2. MICROIRRIGATION – THEORY & PRACTICE

2.1 INTRODUCTION

Irrigation advancements within the last decade have been astounding. Microirrigation is one of the latest innovations for applying water and it represents a definite advancement in irrigation technology. It can be defined as the frequent application of small quantities of water on or below the soil surface as drops, tiny streams or miniature sprays through emitters or applicators placed along a water delivery lateral line. It differs from sprinkler irrigation by the fact that only part of the soil surface is wetted. Microirrigation encompasses a number of methods or concepts such as bubblers, drip, trickle, mist or spray and subsurface irrigation.

2.1.1 Surface Drip Irrigation

The application of water to the soil surface as drops or tiny streams through emitters with discharge rate for point – source emitters less than 8 l/h for single outlet emitter and for line-source emitters less than 4 l/h. Often the terms drip and trickle irrigation are considered synonymous.

2.1.2 Subsurface Drip Irrigation

The application of water below the soil surface through emitters, with discharge rate generally in the range of 0.6 to 4 l/h. This method of water application is different from and not to be confused with the
method where the root zone is irrigated by water table control, herein referred to as sub irrigation.

2.1.3 *Spray Irrigation*

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.

2.1.4 *Bubbler Irrigation*

The application of water to the surface at a small stream or fountain where the discharge rate for point source bubbler emitters are 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.

2.2 *PRESENT DEVELOPMENTS AND EXPANSION OF MICROIRRIGATION*

The first reported microirrigation experiments began in Germany in 1860, where subsurface clay pipes were used in combination with irrigation and drainage systems (Davis, 1974). In the United States, around 1913 House (Davis, 1974) tried to irrigate with perforated subsurface pipes, but he indicated that the method
was too expensive. Irrigation of plants through narrow openings in pipes can also be traced back to green house operations in the United Kingdom in the late 1940s (Davis, 1974).

Current microirrigation technology dates back to the work of Blass (1964). Based on the observation that a large tree near a leaking faucet exhibited a more vigorous growth than other trees in the area, he developed the first patented drip/trickle irrigation system. The availability of low cost plastic pipe for water delivery lines helped to speed up the use of drip irrigation systems. From Israel the drip irrigation concept spread to Australia, North America and South Africa by the late 1960s and eventually throughout the world. The large scale use of drip irrigation system started in 1970s in Australia, Israel, Mexico, New Zealand, South Africa and USA to irrigate vegetables, orchards and its coverage was reported as 56,000 ha. The microirrigated area grew slowly but steadily and it was 0.41 million ha in 1981, 1.1 million ha in 1986, 1.77 million ha in 1991, 3.0 million ha in 2000, 6.2 million ha in 2006 and about 8.0 million ha in 2009 (ICID, 2009). At present United States (1.52 million ha) has the greatest land area under microirrigation followed by Spain (1.5 million ha) and India (1.43 million ha).

Although microirrigation systems are considered the leading water saving technologies in irrigated agriculture, their adoption is still low. At present, of the total world irrigated area, about 2.9% (8 million ha) is equipped with microirrigation. Most of the microirrigated area is concentrated in Europe and the America. Asia has the highest
area under irrigation (193 million ha, which is 69% of the total irrigated area), but has very low area 1.8 million ha (<1.0%) under microirrigation. In some countries such as Israel & Jordan, where water availability limits crop production, microirrigation systems irrigate about 75% of the total irrigated area. In India it accounts for 2.3% of the total irrigated area (62.3 million ha). While the ultimate potential for microirrigation in India is estimated at 27 million ha.

Microirrigation, like other irrigation methods, will not fit every agricultural crop, specific site or objective. Presently, microirrigation has the greatest potential where (i) water and labour are expensive or scarce; (ii) water is of marginal quality viz., saline; (iii) soils are sandy, rocky or difficult to level, (iv) steep slopes and undulated topography; and (v) high value crops are produced. The principal crops under microirrigation are commercial field crops (sugarcane, cotton, tobacco etc), horticultural crops – fruit & orchard crops, vegetables, flowers, spices & condiments, bulb & tuber crops, plantation crops and silviculture/forestry plantations. This method of irrigation continues to be important in the protected agriculture viz., greenhouses shade nets, shallow & walking tunnels etc., for production of vegetables & flowers. Microirrigation is also used for landscapes, parks, highways, commercial developments and residences.

Undoubtedly, the area under microirrigation will continue to increase rapidly as the amount of water available to agriculture declines and the demands for urban and industrial use increase.
Microirrigation is also one of the techniques that enable growers to overcome salinity problems that currently affect 8.0 million ha in India. As this area increases, so too will the use of microirrigation to maintain crop production. In addition, because growers are looking to reduce cost of production but at the same time improve crop quality, the improved efficiency provided from microirrigation technology will become increasingly important.

2.3 POTENTIAL ADVANTAGES OF MICROIRRIGATION

Many reports have listed and summarized potential advantages of microirrigation compared to sprinkler and surface irrigation methods. Each irrigation method has possible advantages and limitations with respect to technical, economical and agronomic (or crop production) factors. Here, an attempt is made to discuss some of the important benefits of microirrigation.

2.3.1 Enhanced Plant Growth, Yield and Quality

The soil water content in a portion of the plant root zone remains fairly constant because irrigation water can be supplied slowly and frequently at a predetermined rate using drip irrigation. Generally, the total soil water potential increases (the soil water suction decreases) with elimination of the wide fluctuations in the soil water content, which typically result from conventional sprinkler and surface irrigation methods (Bresler, 1977). Under traditional irrigation methods plants extract water from the soil from Field Capacity down towards Permanent wilting point. During this transition in the soil
moisture, it becomes increasingly difficult for the plant to extract water and therefore the consumptive water use rate decreases. This reduction in water use accompanied by a reduction in growth of the plants results in reduced yields. Ideally to achieve maximum yields the soil moisture level should be slightly below field capacity. The drip irrigation system with its controlled application of water makes possible the task of maintaining the soil moisture close to the field capacity, thus resulting in noticeable increase in growth and yield. The more favourable growing conditions made possible by drip irrigation will bring the crops into maturity earlier than traditional irrigation methods. Table 2.1 provides data on yield increase with drip irrigation in different crops.

Table 2.1 : Yield improvement with drip irrigation

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield (t/ha)</th>
<th>Conventional</th>
<th>Drip</th>
<th>% Yield increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>57.5</td>
<td>87.5</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Grapes</td>
<td>26.4</td>
<td>32.5</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Sweet lime</td>
<td>100.0</td>
<td>150.0</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Pomegranate</td>
<td>55.0</td>
<td>109.0</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>Papaya</td>
<td>13.4</td>
<td>23.5</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>32.0</td>
<td>48.0</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Water Melon</td>
<td>24.0</td>
<td>45.0</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>Okra</td>
<td>15.3</td>
<td>17.7</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Chillies</td>
<td>4.2</td>
<td>6.1</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Sweet Potato</td>
<td>4.2</td>
<td>5.9</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Sugarcane</td>
<td>128.0</td>
<td>170.0</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>2.3</td>
<td>2.9</td>
<td>26</td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 Water Conservation through increased beneficial use of available water

There is a general agreement that irrigation water requirements can be less with drip irrigation than with conventional surface and sprinkler irrigation methods (Aljibury, 1974; Davis, 1975; Shoji, 1977; Bresler, 1977; Hillel, 1980; Howell et al., 1980). The savings, of course, depend on the crop, soil, environmental conditions and the attainable on-farm irrigation efficiency (Table 2.2). Primary reasons given for the water savings include irrigation of a smaller portion of the soil volume, decreased direct soil surface evaporation (Dan, 1974), reduced water uptake by weeds due to dry surfaces between rows/trees (Lemon, 1956), reduced irrigation runoff from the field (the dry soil between rows could also store more precipitation), prevention of runoff from steep hills (Marsh et al., 1975) and particularly for low-permeability or crusted soils (Kemper and Noonan, 1970) and controlled deep percolation losses (Rawlins, 1973) especially on sandy soils (Roth, 1974) below the crop root zone. Sprinkler irrigation is subject to water loss by wind drift, increased evaporation, or poor application uniformity, especially with strong winds (Seginer, 1969). Further the increase in yields combined with water savings results in higher water use efficiency (WUE) (Table 2.2).
Table 2.2: Water savings & WUE with drip irrigation in various crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield increase, %</th>
<th>Water Saving, %</th>
<th>Increase in Water Use Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>52</td>
<td>45</td>
<td>176</td>
</tr>
<tr>
<td>Chilly</td>
<td>45</td>
<td>63</td>
<td>291</td>
</tr>
<tr>
<td>Grapes</td>
<td>23</td>
<td>48</td>
<td>136</td>
</tr>
<tr>
<td>Groundnut</td>
<td>91</td>
<td>36</td>
<td>197</td>
</tr>
<tr>
<td>Sweet Lime</td>
<td>50</td>
<td>61</td>
<td>289</td>
</tr>
<tr>
<td>Pomegranate</td>
<td>45</td>
<td>45</td>
<td>167</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>33</td>
<td>56</td>
<td>204</td>
</tr>
<tr>
<td>Tomato</td>
<td>50</td>
<td>31</td>
<td>119</td>
</tr>
<tr>
<td>Water Melon</td>
<td>88</td>
<td>36</td>
<td>195</td>
</tr>
</tbody>
</table>


2.3.3 Reduced salinity hazards to plants

Considerable evidence exists that waters of higher salinity can be used with drip irrigation than with other methods without greatly reducing crop yields. Minimizing the salinity hazard to plants irrigated by drip irrigation can be attributed to: (i) dilution of the soil solution’s salt concentration, as a consequence of high frequency the irrigation used to maintain high soil water contents in the root zone (Bernstein and Francois, 1975; Rhoades et al., 1974); (ii) elimination of leaf damage caused by foliar salt absorption with sprinkler irrigation (Gornat et al., 1973; Bernstein and Francois, 1975); and (iii) movement of salts beyond the active plant root zone (Patterson and Wierenga, 1974; Tscheschke et al., 1974).
2.3.4 Improved fertilization through fertigation

Drip irrigation offers considerable flexibility in fertilization (Lindsey and New, 1974; Isobe, 1974). Frequent or nearly continuous application of plant nutrients along with the irrigation water is feasible practice known as fertigation and appears to be beneficial for crop production. Several researchers (Bester et al., 1974; Shani, 1974; Marsh et al., 1975) have proposed various reasons for the increased efficiency of fertilization. (i) decreased quantity of applied fertilizer, because fertilizer is applied only to the root zone (Table 2.3); (ii) improved timing of fertilization to match plant requirements at various growth stages; and (iii) improved distribution of fertilizer with minimum leaching beyond the root zone or runoff.

Table 2.3 : Savings in fertilizer with drip fertigation in various crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Saving in fertilizer, %</th>
<th>Increase in Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Banana</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>Onion</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Cotton</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Potato</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Tomato</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>Castor</td>
<td>60</td>
<td>32</td>
</tr>
<tr>
<td>Okra</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>Broccoli</td>
<td>40</td>
<td>10</td>
</tr>
</tbody>
</table>

However, fertilizers must be completely soluble in water in order to be distributed evenly through the drip system. Chemicals of low solubility may precipitate causing blockage of the emitters. There is usually no problem with nitrogen and potassium compounds (Miller et al., 1976). Phosphorous is usually added in soluble forms as orthophosphate, as mono ammonium polyphosphate, phosphoric acid (Rauschkolb et al., 1976). Microelements may be added in chelate form.

The drip systems is well suited to the application of herbicides and soil-borne diseases and pests, since localized application only in the wetted area results in the chemicals being more effective at lower concentrations

2.3.5 Reduced operation labour

Labour and operational costs can be reduced by simultaneous application of water, fertilizer, herbicide, insecticide, fungicide and other additives through the drip irrigation system (Davis and Nelson, 1970; Sivanappan, 1994; Narayananamoorthy, 2001). Localized dry and wet patterns facilitate these simultaneous operations. Further drip irrigation systems can be easily automated where labour is limited & expensive using simple automation equipment such as electrical, mechanical or battery operated time clocks that activate pumps and solenoid valves at selected time during the day.

2.3.6 Maintaining dry foliage
Dry foliage retards the incubation and development of many plant pathogens. Therefore, less frequent pesticide and fungicide application is required under drip irrigation and the chemicals are not washed from the leaves by irrigation water. An additional advantage of dry foliage is the avoidance of leaf burn when irrigating with saline water (Bernstein and Francois, 1975) and the possibility of using reclaimed sewage water without leaf and fruit contamination. Moreover, dry foliage eliminates direct evaporation loss of water from the canopy, although such evaporation is sometimes desirable for microclimate modification. Shelhevet et al. (1983) showed a 10% reduction in water loss due to avoidance of canopy wetting of potato by drip compared with sprinkler irrigation.

2.4 **POTENTIAL DISADVANTAGES OF MICROIRRIGATION**

Despite observed successes, several problems have been encountered in the mechanics of applying water with microirrigation equipment for some soils, water qualities and environmental conditions. Some of the more important possible disadvantages of microirrigation systems as compared to other irrigation methods include the following:

2.4.1 **Emitter clogging**

Emitter clogging is considered the most serious problem in drip irrigation unless preventive measures are taken (Bucks et al., 1977). Clogging will adversely affect the rate and uniformity of water application, increase maintenance costs (as it becomes necessary to
check, replace or reclaim clogged emitters), and result in crop damage and decreased yield if not detected and corrected early. Researchers and equipment manufacturers have chosen to solve this problem either by developing emitters which may require less maintenance (Solomon, 1977) or by improving the quality of water before it reaches the emitters (Nakayama et al., 1978; Bucks et al., 1977). However, all agree that preventive maintenance (including filtration, chemical water treatment, flushing dripper lines and field inspection) is probably the most effective solution to emitter clogging.

### 2.4.2 Mechanical damage

Damage to drip system is sometimes caused by man (implements and vandalism) or by animals (birds or mammals making holes in the laterals while searching for water). This damage may be partially prevented by covering the laterals and emitters with a shallow layer of soil, but by doing so, problems of clogging by roots may occur and furthermore, the performance of the emitters cannot be easily observed. Trapping, or repelling, the fauna or providing them with an alternative source of water is sometimes effective. Mechanical damage may also be induced by annual removal and subsequent installation of the laterals, by tillage implements or by thermal expansion and contraction, which may disconnect inline emitters.

### 2.4.3 Economic limitations

Because equipment requirements are numerous with microirrigation, initial investments and annual costs may be high. The
actual costs will vary considerably depending on the crop, grade of pipelines, filtration equipment, fertigation equipment and the degree of automation desired. Generally, the system was found to be economically viable in commercial field crops, vegetables, flowers, orchard & fruit crops. Microirrigation systems are generally not applicable to cereals and millets due to prohibitive initial system costs.

2.4.4 Operational constraints

High technical skills are required for the proper design and maintenance of drip irrigation systems. The filtration requirements are stringent and should be designed according to fluctuations in water quality. Careful monitoring of the filtration system, the operating pressures and the emitter flow rates is required. Drip systems have a limited buffering capacity because of the limited wetted root volume. Therefore, any malfunction of pumping, filtration, fertilizing or chlorination equipment or any leak in mains or laterals can have a disastrous consequence, if not corrected in a timely manner. This is especially true for a subsurface system, where the emitters are buried and any failures caused by clogging are difficult to observe and still more difficult to repair.

2.5 SYSTEM COMPONENTS

Much significant advancement has occurred in the design of components and microirrigation systems. The basic components of a microirrigation system can be grouped into three subsystems viz.,
control head unit, water carrier system and water distribution system besides a pumping station (Fig. 2.1).

**Fig. 2.1 : Layout of drip system**

- Head control unit – Non return valve, Air release valve, Vacuum breaker, Filtration unit, Fertigation unit, Throttle valve, Pressure gauge, Water meter, Pressure regulator and Pressure relief valve.
- Water carrier system – PVC main pipeline, PVC submain pipeline, Control valve, Flush valve and other fittings.
- Water distribution system – Drip lateral, Emitters, Micro sprinklers, Grommet, Start connector, Nipple, End Cap.

The water distribution system components vary depending upon the type of emitter device selected by the farmer to suit his soil and crop requirement. For example if the farmer is growing citrus or mango at wider spacing, drip system with online emitters is recommended. On the other hand if he is growing vegetable or field
crop like sugarcane or cotton crop with narrow spacing, integral dripline with line source emitters would be appropriate. In fruit crops with more than 10 years age spray irrigation viz., either micro sprinkler or micro jets may be advisable in view of adaptability problems with drip irrigation.

### 2.5.1 Emitters

Many different emitters have been devised and manufactured within the last decade. Some of the more distinctive designs are the short-path, long-path, short-orifice, vortex, pressure-compensating, self-flushing, perforated single and double - chamber tubing, as well as porous – tubing emitters (Solomon, 1977). These designs can be classified into two types, point source and line source. Point – source systems discharge water from individual or multiple outlets that are spaced at least 1 m apart. Line – source systems have perforations, holes, or porous walls in the irrigation tubing that discharge water at close spacings, or even continuously along a lateral line (Keller and Karmeli, 1975). Typically, point-source emitters are used for tree crops, vines, ornamentals and shrubs, whereas line-source emitters are used for small fruits, vegetables, or other closely spaced row crops. Better materials and manufacturing have improved extrusion and molding of point-source emitters. Multilayer bonding and laser techniques have enhanced the reliability of line-source emitters. A miscellaneous group of emitters (bubblers, low-head sprayers, spitters, foggers, etc.) can also be included, since they resemble both a point – source emitter and a small sprinkler.
Hydraulically, most emitter flow regimes can be characterized by the Reynolds number, \( Re \), defined as

\[
Re = \frac{v d}{\nu}
\]

Where \( v \) is the emitter flow velocity (m/sec), \( d \) is the emitter diameter (m), and \( \nu \) is the Kinematic viscosity (m\(^2\)/sec). Four flow regimes are defined as: (1) laminar, \( Re<2000 \); (2) unstable, \( 2000 \leq Re \leq 4000 \); (3) partially turbulent, \( 4000 \leq Re \leq 10,000 \); and (4) fully turbulent, \( 10,000 \leq Re \).

Keller and Karmeli (1974, 1975) and Howell and Hiler (1974) have suggested that the emitter flow function can be given as

\[
q = cH^e
\]

Where \( q \) is the emitter discharge rate (liters/hr), \( c \) is the emitter discharge coefficient that depends on the choice of units, \( H \) is the emitter pressure head (m), and \( e \) is the emitter discharge exponent that characterizes the flow regime. For fully turbulent flow, \( e = 0.5 \); for partially turbulent flow, \( 0.5 < e < 0.7 \); for the unstable flow regime, \( 0.7 < e < 1.0 \); and for laminar flow \( e=1.0 \). Short-orifice emitters are always fully turbulent, whereas long-path or other emitters may vary in flow characteristics.

Many manufacturers provide standard curves that show average emitter discharge rates for different operating pressure heads under laboratory conditions.

2.5.2 Distribution lines and Fitting
Distribution lines consist of a network of graduated pipe sizes starting with a single, large main line followed by smaller submain and lateral lines. The buried main and submain lines are normally of rigid polyvinyl chloride (PVC) pipe. They can also consist of lay-flat PVC pipe (temporary surface lines for row crops), asbestos-cement pipe (main line for tree crops), or polyethylene (PE) plastic (temporary surface lines for all crops). Main and submain lines range in diameter from 4 to 15 cm and should have valved outlets for periodic pipeline flushing. The submain line may also contain pressure regulators or flow control valves, manual or automatic control valves, secondary filters for final filtration or protection against pipeline breakage, or additional safety devices.

Lateral lines are usually of PE plastic and range in diameter from 8 to 25 mm, with the 14-mm size being most common. Early versions of PE tubing developed cracking problems, caused by polyaxial stress from the insertion of fittings that were larger than the inside diameter of the lateral, and/or by the thermal or chemical environment (Shipston, 1976). Stress cracks also developed where ends of PE lateral were closed off or crimped. Improved PE pipe extrusion techniques, the use of cross-linking methods and ultraviolet decomposition inhibitors, the proper sizing of barb fittings and the development of compression fittings have eliminated most of the problems. Also, polybutylene is sometimes used in place of PE for lateral lines to avoid stress cracking. Howell and Barinas (1980) have measured the pressure losses across emitters and fittings that are
inserted in lateral lines and have presented head loss curves for them in terms of equivalent lengths of pipe as a function of flow rate.

2.5.3 System control, Water measurement and Automation

The main control station for a trickle irrigation system consists of a pump, a backflow – prevention device, a primary filter, a pressure regulator (or automatic or mechanical flow control valves), pressure gauges, a water meter and sometimes automation and chemical injection equipment. Some of these components will be discussed in greater detail later in this chapter. The importance of installing a water measurement device on every trickle system has been too often overlooked. A water meter is needed to check initial designs, to manage or schedule irrigations and to monitor possible maintenance problems. Frequent measurement of the flow rate to various sections of the field facilitates detection of problems before they become serious. For example, a gradual decrease in flow rate may indicate a clogged secondary filter or emitter, whereas a sudden increase in flow could suggest a break in the distribution lines. Because discharge rates for trickle emitters are normally low, smaller capacity and less costly water meters can be used for trickle than for other traditional irrigation methods.

Trickle systems are readily automated. Single and multistation timers or controllers and related solenoid valves are easily installed to eliminate the work of turning water on or off manually. Filter back washing (Wilson, 1972) and lateral line flushing (Shearer, 1977) for
system maintenance can also be automated. Soil moisture sensors 
(Austin and Rawlins, 1977; New and Roberts, 1973) can be used to 
activate control systems. Sophisticated switching tensiometers were 
tested by Wendt et al. (1973). Phene et al. (1973) described the 
successful use of a soil matric potential (heat-dissipation) sensor to 
automate trickle irrigation systems. Pan evaporation measurements 
(Busman and Fangmeier, 1979; Phene and Campbell, 1975) have also 
been used with trickle irrigation systems. Mears et al. (1979) 
developed a microprocessor based controller for automatic trickle 
irrigation. Future trickle irrigation systems will probably use 
microprocessors that monitor not only soil moisture, but also 
hydraulic pressure, flow rate, chemical injection rate and weather 
data.

2.6 SYSTEM DESIGN AND EVALUATION

Before any system is installed, the hydraulic design should be 
adequately evaluated and the emission uniformity continually 
evaluated for assuring maximum economical and efficient operation.

2.6.1 Hydraulics

The flow regime throughout a trickle irrigation system is 
hydraulically steady, spatially varied pipe flow with lateral outflows. 
The total discharge in the distribution network (Lateral, sub main and 
main lines) decreases with respect to distance from the pump. The 
lateral and submain have similar hydraulic characteristics and are 
designed to maintain a small pressure variation along the lateral line.
The main line is designed in terms of input pressures and minimal required pressures at any submain line. Trickle design principles are similar to those developed for sprinkler irrigation systems except that the flow rates are lower and the number of outlets (sub mains, laterals and emitters) is larger.

Trickle irrigation distribution lines are normally considered to be smooth pipes, and either the Darcy–Weisbach or Hazen–Williams equation can be used to compute friction losses for the pipelines.

The Darcy–Weisbach equation is

$$ H_f = 6.38fLD^{-5}Q^2 $$

Where $H_f$ is the pipe friction loss (m), $L$ is the pipe length (m), $D$ is the inside pipe diameter (mm), $Q$ is the pipe flow rate (liters/hr), and $f$ is a dimensionless friction factor. An acceleration of gravity of 9.81 m/sec$^2$ was assumed in this equation. Watters and Keller (1978) proposed a simplified form of $H_f = 6.38fLD^{-5}Q^2$

$$ H_f = 0.465LD^{-4.75}Q^{1.75} $$

Equation $H_f = 0.465LD^{-4.75}Q^{1.75}$ incorporates a friction factor estimated from the Blasius equation for smooth pipes with a water temperature of 20°C ($\nu = 1.0 \times 10^{-6}$ m$^2$/sec).

The empirically developed Hazen–Williams equation is

$$ H_f = 0.628 \cdot LD^{4.865} \cdot [(100Q)/C]^{1.852} $$

Where $C$ is a dimensionless pipe roughness factor. Equation $H_f = 0.628 \cdot LD^{4.865} \cdot [(100Q)/C]^{1.852}$ is widely used because of its simplicity, although it has no correction for viscosity. Care should be taken in
selecting the C values. Hughes and Jeppson (1978) showed that the selection of the proper C for \( H_f = 0.628 \, LD^{4.865} \, [(100Q)/C]^{1.852} \) obviously depends on the Reynolds number \( Re \); and Howell et al. (1980) suggested that the best C values for trickle irrigation systems were C = 130 for 14-15 mm pipe, C = 140 for 18-19 mm pipe, and C = 150 for 25-27-mm pipe. A low estimate of C will overestimate the friction loss, whereas a high estimate will result in more conservative friction loss for design purposes.

Pressure variations along a trickle irrigation line are primarily due to friction and slope. Numerous publications and books describe the basic principles, procedures and details for proper sizing of trickle irrigation pipelines (Baars, 1976; Keller and Karmeli, 1975; Howell et al., 1980; Wu et al., 1979) present design charts for lateral, submain and main lines for different field slopes, shapes and pipe sizes along with design examples. Some of the more recent developments in trickle irrigation hydraulics are as follows; Bresler (1978) introduced a design procedure using both soil water flow models and hydraulics; Keller and Karmeli (1974) developed a compact “polyplot” design technique for tapered submains; Braud and Soom (1981) introduced design equations including both emitter and pipeline hydraulics; and Wu and Gitlin (1981) developed double – inlet and inflow – outflow systems using network design principles.

Steady and nonsteady infiltration models (Bresler, 1978) were used to calculate the desired spacing between emitters as a function of their discharge, soil hydraulic properties and crop sensitivity to
water stress. Ideally, trickle irrigation systems should be designed with emitter spacings and discharge rates such that small depression ponds of less than 0.2 m in diameter will develop beneath or around an emitter without runoff or down slope channelization.

Varying the size of submain lines gives the designer an opportunity to reduce costs, investigate alternate designs and develop site-specific designs (Keller and Karmeli, 1974). Design equations in a form that include emitter characteristics (emitter exponent, emitter variability, etc.) as well as lateral line hydraulics (length, diameter, land slope, etc.) are being developed for analysis by programmable digital calculators (Braud and Soom, 1981). Multiple-inlet systems can be designed with a combination of double-inlet (inflow from both ends of a lateral line from two submains) and inflow – outflow (inflow from a submain to a lateral line with out flow to the next submain line) in a total network design (Wu and Gitlin, 1981). This type of design can permit any length of lateral in varying field shapes and terrain. As a general recommendation, lateral lines should seldom be more than 300 m long and should be laid down slope for less than 5% slopes. If the slope exceeds 5%, laterals should be installed along the field contour, pressure compensating emitters specified, or pressure control devices installed.

Uniformity of water application along lateral lines can also be improved by changing emitter sizes (Myers and Bucks, 1972). The fixed emitter characteristics are normally adequate from a hydraulic standpoint for level terrain.
2.6.2 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 emitter flow variation for a trickle irrigation unit or subunit. Emission uniformity can be a function of: (1) hydraulic variation caused by evaluation 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. Presently, no design equation has been developed that includes all the factors which might affect emission uniformity.