# PERFORMANCE EVALUATION OF MICRO-IRRIGATION DEVICES

**By**
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# Declaration

I hereby declare that this thesis entitled "**Performance evaluation of micro-irrigation devices**" is a bonafide record of research work done by me and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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# Certificate

Certified that this thesis entitled "**Performance evaluation of micro-irrigation devices**" is a bonafide record of research work done by Jacob Bijo Daniel and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title to him.

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*"In my distress I called upon the LORD, and cried unto my God: he heard my voice out of his temple, and my cry came before him, even into his ears"*

(PSALM 18:6)

*"Therefore will I give thanks unto thee, O LORD, among the heathen, and sing praises unto thy name"*

(PSALM 18:49)

**JACOB BIJO DANIEL**

# Dedicated to …

# My Beloved

# Pappa,

**who’s longing gave me the momentum all the way through**

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## Symbols and Abbreviations

| | |
|---|---|
| ASAE | American Society of Agricultural Engineers |
| BIS | Bureau of Indian Standards |
| cm | centimetre(s) |
| $cm^2$ | square centimetre(s) |
| COV | Coefficient of variation |
| CUC | Christiansen's uniformity coefficient |
| Da | mean (average) application depth |
| DC | Distribution characteristic (Merriam and Keller) |
| Dx | maximum application depth |
| *et. al.* | and others |
| Fig. | Figure |
| Ha | hectare |
| hp | horse power |
| hr | hour(s) |
| k | kilo |
| KCAET | Kelappaji College of Agricultural Engineering and Technology |
| $kg/cm^2$ | kilogram per square centimetre |
| lph | litre(s) per hour |
| m | metre(s) |
| mm | millimetre(s) |
| mm/hr | millimetre(s) per hour |
| Pa | pascal |
| R | radius of throw (wetted radius) |
| Tab. | Table |
| % | one hundredth (percentage) |
| < | less than |
| > | greater than |
| ø | diameter |

# Introduction

# INTRODUCTION

In the areas of inadequate rainfall, irrigation plays a prominent role in promoting higher yields and thus leading to better productive use of agricultural land. Average yields under comparable climatic conditions are generally higher in irrigated conditions than under rainfed conditions. Modern technology inputs for agriculture are productive but costly and therefore create a need for good soil moisture regime to support optimum crop growth and reduced risk of failure. Farmers are becoming more aware of irrigation as a tool for optimising production. When all other management practices are carried out efficiently, irrigation can help the farmers to achieve the top yields and quality demanded in today's market.

In the age-old practice of irrigation an over all efficiency of only 30-35% can be achieved; it also causes water logging, salinity etc. The low efficiency may be accounted for, in part by conveyance losses due to seepage, evaporation and non-beneficial use by pretophytes. The losses are partly the result of non-uniform distribution of water due to inadequate land preparation and lack of proper technique in the application of water, with consequent excess applications and deep percolation.

## 1.1. Modern methods of irrigation

Irrigation as a modern science is the science of survival. So as to efficiently apply water, advanced methods of irrigation like sprinkler and drip are adopted. Micro-irrigation has proven to be a very efficient irrigation method, in the recent years. By reducing losses and introducing irrigation systems with uniform low application rates, more cultivable land can be brought under irrigation using the saved water.

Sprinkler irrigation is a pressurized irrigation system which tends to simulate the rainfall, in such a way that the runoff and deep percolation losses are minimised and the uniformity of application is close to that which could be obtained under rainfall conditions. This system is very well suited to closely spaced crops, sandy soils where the vertical water distribution is more than the lateral distribution resulting in high percolation and seepage losses and undulating terrains where it is costly to level the land for surface irrigation.

Micro-irrigation is a broad term that includes pressurized micro-sprinkler/ micro-sprayer/ micro-jet and drip/ trickle systems. Solid set high frequency micro-irrigation provides a way to deliver water to fruit trees that has distinctly different characteristics compared to more traditional methods of irrigation. These characteristics have been used to solve specific problems such as high salinity of irrigation water, difficulty in application of fertilizer or pesticide and adjustment of water shortage.

**1.2. Micro-sprinkler irrigation**

Micro-sprinkler is a low volume sprinkler. Micro-sprinkler irrigation system combines the advantages of the conventional sprinkler system and the modern drip irrigation system. It requires lesser energy than sprinklers and is less susceptible to clogging than drip emitters. It has lower cost of installation than drip system as number of laterals and emitter points are reduced. The cost of micro-sprinkler emitters is very less compared to high-pressure sprinklers. It has much larger area of coverage than drip emitters. In micro-sprinkler irrigation, the plant root system develops evenly due to the larger volume of wetting of the soil than in drip system; resulting in a denser spreading of roots throughout the wetted soil volume. This ensures better supply of water and nutrients to the plant and better anchorage. Micro-sprinkler system has a wide range of applications in fertigation, herbicide application, frost protection, green house and poultry house cooling, etc. The system can be run continuously or intermittently to get the desired rate of application.

Overall system pressure and volume of flow of micro-sprinkler irrigation system will be higher than that of drip irrigation system. It is now possible to incorporate small flow regulators into micro-sprinklers that convert each sprayer into a pressure compensated outlet. This can reduce the application rate and system cost and can deliver better uniformity of irrigation.

**1.3. Uniformity of irrigation**

Ideally, an irrigation system should apply water in a completely uniform manner so that each part of the irrigated area receives the same amount of water. Unfortunately, there seems to be no present way to achieve this. Even natural rainfall is not completely uniform. So the phrase "irrigation uniformity" actually refers to the variation, or non-uniformity, in the amounts of water applied to locations within the irrigated area. Significant effort in irrigation system design and management is directed towards dealing with problems related to irrigation uniformity, or the lack of it.

A micro-sprinkler with water distribution uniformity below acceptable levels will produce over-irrigated and under irrigated areas within its wetted area. This will lead to deep percolation and runoff losses from the over-irrigated areas and may cause water stress for the plants in the under irrigated areas. Studies showed that the optimum irrigation amount, crop yield and engineering costs related to a micro-irrigation system are dependent on the irrigation uniformity. In order to make economically sound micro-sprinkler irrigation design decisions, it is important to be able to measure and predict the uniformity of application.

Irrigation uniformity is also inherently linked to the efficiency with which agricultural resources are used. Since non-uniformity results in the application of excess water, several water-related resources are also lost. These include: energy for pumping the excess water; fertilizers; either applied with the irrigation water or leached by the excess water; other chemicals which may be applied with or washed away by the water; and capital losses due to the extra capacity designed into the irrigation and drainage systems to carry the excess water. As non-uniformity causes crop yield to fall below potential levels, agricultural inputs applied in anticipation of full yield are also wasted.

### 1.4. Evaluation of devices

High uniformity is important for proper irrigation, especially on sandy soils where the lateral re-distribution of water is limited. Excess application of water on these soils often results in deep percolation of water and leaching of nutrients out of plant’s root zone. High uniformity in application is necessary for fertigation and chemigation.

Usually manufacturers of micro-sprinklers are providing very little information about their sprinkling devices. This makes the selection of micro-sprinklers and their operating conditions difficult, during the design of an irrigation system. Most of the micro-sprinklers now available in the market are seldom tested by someone other than the manufacturers. Usually the manufacturers give only the discharge and radius of throw of the emitters at different pressures.

The examination of micro-sprinkler water distribution pattern is required for development of new prototypes, manufacturer’s quality control and sprinkler evaluation by consumer organizations. The last two applications, in particular require routine testing of a large number of sprayer - pressure combinations. Uniformity is an indicator of the equality (or inequality) of the application rates within the pattern diameter of an emitter.

The devices should be tested before field installation to verify the quality of the emitters. Moreover, such tests will help the manufacturers to improve the design (and thus performance) of their products and the end users will get a general guideline for the selection of such products. The information on the effects of operating pressure on uniformity and flow rate is vital for designers and operators of micro-irrigation system to enable a perfect match of emitter performance to the soil and crop irrigated.

**Objectives**

The objectives of the present study may be listed as follows,

1. To analyse the pressure-flow rate relationship of different micro-irrigation devices.
2. To determine the different performance parameters of the emitters with respect to the uniformity of application.
3. To analyse the distribution pattern of various emitters operated at different operating pressures.
4. To analyse the various performance parameters to determine the relative performance of the emitters and to analyse the credibility of manufacturers claim.

# Literature Review

# REVIEW OF LITERATURE

Farmers have always sought ways to supply the crops with water necessary for their development, when rainfall was inadequate. Rapid increase in the world population has made the efficient use of irrigation water vitally important, particularly in poorer countries, where the greatest potential for increasing food production and natural income is often through irrigation. Therefore it is necessary to adopt effective irrigation methods that are economically viable, technically feasible and socially acceptable. Micro-irrigation falls under this category, especially for widely spaced high value crops like coconut, grape, orange, citrus etc. and commercial crops like sugarcane, cotton, ornamental plants etc.

## 2.1. Micro– irrigation

Micro–irrigation is the frequent application of small quantities of water directly on or below the soil surface. Usually water is applied as discrete drops, continuous drops, tiny streams or miniature spray through devices placed along a water delivery line (BIS, 1987 a).

Micro–irrigation may be described as a method of applying low volumes of water directly to the root zone of the crop and limiting it to the root spread volume of the soil layer. Micro-irrigation systems are typically designed to wet only the root zone and maintain this zone at or near an optimum moisture level (James, 1988).

### 2.1.1. Classification

Micro–irrigation systems include low pressure, low volume irrigation systems and can be subdivided in to four main methods according to pressure and volume (Barret, 1979). Drip irrigation applies water directly to the soil surface or subsurface and allows the water to dissipate under low pressure in a pre–determined pattern. The other three methods viz., Mist, Sprayer and Mini sprayer methods that convey water through the air can be termed as micro-sprinkler systems. The wetted area of these emitters is small, can be controlled fairly easily and has different shapes to match the desired distribution patterns.

Micro–irrigation spray and spinner emitters were characterised by Post *et al.* (1985) as devices having operating pressure less than 2 $kg/cm^2$, discharge rates in the range of 20 to 100 lph and throw diameters ranging from 1.5 to 10 m. Losses due to surface evaporation and deep percolation are avoided in this method. The system is limited to water scarce areas and is largely confined to fruit crops, plantation crops, widely spaced vegetables etc. (Walker and Skogerboe, 1987)

## 2.2. Evolution and development of micro-irrigation

The concept of micro-irrigation though simple, was not practiced widely until very recently due to lack of economic materials. The first experiments leading to the development of micro–irrigation were introduced by German researchers in 1860. They pumped irrigation water in to short clay pipes with open joints used for under ground drainage, to maintain a water table near the plant root zone. In the 1920’s porous pipe and canvas was used for subsurface irrigation at Michigan State University, and subsequent experiments were centred on development of perforated pipes made of various materials and on control of flow through the perforations (Bucks and Davis, 1986).

### 2.2.1. Trickle irrigation

The discovery of high-density polyethylene (HDPE) in 1948 made the break through for micro-irrigation. A significant step in the evolution of trickle irrigation took place in Israel in the late 1950’s when long path emitters were greatly improved. By the early 1960’s plastic pipe micro–irrigation systems were being used extensively in greenhouses in most commercial enterprises. Drip irrigation was first tried on a commercial scale for vegetables in Israel, in

1960's in the Arava Valley. In 1969, the first research and demonstration study of micro-irrigation was initiated on an avocado orchard in California (Gustafson *et al.*, 1974). Around that same time, field trials were conducted using surface micro-irrigation on strawberries and tomatoes, also in California (Hall, 1985).

It soon became apparent that drip irrigation almost doubled the yields. The large scale and commercial use of micro-irrigation began in the late 1960's and early 1970's. Numerous inventors and companies began developing drip irrigation emitters, and by mid 1970's well over 250 emitter devices were being marketed.

The interest of micro-irrigation was most keen in Israel, USA and the Middle East since these areas have traditionally suffered shortage of irrigation water.

### 2.2.2. Micro-sprinkler

Micro–sprinklers are small volume sprinklers that operate at low pressures. The concept of micro-sprinklers was materialized in the beginning of 1980's as an improvement over the drip irrigation system, by replacing the trickle emitters by low volume, low pressure sprinklers in the drip irrigation network. They have been introduced to the world of irrigation by fusion of the peculiarities of drip irrigation and sprinkler irrigation methods.

Although sprinkler irrigation and drip irrigation methods are adaptable means of applying water to any crop, soil and topographic conditions, each of these methods has its own demerits also. The micro-sprinkler system combines the merits of both the systems and avoids most of the demerits.

Micro-sprinkler irrigation is a versatile means of applying water. The design principles are similar for micro-sprinkler and the trickle systems (Cuenca, 1989).

Demand for the micro-sprinklers increased greatly when it was found they could provide frost and freeze protection. New citrus planting during and after the severe freezes of the 1980’s made Florida one of the fastest growing markets for micro-sprinkler irrigation between 1985 and 1990. (Smajstrala, 1995)

### 2.3. Growth of micro–irrigation

A survey conducted by the International Commission on Irrigation and Drainage (ICID) indicated that about 1,770 kHa were under micro-irrigation through out the world (Bucks, 1995). The largest use of micro-irrigation was in the United States, where the area has expanded from approximately 4 kHa, in 1972 to over 1 million Ha, in 1994.

There has also been extremely rapid growth in Spain, where the micro irrigated area has increased from 10 kHa, in 1975 to 160 kHa, in 1994.

The main reasons for converting to micro-irrigation were indicated as follows: (1) water and labour were expensive (2) the water supply was limited (3) the water supply was saline (4) the use of conventional irrigation methods was difficult especially in hillside orchards. (5) landscape and greenhouse irrigation required water conservation and (6) improved yield or quality demand, which could only be satisfied with use of micro–irrigation methods (Anonymous, 1995). Application of micro–irrigation for landscaping, greenhouses and nurseries has also increased tremendously and includes ornamental trees and shrubs, ground covers on highway road sides and residential properties, citrus nurseries, forestry trees and others.

#### 2.3.1. Status and scope in India

The farmers of the country are convinced of the usefulness of the system, and the system has emerged as a suitable water-saving and production augmenting technique, especially for widely spaced high value crops in water scarce, undulating sandy or hilly areas. Although research and demonstrations of the system have been in progress from 1970, large-scale adoption has taken place only for last 10 or 15 years (Sivanappan, 1998).

The development of micro-irrigation in many states is very spectacular due to the encouragement provided by the government and promotional efforts by the manufacturers.

The farmers are forced to take up the system since water has become scarce commodity in the states of Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Gujarat and Rajasthan. For example, in Kerala, the coconut and other plantation crops need water during the dry period of January to May and the farmers are installing micro–irrigation systems to manage the shortage of water. They are now convinced that the systems help to get more yields with less input, apart from saving of water.

#### 2.3.1.1. Adoptability constraints

The difficulties experienced in bringing large areas under this method are high initial cost, clogging of the devices, lack of adequate technical knowledge and inputs, high cost of spares and components and insufficient extension efforts.

Puranic and Gaonkar (1992) investigated the constraints and problems of micro–irrigation systems for both adopter and non-adopter farmers. Major constraints to adoption included heavy initial investments, lack of knowledge support, cost and time involved in the maintenance of the system etc. The author suggests that extension agencies, concerned departments and manufacturers must all concentrate on alleviating these problems.

## 2.4. Advantages and disadvantages of micro-irrigation

Micro-irrigation has advantages and disadvantages, the system must be tailored to specific field and water conditions before success will be achieved. Careful attention to irrigation system design and management can make the most of these advantages and often can compensate for the disadvantages as well.

### 2.4.1. Advantages

Obvious advantages of micro-irrigation include a small wetted surface area, minimal evaporation and weed growth, and potentially improved water application uniformity within the crop root zone by better control over the locations and volume of application (Hoffman and Martin, 1993).

The benefits of using micro-irrigation can be listed as,

1. Low application rates - frequent light irrigation or controlled supplementary irrigation - minimal runoff and seepage losses.
2. Higher uniformity of water application - increased efficiency.
3. Exact water placement through the network – reduced weed growth.
4. Controlled root zone environment – reduced overall water requirements.
5. Successful performance in difficult terrains/ rolling topography.
6. Suitability to problem soils and improved tolerance to salinity.
7. Water and energy conservation.
8. Improved chemical application – fertilizers, pesticides etc. can be applied along with the irrigation water itself.
9. Maintenance of optimum soil moistures levels – increased yield and improved quality of products.
10. Diversified uses (Irrigation, greenhouse/ poultry house cooling, frost protection etc.)
11. Ease of automation - less labour requirement and improved precision of irrigation scheduling.

### 2.4.2. Disadvantages

Micro-irrigation has several disadvantages, which can often be overcome by proper system design and management. Individuals considering micro-irrigation should weigh the economic cost against the economic benefits.

Micro-irrigation systems require more maintenance than traditional irrigation systems. The small water flow passageways characteristic of micro-irrigation systems can easily plug. Proper preventive measures can minimise or eliminate this disadvantage. The quality of the irrigation water may affect the micro-irrigation system. The type of water quality problem is somewhat dependent on whether the irrigation water comes from a surface source or a well. In both cases, adequate filtration and chemical treatment is required to prevent emitter plugging. If the source of water is a well, chemical precipitation is the most common problem. If the irrigation water is from a surface source, biological plugging is the most common. Nakayama and Bucks (1986) gives an account of the disadvantages of micro-irrigation compared to conventional systems.

However, micro-sprinkler systems have less clogging problem compared to drip irrigation systems due to the higher pressure of operation, bigger orifice sizes and mechanical movement.

## 2.5. Micro-sprinkler irrigation system

Micro sprinkler is a small sprinkler that works under low operating pressure, sprinkling low volume of water at a low rate that is allowed to fall back either on the canopy or soil surface, covering part of the area allotted to each plant. Here the distribution of water occurs through the medium of air compared to drip and bubbler irrigation where the distribution occurs due to the water movement through the soil.

Spray or spinner micro sprinklers are often preferred over drip systems since they provide a larger diameter wetting pattern. This characteristic is especially desirable in areas with coarse textured soils where lateral movement of water in soil is limited (Boman, 1989). The greater coverage diameter allows a larger percentage of the root zone to be wetted by the irrigation and can result in greater soil moisture reserve and better root development. The larger wetting patterns of spinner and spray emitters also provide advantages when the irrigation system is used to apply herbicides and fungicides or fertilizer.

Micro–sprayer emitters have low precipitation rates, which typically are, less than 4 mm/hr. Thus by applying the right amount of water at the correct irrigation rate, there will be no seepage beyond the root zone, nor the problem of decreased aeration in the root zone, caused by water logging (Chaya and Hills, 1991).

In situations where root system develops according to the natural rainfall, only the micro-sprinkler irrigation system, with its modular design and wide range of operation, is capable of supplying the required quantity of water and nutrients accurately and efficiently to the already developed root system. Considerable saving in water will result in going for micro-sprinkler irrigation system. They wet only 40 to 80% of the soil surface in a mature orchard. The area wetted by the micro-sprinkler can be adjusted according to the development of the root system.

### 2.5.1. Adaptability

Besides the adaptability over a wide range of soil, crop and topographic conditions, some other objectives that can be attained using micro-sprinklers are,

1) Effective use of small, continuous streams of water such as from springs and small tube or dug wells.
2) Proper irrigation of problem soils with inter-mixed textures and profiles or the irrigation of shallow soils that can not be graded without detrimental results.
3) Irrigation of steep rolling topography without producing runoff or erosion.
4) Effective, light and frequent watering may be possible whenever needed.

5) The micro-sprinklers are highly adapted to water sensitive crops where wetting of upper portion of the plant is undesirable.

Davies *et al.* (1988) details the special adaptability of micro-sprinkler systems to difficult situations.

### 2.5.2. Comparison

The concept of micro-sprinkler was made by fusing the advantages of conventional sprinkler and modern drip irrigation system. The micro-sprinklers are generally used for under-tree sprinkling in orchards and for widely spaced crops. The wind drift losses are very less compared to conventional sprinkler system due to shielding by the canopy and lesser wind velocities near the ground.

In conventional sprinklers, large droplets having higher kinetic energy disrupt the soil surface causing reduced infiltration rate due to crusting (Dadiao and Wallender, 1985). This does not occur while using micro-sprinklers, thus preventing losses by runoff, and they apply the right quantity of water only, so that no anaerobic condition is developed within the root zone.

Compared to other methods of irrigation (conventional surface irrigation methods) the micro-sprinkler system has proved to be efficient, water, energy and labour saving, trouble free and economical. Saving due to micro-sprinkler is reported to be the extent of 30 to 60% over traditional methods of irrigation (Mane *et al.*, 1987 and Bankar, 1992). This is due to the partial wetting of the soil volume, reduced runoff and controlled deep percolation losses. The water use efficiency reported under micro-sprinkler system was well above of that under other systems evaluated (Shinde, 1995).

The micro-sprinklers are generally operated at a pressure range of about 1-2 $kg/cm^2$ (100 to 200 kPa), which is very low as against the high pressure operation of conventional sprinkler systems and comparatively high as compared to the operation of drip irrigation systems. Obviously, considerable saving in pumping energy can be attained with micro-sprinklers over conventional systems. The combined effect of larger nozzles (as compared to the tiny openings and small water flow passageways of drip system) and higher-pressure operation minimises the chance of clogging. Thus use of expensive and sophisticated filtration equipments may be avoided except for highly sedimented irrigation water. Singh and Singh (1990) states that micro-sprinklers require lesser energy than conventional sprinklers and are less susceptible to clogging compared to drip emitters.

The canopy to active root ratio is much better under micro-sprinkler than drip irrigation system. Roots of the drip-irrigated trees are concentrated in a shallow, small volume of soil under the dripper, where as a large number of roots penetrated to depth of 70-80 cm in areas irrigated by micro-sprinklers.

Since visual inspection of the micro-sprinkler system is simple and fast, less time is required than for the inspection of several emitters per tree in a drip irrigation system. Micro-sprinklers are also superior to other systems on marginal land and for the use of marginal or saline irrigation water.

The only obvious disadvantage associated with micro-sprinkler irrigation system, as compared to the drip system, is the enhanced weed growth caused by the larger area of wetting, which can be solved by the use of herbicides along with irrigation water.

## 2.6. Irrigation efficiency

Irrigation efficiency indicates how efficiently the available water supply is being used, based on different methods of evaluation. The design of the irrigation system, the degree of land preparation, and the skill and care of the irrigator are the principal factors influencing irrigation efficiency (Michael, 1978). Loss of irrigation water occurs in the conveyance and distribution system, over the field by non-uniform distribution of water, below crop rootzone by percolation; and with sprinkler irrigation, by evaporation from the spray and retention of water on the foliage. In case of large fields loss may occur by runoff at the end of irrigation borders and furrows. The losses can be held to a minimum by adequate planning of the irrigation system, proper design of the irrigation method, satisfactory land preparation and efficient operation of the system.

In micro-irrigation system no conveyance losses occur since the irrigation water is conveyed through pipes. Losses due to runoff, percolation and evaporation are less, due to low application rate and precision application. In the case of micro-sprinkler system the wind-drift losses and evaporation from foliage is very less due to under the canopy operation. So the irrigation efficiency can be expressed as the application efficiency (ratio of the amount of water applied to the root zone to the amount discharged by the system). Thus for a micro-sprinkler irrigation system, the irrigation efficiency will depend up on the degree of uniformity with which the emitter delivers water to the irrigated/ wetted area.

### 2.6.1. Irrigation uniformity

An important component of the evaluation of the irrigation performance is the measurement of irrigation uniformity. Specific quantitative study of sprinkler irrigation uniformity began with the pioneering work of Christiansen in 1942.

Studies show that the optimum irrigation amounts, crop yield and engineering costs related to a micro–irrigation system are dependent on the irrigation uniformity. The level of irrigation uniformity can be used as an indicator to describe the performance of the irrigation system. Chen and Zhen (1995) determined the importance of irrigation uniformity in the design of micro-irrigation system by analysis the relationship between crop yield and water consumption and between irrigation uniformity and engineering costs.

#### 2.6.1.1. Agronomic importance

As Burt (1998) points out, if a volume of water applied to a field is known only as the average applied over the whole field, then one half of the field has received less than the average applied and the other half, more than the average applied. Insufficient water leads to high soil moisture tension, plant stress and reduced crop yields. Excess water may also reduce crop yields below potential levels through mechanisms such as leaching of plant nutrients, increased disease incidence or failure to stimulate growth of commercially valuable parts of the plant. Thus a major aim of irrigation management should be to apply water with a high degree of uniformity while keeping wastage to a minimum.

The ability of a micro-sprinkler system to apply water uniformly throughout the irrigated area is a major factor determining whether or not proper crop growth can be maintained.

#### 2.6.1.2. Engineering importance

Significant effort in irrigation system design and management is directed towards dealing with problems related to irrigation uniformity, or lack of if. A non-uniform irrigation unavoidably results in some degree of under and over watering. Hence, if the average volume applied is the target application required to meet the crop requirements, one half of the field has been over-irrigated, reducing the efficiency of application, while the other half of the field has been under-irrigated, reducing yield.

Since irrigation uniformity relates to crop yield and efficient use of resources, engineers regard it as an important factor to be considered in the selection, design and management of irrigation systems (Solomon, 1988).

#### 2.6.1.3. Economic importance

Kunde (1985) compared investment costs, water costs and power costs for nine micro-irrigation designs. Initial investment costs increased with uniformity, while water and power costs decreased. The water and power cost savings were more than enough to payback the increased cost of higher uniformities. In agricultural areas with higher water and power costs, the savings due to improved efficiencies would be even higher.

**2.7. Performance evaluation**

In a purely volumetric sense, the efficiency of the system should be determined as the ratio of the water used by the plant to the water input. While the ultimate volumetric output of the irrigation system is the water used by the plant, the output product from the whole farming system is commonly viewed as the marketable crop of economic returns. While it is possible to argue that the efficiency of water should not be defined in terms of crop yield produced or value obtained, such gross indicators are of most practical interest to commercial irrigators (Dalton and Raine, 2000).

Since irrigation uniformity is an important component of the evaluation of in–field performance and the determination of application efficiency often involves the crop yield produced or value obtained at the farm level; the performance of single non-overlapping micro-sprinkler systems can be evaluated on the basis of irrigation uniformity measures, in a purely technical sense. The performance of micro-irrigation is heavily influenced by the uniformity of application. Since the uniformity of distribution of irrigation water applied by a micro-sprinkler is the primary factor that determines the application efficiency, a measure of the distribution uniformity can better describe the performance of the system.

**2.7.1. Catch-can test**

The technique of catch-can testing is the suitable method for the performance evaluation of spray-type irrigation systems. ASAE (1991), ASAE (1997) and BIS (1987 a, b) describe the general procedure of catch-can testing and other standard methods of testing of sprinkler systems.

The performance of micro-sprinkler systems has been assessed commonly using catch-can methods with the cans placed in full wetted area or part (one quarter) of the wetted circle (Boman, 1989; Pandey *et al.*, 1995 b; Post *et al.*, 1985).

### 2.7.2. Performance indicators

A large number of indices for the assessment of irrigation performance have been proposed. Willardson (1972) stated that at least 20 definitions of irrigation efficiency existed at that time.

It is difficult to adequately evaluate irrigation performance using a single parameter. Hart (1972) suggests that it is necessary to use three efficiency terms and one distribution uniformity term to adequately describe the hydraulic performance of an in-field irrigation system. However, Walker (1993) used two efficiency and two uniformity indices while Connellan (1994) used only one efficiency and one uniformity term. At the system or whole farm level, a range of performance parameters may be appropriate depending on the spatial and temporal boundary conditions established for the evaluation (Dalton and Raine, 2000). Many irrigation workers and manufacturers of irrigation equipments use only a single term.

Different performance indicators (dimensionless coefficients) are used to describe the individual performance of micro-sprinkler. A wide range of irrigation uniformity coefficients are commonly used in performance evaluation (Jensen, 1983). The different coefficients and methods used for the evaluation of the performance of micro-sprinkler are uniformity coefficient, (UC), distribution uniformity (DU), coefficient of variation (COV), distribution characteristic (DC), distribution pattern (or densogram) and scheduling coefficient (SC).

#### 2.7.2.1. Uniformity Coefficient

One of the basic measures of any irrigation system's performance is Christiansen's (1942) uniformity coefficient, CUC. Christiansen defined the uniformity coefficient as, CUC = 1 – (D/M) ; where D in the average absolute deviation of irrigation amounts, and M is the average irrigation amount.

Although some modifications are also suggested to this relation, CUC is still used as a powerful tool for evaluating the performance of irrigation systems. The modification suggested (which incorporate the standard deviation of the irrigation amounts) are UCW and UCH.

UCW = 1 – (S/M) and

UCH = 1 – (0.798 S/M) ; where S in the standard deviation of irrigation amounts.

One of the limitations of the CUC calculation is that it treats under-watering and over watering the same.

#### 2.7.2.2. Coefficient of Variation

The coefficient of variation, COV of application depths for a particular emitter is calculated by dividing the standard deviation of the depths by the mean of the depths. Since COV is a measure of the deviation of individual depths compared to the average depth, higher values of COV describe poor performance of the system and vice versa. COV is expressed as a percentage.

Boman (1989) evaluated several micro-irrigation emitters to determine their uniformity of distribution. The coefficient of variation of catch depths was selected as the primary performance indicator for the study. The author states that the COV is independent of the scale of measurement, and thus allows dimensionless comparison of variability for emitters with different flow rates. The COV values less than 100 can be considered as good water distribution and values over 200 indicate patterns that have a large portion of the effective area that receive no water. These high COV’s may also signify that the pattern has areas with very high application depths relative to the mean.

#### 2.7.2.3. Distribution Uniformity

The distribution uniformity coefficient (DU) is also widely used for spray systems. It takes into account of the variation of can readings from the mean but concentrates only on the lowest 25% of the readings. The range of DU values for sprinkler distributions will be similar to CUC; however, due to method of calculation, DU will generally be lower. For example, for a system with CUC of 85%, DU will be approximately 78% (Connellan, 1994).

The distribution uniformity coefficient is usually used by turf engineers who often combat with dry spots in the irrigated area, rather than well-watered or wet spots. The use of the ‘lowest 25%’ is purely arbitrary and bears no relationship to the crop’s growing characteristics.

#### 2.7.2.4. Distribution Characteristic

Unlike impact sprinklers, micro-irrigation emitters generally are located in the field with non-overlapping patterns on widely spaced plants. Merriam and Keller’s (1978) distribution characteristic (DC) is the standard method for evaluation for non-overlapping sprinklers. The DC is defined as the ratio of the area that receives more than half of the average application to the total wetted area, expressed as a percentage. The authors suggested that DC value greater than 50% are probably satisfactory and that very good patterns result with DC values greater than 66%.

Although DC is the standard method for evaluation for non-overlapping sprinklers, other methods are also used either singly or in combination with one another. Post (1986) recommended using additional performance indicators in addition to DC in order to better characterise the emitter performance. The coefficient of variation was the indicator suggested by him.

#### 2.7.2.5. Scheduling Coefficient

The scheduling coefficient, SC is a number that relates to the uniformity of coverage and how to operate the system to adequately irrigate the whole area, often used by the turf engineers for over-lapped patterns. Determination of SC requires costly computer software like *SPACE* (Sprinkler Profile And Coverage Evaluation) or *Hyper-SPACE* which uses a sliding window technique to cover the sprinkler pattern area. The software averages the application values falling within the window. The window-averages are then reviewed to identify the driest window, and then the runtime of the system is increased such that adequate irrigation (amount equal to the mean depth or the target application) is provided to the driest window of the coverage area.

#### 2.7.2.6. Distribution pattern and densogram

The distribution pattern or spray coverage pattern is formed by a collection of curves (isograms) plotted by connecting the interpolated points of equal application rates within the wetted area. This gives a rough idea of how the emitter applies water to the irrigated area. A good emitter should produce circular isograms of decreasing application rates from centre to outer perimeter of the wetted area.

Christiansen (1942) was probably the first to point out the significance of distribution pattern in assessing the performance. The distribution pattern of a sprinkler gives water application rates (or depths) as a function of the radial distance from the sprinkler. The distribution pattern is affected by the combination of nozzle and pressure as well as the sprinkler model itself.

The ‘densogram’ is a modification to the distribution pattern. This involves the shading technique to represent the varying application rates. The densogram gives a good visual impression of distribution of irrigation water (as well as overall uniformity of application); it does not provide quantitative way to actually measure the uniformity.

A non-quantitative way to look at the wetted area is to have it graphically displayed using a shading technique. This process transforms the actual catch values into various intensities of shades. The dot matrix printer shading technique used by Centre for Irrigation Technology, Florida is to transform the application rates to different intensities/ densities of dots. The wettest area is displayed as black (solid dots); all other application amounts are scaled between black and white (white represents area receiving no water or the dry spot) with corresponding shades or densities of dots. The resulting densogram gives an excellent visual description of where the high and low watering spots are, how wet or dry they are; and in general, how uniform the water application is.

The feel of over all uniformity of water application; for every emitter, can be produced by giving various shades to different application depths. The individual application depths can be transformed to values represented as percentage of average application depth. Since they are represented as percentage of the average application depth of the corresponding emitter, the emitters can be easily compared for their performance. The densogram will show how much a particular area over-irrigated or under-irrigated as compared to the targeted application rate (corresponds to average application depth, i.e. 100%).

Boman (1989) has evaluated several micro-sprinklers to determine their individual performance. He reported that the application rate of several micro-sprinklers was not very uniform. Some emitters put out a ‘doughnut’ pattern where more water is thrown to the outside and less remains near the centre (an increase and then decrease in application rate from centre to outside). Distribution patterns of a number of micro-sprinklers are shown, to clearly describe their performance. Only one of the emitters tested had a DC value greater than 50%. Apparently, low DC values (less than 50%) are typical for micro-irrigation sprinkler and spray emitters. The average COV values for the spray emitters tested were 181, 165 and 167, and for the spinner emitters were 101, 71 and 73 respectively for the 103, 138 and 172 kPa tests. The higher COV values in the 103 kPa tests were due to a more pronounced doughnut effect in some of the emitters at the lower pressure. This problem is common for high-pressure sprinklers that are operated at too low a pressure.

Pandey *et al.(*1995 a) determined the performance parameters such as average application rate, absolute maximum depth and coefficient of variation by single nozzle test for five makes of micro-sprinklers, designated for reference as A, B, C, D and E. The range of mean depth at varying pressures and heights for micro-sprinklers A, B, C, D and E respectively were found to be 6 to 2 mm, 6 to 4 mm, 16 to 5 mm, 3 to 2 mm and 9 to 2 mm and the range of COV were found to be 254 to 76, 207 to 90, 189 to 66, 199 to 105 and 215 to 63 respectively.

### 2.8. Effect of pressure on distribution uniformity

The operating pressure is one of the main factors influencing the distribution uniformity of a micro-sprinkler system. The operation of a micro-sprinkler system at a very low or very high pressure (compared to the optimum/ recommended operation pressure) will result in poor uniformity.

Post *et al.* (1985) reported that most of the emitters tested had no appreciable difference in its DC when operated at the three testing pressures, but coefficient of variation has shown remarkable variations.

Boman (1989) reported that a slight drop in the operating pressure (from 138 kPa to 103 kPa) has caused a sudden increase in COV of all the emitters tested. The COV of some emitters more than doubled with this pressure drop. The development of a doughnut pattern was also observed, when the operating pressure was dropped. At 172 kPa most of the emitters have shown very good performance, at 138 kPa, beginnings of a doughnut pattern near the outer perimeter of the distribution pattern was observed. The emitters when operated at 103 kPa, has produced a pattern with a well-developed ‘doughnut’.

### 2.9. Management of the irrigation system

Improved irrigation system hardware or management may result in greater distribution uniformity and improve the potential for higher application efficiency. It follows that distribution uniformity is the first concern when improving irrigation system performance.

Achieving high application efficiency ultimately depends on the management of the system. (Hermanson and Canessa, 1995)

Responding to the increased demand, new developments have made many more brands of micro-sprinklers and spray patterns available. A number of manufacturers have introduced new emitters to the market. Today, growers have an extensive choice of emitters that vary widely in output discharge, spray diameter and spray patterns. This large selection of emitters is beneficial but the growers may be unaware of the performance capacity of the emitters. Accurate information on the efficiency/ uniformity of various patterns produced by the emitters is very essential for better designs of irrigation systems and for good irrigation management. When selecting a nozzle, the grower should insist on seeing the information regarding the performance (irrigation efficiency or uniformity of application) and should look for a brand/ model that have a relatively flat emission with distance from the emitter.

# Materials & Methods

# MATERIALS AND METHODS

This chapter gives an account of the various materials used as well as the methodology adopted for achieving the objectives of the present study.

## 3.1. Evaluation of micro-irrigation emitters

The general test conditions and equipments are detailed in this section.

### 3.1.1. Location

The present study was aimed at evaluating the performance of various micro-sprinkling devices; including the analysis of distribution pattern and uniformity of application of the irrigation devices. Since such experiments require a windless condition, the present study was conducted inside the SWCE (Soil and Water Conservation Engineering) laboratory, K.C.A.E.T., Tavanur. The place is in Malappuram district, situated at 10º52’30” North latitude and 76º East longitude.

### 3.1.2. Experimental setup

The area selected inside the laboratory for the present study was cleared and boundaries were marked. The floor surface was level so that the micro-sprinkler when mounted over the stake remained vertical. The source of water was a water tank fitted with a float mechanism to ensure a fixed water level in the tank throughout the experiment. Water was filtered before collecting in the tank.

A centrifugal pump (1 HP, 50 m of total head) operated by an electric motor was used to create the necessary pressure to operate the emitters. The main line was constituted by 32 mm Ø PVC pipe and the lateral by 16 mm Ø LDPE tube. Three gate valves connected to the delivery line of the pump were used to control the discharge from the pump and a pressure gauge was used to monitor the pressure head applied. A pressure gauge of 0 - 4 kg/cm$^2$ (± 1%)

was connected to the mainline such that it indicated the pressure head near the base of the emitter at a point situated about 20 cm below the nozzle of the emitter; but with the gauge situated in the same plane as the emitter. The Plates 1(a), (b) and (c) show different views of the overall experimental setup.

### 3.1.3. Emitters

The number of micro-sprinkler models selected for the present study was ten. The emitter samples were randomly selected, by choosing few numbers of each of the ten different models (from the supplier's lot). They could be identified by the general appearance (design/ structure) of the emitter and the colour of the nozzle (The data provided by the manufacturers are given in Appendix I). The emitters were categorised to three general types, viz. single jet self thread type (ALBL, ALGR, ALRD), single jet adapter type (JNBK, JNBL, JNGR, JNWH) and double jet type (D-BR, D-LG, D-NG) - three models each from single jet self thread type and double jet type and four models from single jet adapter type. Plate 2 shows the emitters in assembled condition and Plate 3 shows them in exploded condition; the micro tubes, connectors or adapters provided are not shown.

The design of single jet self thread type emitters was such that they could be connected directly to a PVC pipe, a spaghetti micro tube or the connector provided by the manufacturer (for the present study the connector provided by the manufacturer was used; the emitter could be threaded to one end and the micro tube was pushed fit to the other end of the connector).

The single jet adapter type emitter could be connected to a threaded adapter-cum-stake, on to which the 16 mm LDPE lateral could be directly push fit connected.

The double jet type emitters were provided with their own spaghetti micro tube that can be connected to the LDPE lateral using a pin connector. The double jet emitters could be easily distinguished by the special design of the rotor/ spreader.

### 3.2. General, Functional and Operational tests

All the tests were conducted as per the standard recommendation of ASAE: S 330.1 - 1991, ASAE: S 398.2 - 1997, BIS: 12232 (part 1, 2) - 1987; suggestions of the draft Indian standard BIS: FAD 54 (590) C - 1997 were also took into consideration (derived from ISO: 8026, 1995).

#### 3.2.1. General tests

All of the emitters were subjected to ocular inspection and strength tests before acceptance.

##### 3.2.1.1. Visual inspection

The emitters were subjected to visual inspection of the individual parts. They were inspected for visible cracks, holes, air bubbles or other defects that may impair the performance and durability of the sprayer, its operation and suitability for installation. The surface smoothness and the ease of change or replacement of parts (e.g. the nozzle) were also observed.

##### 3.2.1.2. Hydrostatic strength test

The emitters were tested to analyse their resistance to hydrostatic pressure. Each of the emitter was connected to the lateral tube; as per the manufacturer's instruction, ensuring no air remains in the system. The water pressure was gradually increased from zero up to 1.2 times the maximum effective pressure (highest working pressure) declared by the manufacturer. The emitter was inspected for leakage or other visible damage during this test.

##### 3.4.1.3. Travelling microscope

The emitters selected were closely examined through a travelling microscope for the exact size and quality of the nozzles. The general shape and smoothness of the nozzle edges were observed to describe the quality of workmanship of the nozzles.

The emitters were selected for the rest of the tests only if they were found satisfactory in the ocular inspection and strength test. Three numbers of each of the ten emitter models of the micro-sprinklers were selected. Based on the nature and quality of the nozzle they were designated as replication R1, R2, and R3.

**3.2.2. Functional test**

The emitters selected after the visual inspection and strength test were subjected to the functional test for uniformity of flow rate. The testing pressures selected for this were designated as p1, p2, p3, p4 and p5 (p3 being the recommended operating pressure; p2 and p4 being the lowest and highest working pressures declared by the manufacturer and p1 and p5 falling outside the effective operating pressure range recommended by the manufacturer, such that p1 < p2 and p5 > p4).

As per the instructions of the manufacturer and recommendation of the test standards, the emitter was connected to the LDPE lateral (either directly by means of the adaptor or using a spaghetti micro tube).The emitter connected to the lateral was mounted on a stake assembly and was placed inside a collection vessel. The water pressure of the system was raised to the required testing pressure and a small plastic vessel was placed over the emitter without disturbing the operation, to confine and direct the stream ejected from the emitter to the collection vessel. Plate 1(d) shows the arrangement.

The discharge from the emitter was collected for a specific known period of time and the flow rate of the emitter was calculated as,

$$\text{Flow rate (lph)} = \frac{\text{volume of water collected (ml)/ 1000}}{\text{Time (min)/ 60}}$$

The procedure was repeated for pressure p1, p2, p3, p4 and p5 for replications R1, R2 and R3 of each micro sprinkler model. The functional relationship (pressure Vs discharge relation) of each model was established by plotting the flow rate against the operating pressure.

### 3.2.3. Operational test

Indoor measurement of single-leg micro-sprinkler patterns were carried out to analyse the distribution performance of the emitter. The technique of catch-can test was considered to be suitable for this purpose.

#### 3.2.3.1. Test Equipment

Catch-cans were placed on 60 cm grid intervals in a matrix extending to a distance of 4.8 m from the emitter, on either side. The emitter was placed exactly at the centre of the matrix. The collectors were 2 litre straight walled cans made of virgin plastic material. The catch-cans were placed at the centre of each square formed by the grid, assuming that each catch-can represents the precipitation rate over that area of 60 cm x 60 cm. The catch-cans were named according to their relative distance and position with respect to the emitter location. The nomenclature of the collectors is shown in Appendix II.

A stake assembly was used to hold the emitter at a height of 20cm above the horizontal plane of the openings of the catch-cans; care was being taken that the stake riser was fixed vertically and did not bend or deviate from that position during the tests. Plate 1(e) shows the stake assembly. The collector at the geometric centre of the matrix of catch-cans surrounded by the adjacent eight collectors was removed and the emitter mounted on the stake was placed there. The Plate 1(f) and Fig. 1 describe the catch-can arrangement and the emitter location.

No evaporation suppressant was used for the present study.

#### 3.2.3.2. Performance testing

Prior to conducting the test, the emitter was operated at the test pressure for some time to wet the surroundings and to ensure trouble free operation. The emitter was then operated for a period of 1 hr while maintaining the test pressure. The emitters were tested at the recommended operating pressure and minimum and maximum effective operating pressures declared by the manufacturers, in three replications. Immediately on conclusion of the test the amount of water collected in each can within the spray coverage area was measured and recorded against the corresponding catch-can location.

### 3.3. Distribution performance

The catch-can data collected after each test was used to analyse the performance of each micro-sprinkler model. The different factors or indices used to analyse the performance are wetted radius, average application depth, uniformity coefficient, coefficient of variation, distribution characteristic and the distribution patterns.

#### 3.3.1. Determination of wetted radius

As per the standard recommendation, the wetted radius was calculated to be the distance measured from the emitter location to the farthest point at which the emitter deposits water at a minimum rate of 0.26 mm/hr; typically measured at any arc of coverage.

#### 3.3.2. Determination of application depths

The maximum application depth (Dx) was determined as the greatest depth caught in any of the containers for a particular emitter, in cm. The mean application depth (Da) was calculated by averaging the depths of water caught in the cans located within a distance of R from the emitter. The ratio (Dx/Da) was calculated and was represented by 'MAX%' as a percentage. The ratio MAX% being dimensionless was used as a measure for comparison.

#### 3.3.3. Performance indices

The various performance indices used to describe the uniformity of application of the emitters were calculated and the distribution patterns were plotted to get an exact understanding of the water distribution by the emitters.

##### 3.3.3.1. Coefficient of uniformity

The Christiansen's uniformity coefficient was calculated as

$$CUC = 100(1 - da/Da) \text{ ; where}$$

'CUC' is the Christiansen's uniformity coefficient (%)

'da' is the average absolute deviation from Da

$$da = \frac{\sum |(di - Da)|}{N} \text{ ; where}$$

'di' is the individual application depth

'|(di-Da)|' is the absolute deviation of di from Da

'N', the total number of individual application depths.

#### 3.3.3.2. Coefficient of variation

The coefficient of variation (COV) of the application depths for a particular emitter was calculated by dividing the standard deviation of the application depths by the mean application depth, expressed as a percentage.

$$COV = (SD/Da) \times 100 \text{ ; where}$$

'SD', is the standard deviation of individual application depths

$$= \frac{\sqrt{\sum (di - Da)^2}}{N}$$

#### 3.3.3.3. Distribution characteristic

'Merriam and Kellers' distribution characteristic (DC) was defined as the ratio of the area; which receives more than half of the average application depth, to the total wetted area, expressed as a percentage. The coefficient was calculated as the ratio of the number of individual application depths greater than half of the mean application depth (i.e. > Da/2) to the total number of the individual application depths.

DC = <u>Area receiving more than half of the mean application depth</u>

Total wetted area

$$= \frac{\text{n, number of individual application depths, greater than Da/2}}{\text{N, total number of individual application depths}}$$

### 3.3.4. Distribution pattern

The catch-can data was used to plot the ‘densograms’ corresponding to the spray coverage of the emitters. For a particular test, the amount of water collected in each catch-can was expressed as a percentage of the mean application depth, Da. The computer software ‘SURFER’ was used to plot the curves by connecting the interpolated points of equal collection (application) rates. The software fills the area between the contour lines; the isograms, connecting points of equal collection rates according to the levels specified. The different levels specified were <10, 10-25, 25-50, 50-100, 100-150, 150-200, 200-300, 300-500, 500-700 and >700 percent of the mean application depth. Thus the contour lines and the filled area together formed the distribution pattern; the densogram, which is most suitable to represent and compare the performance of different micro-sprinklers. The densograms were closely examined to have a critical analysis of the distribution performance of various micro-sprinklers at different applied pressures.

## 3.4. Comparison Analysis

The different performance indices were used to compare the performance of each micro-sprinkler and to analyse the claim of the manufacturer.

### 3.4.1. Statistical method

The emitters were categorised in to three groups according to their recommended operating pressures. The emitters ALBL, D-NG and D-BH were in the LOW operating pressure group (1.25 $kg/cm^2$); emitters ALGR, JNBK, JNBL, JNGR and JNWH were in the MEDIUM operating pressure group (1.5 kg/$cm^2$); and emitters ALRD and D-LG were in the HIGH operating pressure group (2 kg/$cm^2$), respectively.

The analysis of various performance parameters (CUC, COV, DC and MAX%) of the emitters were done to evaluate their relative performance, separately for the three groups.

The Kruskal-Wallis test for one way analysis of variance was done to determine whether there was a significant shift in the centres of different parameters used to describe the performance of the emitters. The boxplots of the values of different performance parameters were drawn to get a visual comparison of the performance of the emitters. The software *SYSTAT* (ver 8.0) was used for both the tasks.

### 3.4.2. Ranking

The method of ranking of different performance parameters was used to compare the individual performance of the emitters at different applied pressures. The final ranking of the total value (sum) of each performance parameter (in three replications) was done to analyse the relative performance of the emitters, among themselves. The emitters were ranked from 1 to 10 according to their performance, based on CUC, COV, DC and MAX%.

## 3.5. Floppy sprinklers

The floppy sprinkler is one of the newest innovations in the field of sprinkler irrigation technology. The floppy sprinkler has a special type of flexible silicone rubber tube, which becomes instrumental in sprinkling the water. When water is applied under pressure to the device, the water is ejected through the silicon tube to the air, and the pressure difference in and out of the tube causes the tube to vibrate and oscillate in a particular manner such that the water is sprinkled in a circular pattern. The floppy sprinklers operate more or less like a common high pressure sprinkler.

### 3.5.1. Evaluation of floppy sprinklers

As part of the present study, two models of floppy sprinklers were also evaluated for distribution performance. The sprinklers were designated as JFLP and JFPP. The sprinkler JFPP was a pop-up version of floppy sprinkler, in which the silicone tube is hidden in the emitter body while not in operation. When pressure is applied the tube comes out of the emitter body and operates like a normal sprinkler. The Plate 4(a) shows both types of the devices (note that the silicon tube of the emitter JFPP is pulled out for the sake of taking photographs).

The devices were subjected to catch-can testing and performance parameters were calculated. The procedure adopted for the evaluation of the distribution performance of the floppy sprinklers was similar to that followed for the evaluation of micro-sprinklers. But since the throw radius of the floppy sprinklers were much higher than that of the micro-sprinklers, indoor tests were not possible. The catch-can testing was conducted outdoors, considering the floppy sprinklers to be comparable to common high pressure sprinklers, at the basket-ball court of KCAET, Tavanur (the surface was level with <1% slope). The average wind speed during the test was measured with sensitive uni-directional anemometer placed just outside the catch-can grid at the same level of the irrigation device. The catch-can grid spacing selected was 150 cm, the emitter being placed at the centre of the of the grid work, surrounded by eight adjoining cans. The Plate 4(b) shows the overall experimental setup.

As per the manufacturers recommendation, the emitter JFLP was operated at a height of 2 m above the plane of the catch-can openings, like common sprinklers (the emitter was connected to a riser tube to raise the emitter to this height) and JFPP was connected directly to the mainline such that the water is sprinkled at a height of about 20 cm above the plane of the catch-can openings. The Plate 4(c) shows the devices JFPP and JFLP .

The operating pressure range specified by the manufacturer for both devices was 2-6 $kg/cm^2$. The manufacturer has assured constant pressure compensated performance throughout the specified pressure range. But the emitter JFLP did not work well even at a pressure of 3.5 kg/cm$^2$, the performance of the emitter did not improve even when the emitter was connected directly to the mainline.

The emitter JFPP was operated at an operating pressure of 3 kg/cm$^2$ for a period of 1 hr, at the end of the test period the catch-can data was recorded and the performance parameters were calculated.

# Results & Discussion

# RESULTS AND DISCUSSION

The results of the present study conducted to evaluate the performance of various micro-irrigation devices available in the market were also used to identify the emitters, which showed better performance. This chapter gives a detailed description of the results of the experiments conducted.

## 4.1. Evaluation for performance

A total of thirty micro-sprinklers (ten different models in three replications) were tested for their individual performance. The emitters were tested to determine their flow rate, water distribution patterns and various performance indices at different operating pressures.

## 4.2. Acceptance and performance tests

The emitters were subjected to various acceptance tests prior to conducting the performance tests. The acceptance tests included visual inspection, close examination using travelling microscope and hydrostatic pressure strength tests. The performance tests were done to determine the flow rate and the spray distribution characteristics.

### 4.2.1. Acceptance tests

The emitters selected randomly; from the manufacturer or supplier, were subjected to visual inspection for shortcomings. Some of the samples were found to be defective and they were immediately replaced with other samples of the same make/ model. The emitters were then subjected to the strength test to analyse their resistance to hydrostatic pressure. Only one emitter was found to be having leakage through the gap formed between the threads of the nozzle body and the adapter. The emitter (ALBL) was replaced with another sample of the same model. The nozzles of the emitters were then closely examined through a travelling microscope. The exact size of the nozzles and their general shape and quality are described in Appendix III. The size, shape and smoothness of the nozzle edges are the main factors influencing the functional nature of the emitters.

The emitters chosen after the acceptance tests were selected for further performance testing.

#### 4.2.2. **Flow rate**

The emitters were tested for the flow rate at different operating pressures. The pressures were selected in such a way that emitters were operated at minimum effective pressure, maximum effective pressure and recommended operating pressure declared by the manufacturer and at pressures below and above the recommended pressure range. The results of the tests are given in Tab. 1 (i, ii). The functional performance of the emitters was determined by analysing the pressure - flow rate relationship established by plotting the flow rate against the operating pressure. Fig. 2(a), (b) and (c) show this relationship of single jet self thread type, single jet adapter type and double jet type of emitter respectively. The curves show a general trend of variation of the flow rate with respect to the operating pressure, which is typical for the sprinkler emitters. The nature of the curve (concave curvature to the axis of operating pressure) satisfies the general relationship of "$q \quad H^{½}$". As the nozzle size and operating pressure was increased, a corresponding increase in the flow rate was observed, in all cases. The discharge rate of ALRD was much higher than that of the other emitters in single jet self thread category. The same was observed in case of JNBL and D-LG in their respective categories (this was either due to the larger size of the nozzle or the operation at a higher pressure or a combined effect of both).

Some of the emitters have shown variation in flow rate compared to the data published by the manufacturers. This was obviously due to the variation in the size, shape and quality of the emitter nozzle in contrast to the manufacturers' data. Such observations with large variation were not considered for determining the feasibility of applying a general relationship to the test results.

#### 4.2.3. Distribution performance

The technique of catch-can test was used for the determination of single-emitter micro-sprinkler patterns and their distribution performance. A total of 90 tests were done for ten different micro-sprinkler models at three different operating pressures in three replications. The catch-can data observed in these tests are given in Appendix IV.

### 4.3. Analysis of distribution performance

The catch-can data was analysed to determine the wetted radius, application depths, different performance parameters and the non-overlapped distribution patterns.

#### 4.3.1. Wetted radius.

The wetted radius was (R) calculated as the distance measured from the emitter location to the farthest point at which the emitter deposits water at a minimum rate of 0.26 mm/hr. All the emitters except D-LG have shown wetted radius equal to or more than 300 cm. The maximum wetted radius was, for emitter JNBL operating at 1.5 and 2.0 kg/cm$^2$, 485cm. In single jet self thread type, ALRD has the highest R of 365 cm; at 2.5 kg/cm$^2$. In single jet adapter type JNBL has the highest R, 485 cm at 1.5 kg/cm$^2$; and for double jet type 457 cm (D-BR operating at 1.5 kg/cm$^2$). Tab. 2 shows the wetted radius of the emitters at different operating pressures.

#### 4.3.2. Application depth

The maximum application depth (Dx) and mean/ average application depth (Da) were determined for each micro-sprinkler model for different operating pressures (three replications). The highest average application depth was 0.556 cm, shown by emitter D-LG at 2.5 kg/cm$^2$ and the lowest average application depth was 0.126 cm, shown by emitter JNBK at 1.0 kg/cm$^2$. Tab. 3 shows application depth and MAX% observed in the tests.

### 4.3.3. Performance parameters

Since the micro-irrigation emitters available in the market are different in many aspects, it becomes necessary to use some dimensionless parameters to compare their performance. The uniformity coefficient, the coefficient of variation and the distribution characteristic are the indices calculated, to compare the performance of the devices evaluated in this study. They offered a way to easily weigh the performance of the emitters against each other.

#### 4.3.3.1. Uniformity Coefficient

The Christiansen's Uniformity Coefficient directly gives a measure of the uniformity or non-uniformity of distribution of micro-sprinklers. The highest and lowest values of CUC shown by single jet self thread type emitters were 49% (ALBL at 1.0 kg/cm$^2$) and 20% (ALGR at 2.0 kg/cm$^2$); for single jet adapter type emitter the values were 38% (JNBL at 1.0 kg/cm$^2$) and 11% (JNBK at 1.0 kg/cm$^2$) and for double jet type emitters 55% (D-NG at 1.25 kg/cm$^2$ and 1.5 kg/cm$^2$) and 7.3% (D-LG 1.5 kg/cm$^2$) respectively. Tab. 4 shows the values of CUC shown by the emitters at different pressures.

#### 4.3.3.2. Coefficient of Variation

Tab. 5 shows the values of coefficient of variation of catch-can observation data of the tests conducted. Since the coefficient of variation is the measure of the deviation of individual observation from the mean higher values of COV represent a poor distribution (large deviation from the average application depth) and lower values represent better performance. A COV value of an emitter which is less than 100% indicates “good” performance by that emitter.

Based on the COV values the best performance observed was by emitter D-NG (53% at1.25 kg/cm$^2$). The highest and lowest values of COV (poor and good performance) shown by single jet self thread type emitters were 114% (ALGR at 2.0 kg/cm$^2$) and 66% (ALBL at 1.0 kg/cm$^2$), single jet adapter type emitters were 125% (JNBK at 1.0 kg/cm$^2$) and 80% (JNWH at 1.0 kg/cm$^2$) and by double jet type emitters were 160% (D-LG at 1.5 kg/cm$^2$) and 53% (D-NG at 1.25 kg/cm$^2$)

#### 4.3.3.3. Distribution Characteristic

Merriam and Keller's distribution characteristic shows the percentile area receiving irrigation water at a rate, higher than half of the average application rate over the total irrigated area. It was calculated as the ratio of the number of catch-cans that received more than half of the average application depth, to the total number of catch-cans placed over the wetted area. The best performance shown by an individual emitter (D-NG) in the present study was a DC of 79.5%. This shows that about 80% of the total wetted area receives more than half of the average application depth. The good and poor performance shown by single jet self thread type emitters were 76% (ALRD at 1.5 kg/cm$^2$) and 51% (ALGR at 2.0 kg/cm$^2$), 72% (JNBL at 1.0 kg/cm$^2$) and 44% (JNBK at 1.0 kg/cm$^2$) by single jet adapter type emitters and 80% (D-NG at 1.25 kg/cm$^2$) and 47.6% (D-LG at 1.5 kg/cm$^2$) by double jet type emitters. Tab. 6 shows the values of DC.

### 4.3.4. Distribution Pattern

The densograms plotted, by joining the points of equal application rate and shading the space between those isograms corresponding to the percentile proportion of the corresponding application rate, (compared to Da) were analysed. The densograms gave a good visual impression of the nature of water distribution under different emitters. The isograms were seen to curve to the direction of the emitter (to the centre) from the left side of the figures.

This is obviously due to the low application depths in those regions caused by the shading effect of the frame/ arm of the emitter, directed towards the grid point A8 (0,450).

#### 4.3.4.1. ALBL

The Fig. 3(a), (b) and (c) show the densograms of emitter ALBL at 1.0, 1.25 and 1.5 kg/cm$^2$ respectively. The densograms show a gradual increase in the application rate from the outer perimeter to the centre (location of the emitter). The entire distribution pattern and the isograms are almost circular, although the central part of the figures shows some skewed patterns. In all three cases, a large portion at the centre of the pattern is representing application depth greater than 50% Da, thus having higher values of DC. While operating at 1.25 kg/cm$^2$ the emitter produces application depths more than 3 times Da, shown by the darker area at the centre.

#### 4.3.4.2. ALGR

The Fig. 4(a), (b) and (c) show the densograms of emitter ALGR at 1.0, 1.5 and 2.0 kg/cm$^2$. All the three figures show clear indication of poor performance by ALGR emitter. Although there is a constant increase in application depth up to 150% Da, the distinct zones of higher application depth at the central part of the wetted area shows high non-uniformity of application. The emitter even produces application depths more than 6 times Da at 2.0 kg/cm$^2$. Although the DC values are high, the densograms justifies the low values of CUC and high values of COV (eg. COV, 108 at 2 kg/cm$^2$); indicating low uniformity.

#### 4.3.4.3. ALRD

The Fig. 5(a), (b) and (c) show the densograms of ALRD at 1.5, 2.0 and 2.5 kg/cm$^2$. As expected the wetted area is more in case of the ALRD emitter (compared to other emitter in the single jet self thread emitter), in response to the higher operating pressures. A constant increase in the application depth towards the centre is observed although there is a skewed pattern of higher application at 1.5 kg/cm$^2$, creating a visual effect of a doughnut development. This effect is not clear at 2.5 kg/cm$^2$.

Although the DC value is high, the presence of a considerable area with application depth more than 3 times Da at 2.5 kg/cm$^2$ reduces the uniformity (low values of CUC and high value of COV).

**4.3.4.4. JNBK**

The JNBK is another emitter that shows very poor distribution performance. The densograms of this emitter are shown in Fig. 6(a), (b) and (c) corresponding to operating pressure 1.0, 1.5 and 2.0 kg/cm$^2$ respectively. The distribution patterns are of irregular rectangular shape rather than the general circular pattern.

The shading effect of the emitter frame is noticeable in all three cases, and the uneven placement of the high and low application depths results in patterns of very complex nature. Most part of the distribution patterns correspond to application depths < 50% Da; the patterns include considerable areas of higher application depths (> 300% Da) also, thus the densograms comply with the performance parameters indicating poor performance.

**4.3.4.5. JNGR**

The Fig. 7(a), (b) and (c) represents the distribution patterns of JNGR operating at 1.0, 1.5 and 2.0 kg/cm$^2$. The 'irregular kite' shaped densograms (the shading effect of the emitter frame on both sides) justifies the indication of the performance parameters. Although more than half of the pattern area corresponds to application depths > 50% Da, the presence of significant area of high application depths result in poor performance by the emitter (the densogram at 1.5 kg/cm$^2$ includes a region of application depth > 500% Da, represented by a small circular area adjacent to the emitter location).

#### 4.3.4.6. JNWH

The JNWH is the only emitter that showed a general circular wetting pattern among the single jet adapter type emitters. The Fig. 8(a), (b) and (c) show the densograms corresponding to operation at 1.0, 1.5 and 2.0 $kg/cm^2$. Although the performance parameters indicate comparable good performance at 1.0 $kg/cm^2$, as the pressure is increased the performance is diminished as a result of the increased pattern area and presence of high application depths.

The densogram at 1.0 $kg/cm^2$ shows even placement of water and gradual increase in application depth; the maximum application depth being less than 300% Da, while considerable portion of the pattern corresponds to application depths even more than 500% Da at higher operating pressures.

#### 4.3.4.7. JNBL

The densograms of the emitter JNBL shown in Fig. 9(a), (b) and (c) corresponding to 1.0, 1.5 and 2.0 $kg/cm^2$ gives an impression of better performance; the coverage area is more compared to other emitters in single jet adapter type emitters. The shading effect of the emitter frame is present at all the three operating pressures. The application depths corresponding to most parts of the wetted area are more than 50% Da in all three cases.

As the operating pressure is increased the radius of throw is also increased; the increased wetted area results in a corresponding decrease in the DC value. At higher operating pressures the application depth at the centre of the patterns increases from 300% Da to depths > 500% Da (at 2.0 $kg/cm^2$ the emitter produces application depths even > 600% Da) Corresponding changes in COV and CUC are also observed indicating reduced performance.

#### 4.3.4.8. D-NG

The Fig. 10(a), (b) and (c) show the distribution performance of D-NG emitter, at 1.0, 1.25 and 1.5 $kg/cm^2$ respectively. The patterns are of good circular shape and good performance of the emitter (as indicated by the performance parameters) may be inferred from the densograms also. A comparably larger area having application depth more than 50% Da and good distribution of high and low amounts of application depths (only a small part of the wetted area corresponds to application depth more than 2 times Da) justifies the performance indicators of the emitter. But all the three densograms clearly show uneven placement of water within the wetted area. The water application depth is more to the right and top sides compared to left and bottom sides of the densograms, due to the distinct incomplete circular patterns of high application depth.

As the operating pressure is increased from 1.0 to 1.5 kg/cm$^2$, the performance indicators show a general trend of reduced performance. But by closely analysing the densograms it is evident that the placement of the applied water depths is becoming more even as the pressure is increased. It may be concluded that the emitter may perform better if the operating pressure range is modified. The emitter should be tested at higher operating pressures to confirm this possibility.

#### 4.3.4.9. D-LG

The distribution performance of the emitter D-LG is represented by Fig. 11(a), (b) and (c) at 1.5, 2.0 and 2.5 kg/cm$^2$ respectively. The poor performance by the emitter is clearly visible from the densograms. At all the three operating pressures, the entire distribution pattern is skewed to the opposite side of the frame/ arm of the emitter; thus leaving the most part of the area intended to irrigate (the circular area of radius equal to the radius of throw, R) un-irrigated.

The distribution pattern is formed by irregular shaped, distinct areas of very high and low application depths. The application depth corresponding to the area adjacent to the emitter location is very high compared to the average application depth (about 700% Da). By analysing the densograms it can be generally stated that the performance of the emitter is improved when the operating pressure is increased (the doughnut patterns disappeared and the whole pattern became more evenly and circularly distributed). The operation of this emitter may become beneficial or improved from the manufacturer’s point of view, but the performance of the emitter in the present condition is not acceptable from the farmers’ point of view.

#### 4.3.4.10. D-BH

The densograms of the emitter D-BH are shown in Fig. 12(a), (b) and (c) corresponding to operation at 1.0, 1.25 and 1.5 kg/cm$^2$ respectively. A comparable good performance of the emitter is evident as indicated by the regular increase in application depth towards the centre and a larger area of an application depth > 50% Da. The densograms have a rectangular shape with curved corners. In all the densograms wetted area corresponding to the level 50 - 100 % Da was more compared to other emitters.  The shading effect of the emitter frame was apparent in all the three operating pressures. There were distinct zone of higher application depths (> 3 times Da) at the central portion of the densograms. As the pressure was increased from 1 to 1.5 kg/cm$^2$, gradual development of a zone of low application was observed, at the top of the densogram. At 1.25 and 1.5 kg/cm$^2$, the emitter puts water to the farthest catch-cans placed at the extreme top and right sides of the grid.

### 4.4. Comparison of the performance

The values of different performance parameters calculated were used to compare the performance of the emitters. The comparison was done by different statistical and ranking tools.

#### 4.4.1. Comparison by statistical methods

The statistical methods used include the analysis of variance and boxplots. The Kruskal-Wallis one way analysis of variance of the different performance parameters were done to investigate whether the mean of the values of each of the parameter equal or not. The boxplots represents the values of the performance parameter corresponding to the density function of the occurrence of the values of the performance parameter.

#### 4.4.1.1. Kruskal-Wallis test

The analysis is done by determining the acceptance of the hypothesis that the means of the performance parameter (CUC, COV, DC or MAX%) corresponding to each emitter are equal.

The Appendix V shows the result of the Kruskal-Wallis tests done with the performance parameter as the dependent variable and the emitter as the independent (or grouping variable). The results clearly show that the hypothesis is rejected in all the cases (LOW, MEDIUM and HIGH operating pressure groups). It could be inferred from these results that the emitters were performing in a very dissimilar way among themselves. So, on the basis of the performance of the emitters they could easily be distinguished from each other. (The test failed to clearly explain the dissimilarity in the case of HIGH pressure group since the degree of freedom was only 1. So the test was repeated for all the ten emitters together, and the result show that there is significant variation in the mean of the different performance parameters).

#### 4.4.1.2. Boxplot

The boxplots were drawn to visually differentiate the performance of the emitters. The boxplots also help in observing whether there was a comparable performance between any combinations of the emitters. The Appendix VI shows the boxplots of various performance parameters against the emitter for LOW, MEDIUM and HIGH operating pressure groups and for all the ten emitters together. Each of the boxplot corresponds to the values of the performance parameter in 95% confidence interval of the mean value. The box represents the values that fall in 50% confidence interval and the central line dividing the box in to two represents the median of the values of the dependent variable (the performance parameter). The longer boxplot (and/or the box) represents higher variation in the performance of the emitter (represents poorer performance) and two boxplots having their box overlapped each other in a plane represents comparable performance.

A general conclusion inferred from the boxplots is that the emitters in the MEDIUM pressure group have performance which is nearly analogous among them; emitters in HIGH pressure group perform very dissimilarly, and emitters ALBL and D-BR in the LOW pressure group have comparable performance. The emitter D-NG performs a cut above all other emitters and emitter D-LG performs inferior to all other devices.

### 4.4.2. Comparison by ranking

The method of ranking of the various performance parameters were used to rate the performance of the emitters from 'superior' to 'unsatisfactory'. (i.e. from rank 1 to 10). The Appendices 7 (i to iv) shows the relative ranking of various emitter-pressure combinations in different replications and the ranking of each emitter based on different performance parameters. The rating of the emitter-pressure combinations are given in Tab. 7 and final ranking of the emitters (based on the rank sum) is given in Tab. 8. The ranking is self explanatory and gives a suitable method of easy comparison of the performance of the emitters.

## 4.5. Performance evaluation of floppy sprinklers

The floppy sprinklers tested were not performing at the specified operating pressure range, as per the manufacturer's proposition. The prime mover used in the present study was capable of generating a water pressure of 3.5 $kg/cm^2$ (indicated on a sensitive pressure gauge connected to the mainline just before the emitter). Both emitters did not work well at operating pressures $< 3$ $kg/cm^2$, the rotation of the silicon tube was got halted after operating for sometime, say 10 min, so that water is sprinkled only in a vertical plane (water is applied to a small horizontal strip of land). But at an operating pressure just above 3 kg/ $cm^2$ the emitter JFPP started working satisfactorily for a period more than the test duration of 1 hr. Since the emitter JFLP did not work well even at 3.5 $kg/cm^2$, the emitter was connected directly to the mainline (the emitter was connected avoiding the riser tube) to get more applied pressure at the emitter point. But the emitter was found to be operating more or less the same as in the previous condition. So the emitter JFLP was discarded from further investigation.

The performance parameters of JFPP were calculated; shown in Tab. 9. The Fig. 13 shows the distribution pattern of JFPP. The performance parameters imply a comparatively better performance of the sprinkler. A value of COV less than 100 and higher value of DC clearly represent good performance. The densogram describes a fairly good performance of the emitter; a circular wetting pattern of gradually increasing application depth justifies the manufacturer's declaration. But the localised higher application depth zones on either side of the distribution pattern and the region of low application depth at the centre of the pattern is an indication of the operation of the emitter at a lower pressure. More studies in this direction are believed to become fruitful to the farming community.

# Summary & Conclusions

# SUMMARY AND CONCLUSIONS

The micro-sprinkler irrigation is the most versatile means of applying irrigation water, as it combines most of the advantages of conventional sprinkler and modern drip irrigation systems. A total of thirty micro-sprinklers (ten different models, in three replications) were tested for their individual performance and were compared and ranked based on various performance indices.

The emitters were categorised into three groups viz. single-jet self thread type, single-jet adapter type and double-jet type emitters. They were tested at three different operating pressures (at the operating pressure recommended by the manufacturer and above and below the recommended pressure) in three replications.

One important observation made during the acceptance test of the emitter is that the quality of the nozzles of the double-jet type emitters was excellent while that of the single-jet self thread type and adapter type emitters was generally poor. The quality of the nozzle is one imperative factor that affects the performance of the devices.

The determination of the application uniformity (more precisely, the distribution uniformity) of the micro-sprinkler devices was identified to be very essential in assessment of the performance of the irrigation system. The emitters were subjected to the catch-can testing and various performance parameters (CUC, COV, DC and MAX%) were calculated.

The average application depth, Da observed during the 1 hr catch-can test ranged from 0.13 cm to 0.17 cm (for emitters ALBL, ALGR, JNBK, JNGR, D-NG and D-BR); 0.17 cm to 0.19 cm (JNWH); 0.19 cm to 0.27 cm (JNBL); 0.3 cm to 0.4 cm (ALRD), and 0.52 cm to 0.56 cm (D-LG). The MAX% (ratio of highest application to the average application depth in a particular test, represented as a percentage) of single-jet self thread type, adapter type and emitter D-BR was in the range of 300 to 600, while that of the emitter D-NG was $<350$ and that of D-LG was $>600$; clearly explaining the superiority of emitter D-NG over the other emitters.

The values of the performance parameters CUC, COV and DC showed that the emitters D-NG, D-BR and ALRD perform comparatively better than the other emitters. The emitter D-LG was proved to be inferior to all other emitters in almost all of the analyses. The emitter D-NG was superior to even D-BR and ALRD because of the comparatively lower values of coefficient of variation.

The emitters in the single-jet adapter type (except JNBL) performed very poorly in contradiction to the manufacturer’s assertion. Despite the fact that the single-jet self thread type emitters were put on the market without much promotion, they performed well above the expectations. Although the double-jet type emitters (except D-LG) are performing admirably, they have not been fully acknowledged yet.

The densograms (graphical representation of the water distribution) gave a better perspective of the emitter performance and an easy means of comparison. They explain how well or bad the actual distribution of water occurs over the wetted area. The graphical interpretation was easy and better than that provided by the numerical values of the performance indices.

Various statistical and ranking methods were used in an attempt to compare and grade the emitters. All the analyses have shown the superior performance of the emitter D-NG over the others. The emitters were ranked from 1 to 10 based on different performance parameters.

In general, it could be concluded that the manufacturer’s data alone should not be taken into consideration while selecting the irrigation devices. From the farmers’ point of view it is safer to depend more on the technical information resulting from scientific investigations. The selected devices should be assessed in the actual field conditions also to have a view of stable performance over longer runs. Similar future studies on latest devices should also be encouraged to get up to date technical data.

Suggestions for future studies:

1) Analysis of the area of distribution pattern that receive specific application rate: Appendix VIII shows the amount of area that receive water at a rate specified as a fraction or multiple of Da. Future studies may concentrate on determining 'emitter - operating condition combinations' that will optimise the area that receive water at a rate equal or near Da.
2) The use of patterns similar to CIT densogrms: The Appendix IX shows the densograms formed by varying colour shades (representing varying fractions of Dx), corresponding to the recommended operating pressure. It gives a better perspective of the varying application rates within the pattern area. The future studies should also entertain use of such patterns and analysis of those patterns using versatile software and analytical tools. The use of computer software SPACE is also appreciated.

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# Appendices

# PERFORMANCE EVALUATION OF MICRO-IRRIGATION DEVICES

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## ABSTRACT OF THE THESIS

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## Abstract

Several micro-irrigation emitters were evaluated for their individual performance and were compared among themselves on the basis of different performance parameters, and the results were used to analyse the credibility of the claim of the manufacturers. The emitters were tested for their quality of the workmanship, uniformity of flow rate and for their distribution performance. A total of thirty micro-sprinklers (ten models in three replications) were evaluated. The distribution performance of each of the devices was described by different performance parameters. The performance parameters used for this purpose were uniformity coefficient, coefficient of variation, distribution characteristic etc. The distribution patterns (densograms) were drawn and carefully studied to analyse the nature of distribution performance of the emitters. The values of the performance parameters were used to grade the devices using different statistical and ranking tools. It is generally concluded that only the manufacturer data should not be taken into consideration while selecting the irrigation devices and from the farmers' point of view it is safer to depend more on the technical information resulting from scientific investigations.

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