floor area. There are few types of ventilation methods that you could use in your greenhouse, depending on the type of greenhouse that you have.

Few models of greenhouse are supplied with enough ventilation as standard, so you might need to order some additional air vents, hinged and louver windows or extractor fans when buying a new greenhouse.

Wind ventilation system: The position of ventilators is important in the air exchange in the greenhouse. If ventilators are placed on the sides and roof of the greenhouse and are also staggered, this will ensure that air circulates throughout the entire area of the greenhouse. If vents are placed directly opposite one another, air will simply blow straight through the greenhouse. To increase ventilation over the summer you may also keep the doors open.

Chimney ventilation system: This system depends on warm, humid air rising out of roof vents and being replaced by fresh air that is drawn in as a result through lower ventilations, which are usually positioned along the sides of the greenhouse either above or below the staging.

Fan ventilation system: This is a mechanically driven system that works by extracting air from the greenhouse at head height or slightly higher and drawing in fresh air through vents lower down and usually at the opposite end of the greenhouse.

Hinged ventilators: This system will allow maximum airflow while at the same time will prevent direct gusts of wind from entering the greenhouse. These may be fitted to the sides or roof of the greenhouse and should open wide to an angle of about 45 degrees.

Automatic vent openers: This system simplifies the temperature control in the greenhouse as they open automatically. They should be fitted to at least some of the hinged or louvre ventilators. There are many models of auto vent openers available.

Extractor fans: Primarily designed to be used in the kitchen, this system is also ideally suited for use in the greenhouse. Choose a fan that is powerful enough for the particular size of your greenhouse. A louvre window positioned at the opposite end of the greenhouse to the extractor fan and set lower down is essential to provide a flow of fresh air to replace the stale air that is drawn out by the fan.

Greenhouse Misting

Shading and ventilation will prevent the greenhouse from seriously overheating, but it is evaporation of moisture inside the greenhouse that will actually cool the greenhouse. Evaporating water soaks up heat like a sponge because heat is used when water changes from a liquid to a gas. Good air circulation from fans increases evaporation. The amount of moisture necessary to cool the greenhouse will vary considerably depending on the amount of ventilation and shading provided, the local climate, and daily weather changes. Generally, 1 to 2 gallons per hour for each 10 square feet of floor area will provide enough moisture. A good misting system will disperse the water evenly around the greenhouse in a fine mist without soaking the plants. There are several ways to provide moisture in the greenhouse. Most common is to soak the floor with a sprinkler hose. Water can be stored for slow release in 3" - 4" of pea gravel on the greenhouse floor. More accurate and reliable is an automatic system of misting nozzles. A humidistat set at 60% to 70% relative humidity will keep most plants comfortable and provide plenty of moisture for evaporation through the mist nozzles. The location of the nozzles can vary. They can be mounted under the benches, especially in front of the fresh air intake vents.

Apply mist only during daylight hours to avoid excessive humidity at night, which encourages disease. Remember, when the greenhouse cools at night, the relative humidity will rise even with the misting system off. Use a 24-hour timer to shut off the misting system 2 hours before sundown.

Greenhouse Shading

Shading the greenhouse will help to control the temperature levels if the ventilation system is insufficient. It also helps to protect vulnerable plants from too much direct sunlight. This will reduce the risk of leaf scorch and will prevent flower colors from fading in strong sunlight. Shadings applied primarily to control the temperature levels should be placed on the outside of the greenhouse as internal shadings are unlikely to reduce the temperatures significantly. Install shading to shield the greenhouse or sunroom from excess sun between 9 a.m. and 5 p.m. Shading should cover the roof and at least the upper half of the south wall. The amount of shading needed (expressed as a percentage of light blocked) will vary depending on your local climate, greenhouse design, and light requirements of your particular plants. Use the least amount of shading necessary, because excessive shading can slow plant growth of cause plants to "reach" for more light.

The amount of shade that is required in a greenhouse is not always the same; it depends on the season and the plants that are grown in the greenhouse. In the months of strongest sunlight, shading that reduces the light by 40-50 per cent is suitable for a typical mixed greenhouse. There are some types of shadings that you can use for your greenhouse: shading washes, blinds, meshes and fabrics or rigid sheets. In the next lines there will be a short description for each of them and how to use them efficiently.

Shading washes

This type of shading is often considered to be the most effective and cheapest method of reducing heat from the sun while still allowing enough light to penetrate for good plant growth. Paint or spray the wash onto the outside of the glass at the beginning of the sunny season and remove it in late summer by rubbing or washing it off using a cleaning solution.

Shading washes are inexpensive but they may be messy to apply and to remove. Also their appearance is sometimes unattractive in a small garden where the greenhouse represents the major feature. Some washes become more transparent when wet, so that on rainy days or when the weather is dull they allow more light penetration.

Blinds

Blinds are mainly used on the outside of the greenhouse and they control temperature effectively but they should be hard wearing since they will be in place for long periods. Blinds are more versatile than shading washes since they may be rolled up or down depending on the intensity of light regained. They may be used where only a section of the greenhouse needs to be shaded. Manually operated blinds need constant attention, while automatic blinds, which come into operation as soon as the temperature rises to a predetermined level, are more convenient to use, but they are expensive.

Meshes and fabrics

Flexible mesh shading materials are suitable for either interior or exterior use. They are less adaptable than blinds because they are generally fixed in position for the entire season and are less satisfactory than shading washes in helping to control plant growth. Woven and knitted fabrics are also suitable for both interior and exterior greenhouse use, but the amount of light reduction varies considerably depending on the type of fabric fitted. The quality of light allowed through to the plants is usually perfectly adequate for good growth, but the temperature in not significantly reduced.

Rigid sheets

Rigid polycarbonate sheets are sometimes used for shading in greenhouse. The sheet may be fixed either inside or outside depending by the greenhouse manufacturer recommendations. They cut down the light effectively but unless they are white in color the quality of light transmitted to the plants may not be mf patent for good growth.

Evaporative Coolers

An evaporative cooler is a device that cools air through the evaporation of water. Evaporative cooling differs from typical air conditioning systems which use vapor-compression or absorption refrigeration cycles. Evaporative cooling works by employing water's large enthalpy of vaporization. The temperature of dry air can be dropped significantly through the phase transition of liquid water to water vapor (evaporation), which can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of building occupants. Unlike closed-cycle refrigeration, evaporative cooling requires a water source, and must continually consume water to operate. Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. Latent heat, the amount of heat that is needed to evaporate the liquid, is drawn from the air. When considering water evaporating into air, the wet-bulb temperature which takes both temperature and humidity into account, as compared to the actual air temperature (dry-bulb temperature), is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect. When the temperatures are the same, no net evaporation of water in air occurs, thus there is no cooling effect. The wet-bulb temperature is essentially the lowest temperature which can be attained by evaporative cooling at a given temperature and humidity. A supplement to the misting system is an evaporative cooler. It works well in dry climates where the humidity is below 50%. Air is cooled 10° to 20° F by water evaporation as it is drawn through the cooler and into the greenhouse.

Advantages

Less expensive to install

Estimated cost for installation is about half that of central refrigerated air conditioning.

Less expensive to operate

Estimated cost of operation is 1/4 that of refrigerated air.

Power consumption is limited to the fan and water pump. Because the water vapor is not recycled, there is no compressor that consumes most of the power in closed-cycle refrigeration.

The refrigerant is water. No special refrigerants, such as ammonia, sulfur dioxide or CFCs, are used that could be toxic, expensive to replace, contribute to ozone depletion and/or be subject to stringent licensing and environmental regulations.

Ease of maintenance

The only two mechanical parts in most basic evaporative coolers are the fan motor and the water pump, both of which can be repaired at low cost and often by a mechanically inclined homeowner.

Ventilation air

Evaporative cooling increases humidity. In dry climates, this may improve comfort and decrease static electricity problems.

Disadvantages

Performance

High dew point (humidity) conditions decrease the cooling capability of the evaporative cooler.

No dehumidification. Traditional air conditioners remove moisture from the air, except in very dry locations where recirculation can lead to a buildup of humidity. Evaporative cooling adds moisture, but in dry climates, dryness may improve thermal comfort at higher temperatures.

Comfort

The air supplied by the evaporative cooler is typically 80–90% relative humidity; very humid air reduces the evaporation rate of moisture from the skin, nose, lungs, and eyes.

High humidity in air accelerates corrosion, particularly in the presence of dust. This can considerably shorten the life of electronic and other equipment.

High humidity in air may cause condensation of water. This can be a problem for some situations (e.g., electrical equipment, computers, paper, books, old wood).

Water

Evaporative coolers require a constant supply of water to wet the pads.

Water high in mineral content will leave mineral deposits on the pads and interior of the cooler. Depending on the type and concentration of minerals, possible safety hazards during the replacement and waste removal of the pads could be present. Bleed-off and refill (purge pump) systems may reduce this problem.

31.4 Measuring Instruments: Temperature, Radiation, Relative humidity, Air flow, Photosynthesis, Soil temperature

Temperature

Thermometer: A thermometer is a device that measures temperature or temperature gradient using a variety of different principles. A thermometer has two important elements: the temperature sensor (e.g. the bulb on a mercury-in-glass thermometer) in which some physical change occurs with temperature, plus some means of converting this physical change into a numerical value (e.g. the visible scale that is marked on a mercury-in-glass thermometer).

Radiation

Lux meter: The lux (symbol: lx) is the SI unit of illuminance and luminous emittance, measuring luminous flux per unit area. It is equal to one lumen/m^2. In photometry, this is used as a measure of the intensity, as perceived by the human eye, of light that hits or passes through a surface. It is analogous to the radiometric unit watts per square meter, but with the power at each wavelength weighted according to the luminosity function, a standardized model of human visual brightness perception. In English, "lux" is used in both singular and plural.

Relative humidity

Hygrometer: A hygrometer is an instrument used for measuring the moisture content in the environment. Humidity measurement instruments usually rely on measurements of some other quantity such as temperature, pressure, mass or a mechanical or electrical change in a substance as moisture is absorbed. By calibration and calculation, these measured quantities can lead to a measurement of humidity.

Air flow

Anemometer: An anemometer is a device for measuring wind speed, and is a common weather station instrument. The term is derived from the Greek word anemos, meaning wind, and is used to describe any air-speed measurement instrument used in meteorology or aerodynamics.

Photosynthesis

Photosynthesis meter: This device is used for measuring the photosynthesis.

Soil temperature

Soil thermometer: A soil thermometer is a thermometer specifically designed to measure soil temperature.

Lesson 32. Crop Production Management in Greenhouse

32.1 Soil treatment

Soil solarization is a method of heating soil by covering it with transparent polythene sheeting during hot periods to control soil borne diseases. The technique has been commercially exploited for growing high-value crops in diseased soils in environments with a hot summer (maximum daily air temperatures regularly exceeding 35°C). Examples include control of verticillium and fusarium diseases in vegetable crops in Israel, control of verticillium dahlias in pistachio orchards and control of chickpea and pigeon pea wilt in India. Although the major benefit of solarization is reduction of soil borne pathogens by soil heating effects, there are many other possible additional beneficial effects that can result in an increased growth response (IGR) of plants. Such additional effects include control of weeds and insect pests and release of plant nutrients.

Soil mixes used for greenhouse production of potted plants and cut flowers are highly modified mixtures of soil, organic and inorganic materials. When top soil is included as a portion of the mixture, it is generally combined with other materials to improve the water holding capacity and aeration of the potting soil. Many greenhouses do not use topsoil as an additive to the soil mixes, but rather use a combination of these organic and inorganic components as an artificial soil mix. When managed properly as to watering and fertilization practices, these artificial mixes grow crops that are equal to those grown in top soil.

Media preparation for greenhouse production

The media used in greenhouse generally have physical and chemical properties which are distinct from field soils.

- A desirable medium should be a good balance between physical properties like water holding capacity and porosity.
- The medium should be well drained.
- Medium which is too compact creates problems of drainage and aeration which will lead to poor root growth and may harbour disease causing organisms.
- Highly porous medium will have low water and nutrient holding capacity, affects the plant growth and development.
- The media reaction (pH of 5.0 to 7.0 and the soluble salt (EC) level of 0.4 to 1.4 dS/m is optimum for most of the greenhouse crops).
- A low media pH (<5.0) leads to toxicity of micronutrients such as iron, zinc, manganese and copper and deficiency of major and secondary nutrients while a high pH (>7.5) causes deficiency of micronutrients including boron.

- A low pH of the growth media can be raised to a desired level by using amendments like lime (calcium carbonate) and dolomite (Ca-Mg carbonate) and basic, fertilizers like calcium nitrate, calcium cyanamide, sodium nitrate and potassium nitrate.

- A high pH of the media can be reduced by amendments like sulphur, gypsum and Epsom salts, acidic fertilizers like urea, ammonium sulphate, ammonium nitrate, mono ammonium phosphate and aqua ammonia and acids like phosphoric and sulphuric acids.

- It is essential to maintain a temperature of the plug mix between 70 to 75°F. Irrigation through mist is a must in plug growing. Misting for 12 seconds every 12 minutes on cloudy days and 12 seconds every 6 minutes on sunny days is desirable.

- The pH of water and mix should be monitored regularly.

Gravel Culture

Gravel culture is a general term which applies to the growing of plants without soil in an inert medium into which nutrient solutions are usually pumped automatically at regular intervals. Haydite (shale and clay fused at high temperatures), soft- or hard-coal cinders, limestone chips, calcareous gravel, silica gravel, crushed granite and other inert and slowly decomposing materials are included in the term "gravel". The more important greenhouse flowering crops include roses, carnations, chrysanthemums, gardenias, snapdragons, lilies, asters, pansies, annual chrysanthemums, dahlias, bachelor buttons and others.

32.2 Crop sequence

Crops for growing in greenhouses should be selected carefully keeping in view the quality aspects and market price.

Vegetables

Off-seasonality should be the main criteria to fetch higher profits. Sweet pepper, tomato and cucumber

Flowers

Blooms as per market demand.

Depending on climate, rose, gerbera, anthurium, carnation, lillium, orchids, chrysanthemum

Table 1 Crop sequence under the greenhouse

Month	Crop
Sept - Dec	Cucurbits Summer squash/ Cucumber
Dec-Jan	Vegetable nursery/ Cucurbits
Jan-April	Summer squash/ Cucumber

32.3 Crop growth Parameters Monitoring

Plant height, number of leaves, leaf area index (LAI), stalk length, flower diameter and yield per meter square area are the main growth parameters that describes the crop performance. Plant height, stalk length and flower diameter is measured by means of a meter scale with an accuracy of ±1mm. Leaf area of the plants in each treatment is measured by a planimeter by non-destructive sampling method. Leaf area Index (LAI) is derived from the total leaf area of the plant sample divided by the floor area occupied by the sample.

32.4 Economic Analysis

Economic analysis of greenhouse covered with UV stabilized film is carried out considering associated costs such as initial investment, cost of shade net, cost of cultivation including fertilizers, pesticides, drip and economic return through the yield during entire year. The service life of greenhouse is considered as 20 years and shade net, insect-proof nets of 3 years. The annual cost of the structure is computed using capital recovery factor (CRF) considering interest rate of 12%. The life of structure, cladding materials including shade net, Insect-proof nets and drip irrigation system is considered as 20 years, 3 years and 7 years, respectively. Using these data, net benefit, benefit-cost ratio andpay-back period is computed. The capital recovery factor is computed from the formula

$$CRF = \frac{i(1+i)^n}{i(1+i)^n - 1}$$

Where,

i = rate of interest,

n = expected life of the component.

Benefit cost ratio

$$B - C\ ratio = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

Where,

C_t = Cost in each year,

B_t = Benefit in each year,

t = 1, 2, 3...n,

i = discount rate