SUBSURFACE DRIP IRRIGATION OF LADIES FINGER IN SANDY LOAM SOIL

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Technology in Agricultural Engineering

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DECLARATION

I hereby declare that, this thesis entitled ***"Subsurface Drip Irrigation of Ladies Finger in Sandy Loam Soil"*** is a bonafide record of research work done by me during the course of research, and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

15/01/08

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Date: 11-01-2008

CERTIFICATE

Certified that this thesis entitled ***"Subsurface Drip Irrigation of Ladies Finger in Sandy Loam Soil"*** is a record of research work done independently by Kum.Nisha.T.V under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Nisha.T.V

DEDICATED

TO THE FARMING COMMUNITY

CONTENTS

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LIST OF TABLES

....

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

′	minute
″	seconds
$<$	less than
$>$	greater than
&	and
/	per
0	degree
^0C	degree Celsius
%	percentage
AICRP	All India Co-ordinated Research Project
ANOVA	Analysis of Variance
ARS	Agronomic Research Station
ASAE	American Society of Agricultural Engineers
BIS	British Indian Standards
cm	centimeter (s)
Cv	Manufacturing coefficient of variation
CWRDM	Centre for Water Resources Development and Management
D	Depth of installation
d.f	degrees of freedom
E	evaporation
ET	evapotranspitration
Eu	Emission uniformity
et. al.	and others
Fig	Figure
g	gram
ha	hectare
hr	hour (s)
I	level of irrigation

i.e.	that is
ICAR	Indian Council of Agricultural Research
i/c	in charge
IDE	Irrigation and Drainage Engineering
INCID	Indian National committee on Irrigation and Drainage
KAU	Kerala Agricultural University
KCAET	Kelappaji College of Agricultural Engineering and Technology
km^2	square kilometer
lph	litre per hour
lps	litre per second
LWRCE	Land and Water Resources Conservation Engineering
m	metre (s)
max	maximum
min	minimum
mm	millimetre (s)
M ha	million hectare
M ha m	million hectare metre
min	minute
no.	number
NCPAH	National Committee on Plasticulture Application in Horticulture
PFDC	Precision Farming Development Centre
Proc.	Proceedings
PVC	Poly Vinyl Chloride
PW	Percentage wetted
R^2	regression coefficient
SAC	Supportive and Allied Cources
Sec	second

SDI	Subsurface drip irrigation
T	Treatment
t/ha	tones /hectare
USDA	United States Department of Agriculture
Vs	versus

INTRODUCTION

CHAPTER I

INTRODUCTION

Water, mankind's most vital and versatile resource is a basic human need and a precious national asset. 'Water is life' is truly experienced in water scarce regions. It is essential for broad based agricultural and rural development in order to improve food security and poverty alleviation. Water, a life sustaining resource, closely linked to the quality of life, a renewable resource is getting deteriorated in terms of quality as well as quantity. The International Conference on Water and the Environment, Dublin and the United Nations Conference on Environment, the Earth Summit, Rio–De Janeiro both held in 1992, the Millennium Summit 2000, the Earth Summit, 2002 and Ramser Summit 2005 had drawn world's attention to this crisis.

Water is one of the critical inputs for sustainability of agriculture, which consumes about 80 % of available water, but irrigation efficiency continues to be only about 40 %. The demand for water for agricultural purpose is estimated to increase from 50 M ha m in 1985 to 70 M ha m by 2050. The world water council believes that by the year 2020 we shall need 17 % more water than is available to feed the world. Therefore utmost care in management and foresight is necessary to use water judiciously and economically by various means through conservation, development, storage, distribution, reclamation and reuse in the 21st century for sustainable food security in the country as well as in the world.

As far as the Indian agriculture is concerned, irrigation plays a crucial role in the various development projects of the country. The existing methods of surface irrigation are less efficient and we are confronted with many problems regarding soil and water. A major challenge is to develop systems for greater precision in water and plant nutrient control, so as to increase the use efficiencies of soil, water and energy resources and to improve the environment for mankind. Expansion of irrigation is also essential for increasing food production for the alarming Indian population of one billion at present. With present potential of 114 M ha m of water, only 57 M ha (40 per cent) is under irrigation in India against the total cultivated area of 145 M ha. Therefore the effective management of water resources is essential to meet the increasing competition for water between agricultural and non-agricultural sectors. Also plans are to be introduced to reduce the present day share of 90 per cent of water used for agriculture to 75 to 80 per cent in the coming decades. This necessitates the scientific management of the available water resources in agricultural sector (source: CWRDM report., 2005).

Surface irrigation method, with an overall efficiency of only 20 to 50 per cent usually causes erosion, salinisation and water logging problems. Two important aspects to be considered in this regard are uniform water distribution in the field and accurate amount of water application by permitting accurate delivery control. These requirements are accomplished by adopting the promising drip / micro irrigation techniques.

The micro irrigation system is one of the most efficient methods of water application directly into soil at the root zone of plants. Simca Blass, a water engineer, originated drop by drop application of water to the plants through the drip irrigation system in Israel in the early 1960's. Now a days this system of irrigation finds its roots in countries like America, Australia, South Africa, Southern Europe etc. In India it was introduced in the early 70's and during the last few years this system has started gaining momentum. About 4 lakh ha of cultivated lands in India utilize this system of irrigation. Among the states, Maharashtra is the leading state covering 1, 42,347 ha under micro irrigation followed by Karnataka with 64,680 ha and Tamil Nadu with 43,292 ha. It is also expected that the projected area of 1 M ha (i.e. 1 per cent of irrigated area) will be brought under micro irrigation in the next 5 years and about 10 M ha by the year 2020 / 2025 AD. About 55 per cent of the total area of Kerala State with a humid tropical climate is under agriculture. The irrigated area in Kerala is estimated to be 1, 55,130 ha (1998) and the irrigated area in the plantation crops constitute only about 2.8 per cent of the total irrigated area in the State. The area under micro irrigation in Kerala is as low as 6000 ha (2001). So there is still ample scope, for this technique of irrigation in Kerala (source: CWRDM report., 2005).

Research activities in the field of micro irrigation systems are conducted all over the country through ICAR institutes and State Agriculture Universities, AICRP on application of plastics in agriculture, AICRP on water management, DRIPNET project and Adhoc schemes. The ministry of agriculture through NCPAH, which has 17 precision farming development centers (PFDC) located in different agro climatic conditions has also focused attention to develop regionally differentiated technologies on micro irrigation, besides imparting training to a large number of farmers and department staff. Now the adoption of the micro irrigation system started in areas having water scarcity, poor quality water and undulating terrain.

Micro irrigation which includes mainly drip and micro sprinklers is an effective tool for conserving water resources. It is an irrigation system with high frequency application of water in and around the root zone of plant system, which consists of a network of pipes along with suitable emitting devices. It permits a small uniform flow of water at a constant discharge, which does not change significantly through out the field. It also permits the irrigation to limit the watering closely to the consumptive use of plants. Thus it minimizes the conventional losses such as deep percolation, runoff and soil evaporation. It also permits the utilization of fertilizer, pesticides and other water-soluble chemicals along with irrigation water for better crop response.

It has been found that the micro irrigation saves fertilizer up to 30 per cent, increases the yield up to 100 per cent with saving of water up to 70 per cent. It also prevents weed growth, saves energy and improves the quality of the produce. Thus the micro irrigation system has to be seen as a holistic approach to address poverty alleviation, horticulture-led diversification of agriculture, enhanced productivity, environmental protection and ecological security, promotion of equity and reduced biotic and abiotic stresses. Now micro irrigation is a means of precision farming too.

But there are constraints in the development of micro irrigation systems. These constraints include lack of credit facilities, skilled human resources, availability of appropriate material and technical know how. Micro irrigation is generally perceived as a technology-driven movement, hence receives resistance from certain quarters. The initial cost of establishing micro irrigation system is as high as Rs 30,000 to 75,000 per ha, hence generally out of reach of resource poor farmers. Micro irrigation is not integrated with total water management system, hence generally viewed in isolation. Lack of information on temporal and spatial variation in soil moisture and on the optimal fraction of soil to be wetted, lack of availability of low cost soluble fertilizers and other agro chemicals and poor institutional support system are also the constraints.

Now these constraints are being solved to some extent. There are lot of schemes that provides financial assistance to the farmers up to the extent of 90 per cent of the capital cost of the system for a hectare or Rs.25,000/-per ha whichever is less for SC/ST, small or marginal and women farmers, and 70 per cent of the cost for other categories of farmers. The cost of incentive is shared in the ratio of 90 per cent by Central and 10 per cent by the State Governments. Moreover even with all these constraints and high initial investment it has also been observed that the pay back period of micro irrigation project is about one year only for most of the crops and benefit cost ratio varies from 2 to 5 (source: CWRDM report., 2005).

Presently water is applied once in every 7 to 15 days in surface or gravity irrigation depending on the soil. Hence moisture or water stress will be noticed just before irrigation and the growth of the crop is affected. Further more, it is difficult to give constantly the required quantity of water to the root zone using surface irrigation methods. So the yield is often less than the optimum. But in micro irrigation water is given daily and hence moisture is available always to the plants at field capacity. Large variety of crops such as orchards like grape vines, citrus, mangoes, guavas, vegetable crops like tomato, potato, peas, green pepper, okra, row crops like sugarcane, cotton, ornamental flowers like rose, jasmine and plantation crops like coconut have been successfully grown under drip system in the country.

As far as Indian economy is concerned, growing vegetable yields a much higher income per ha than any other type of farming. Tomato, brinjal, okra (Ladies Finger), cabbage, cucumber, amaranthus etc are some of the vegetables grown in India. It occupies an area of about 1.5 M ha in Indian agriculture. In many areas of India, vegetable is taken as a third crop in paddy field in summer season. Irrigation is an essential practice for the same. But the same is frequently interrupted due to the scarcity of water during the season. In this context drip irrigation is an effective method that can be resorted to improve the vegetable production. So during summer season, the aim is to utilize the available water effectively as well as to conserve whatever moisture available in the soil.

Kerala, which lies in the humid subtropics, gets a rain of an average of 300 cm per year out of which almost 70 per cent is received from the Southwest monsoon. Throughout Kerala, especially in northern regions, it is relatively dry during the periods from December to May. The amount and distribution of rainfall in many parts are not adequate to meet the total water requirement of crops. Kerala being dominated by plantation crops in two-third of the cropped area and due to uneven topography, drip irrigation is expected to have high demand. According to the latest data available 86.55 per cent of total cropped area is covered by plantation and horticultural crops. The contribution being 50.9 per cent by plantation crops, 12.16 per cent by spices, 13.55 per cent by fruits and 10.14 per cent by vegetables. Presently, the productivity of most of the plantation and horticulture crops in the state is far below the potential. Among other things, moisture stress during summer months is believed to be one of the reasons for this low productivity. The declining trend in the productivity of these crops which support vast majority of small and marginal farmers in the state is a matter of serious concern and could be addressed to a certain extent through adoption of better water management practices like micro irrigation. The average size of land holding in the state is 0.33 ha and the man to land ratio is declining fast. The per capita net zone area is 0.09 ha and gross cropped area is 0.11 ha. It is also reported that 85 per cent of the coconut, 79 per cent of arecanut, 76 per cent of pepper, 60 per cent of cashew, 55 per cent of rubber, 45 per cent of coffee and 86 per cent of banana are grown in holdings less than 2 ha. The nature of farming therefore is homestead with a mixture of crops in each tiny holding except for crops like rubber, cardamom and tea. The irrigation system suitable for these crops in homestead condition is minor irrigation with emphasis on drip or micro sprinkler irrigation (source: CWRDM report., 2005).

More over the soils of Kerala State being good in infiltration with low water holding capacities, surface methods of irrigation are inefficient causing frequent irrigation and excess wetting of soils by wasting water. The adoption of sprinkler and drip irrigation in such conditions improve the irrigation efficiency considerably over the surface methods. The state water bodies, especially wells in the coastal regions have high salt content. Hence adoption of drip irrigation opens the chances of using the saline water for irrigating crops like coconut. In most of the homestead farms in Kerala, irrigation is well - water based and the quality of water is excellent. This helps in reducing the problem of clogging. Hence there is ample scope for adoption of this advanced technique of irrigation in Kerala.

The micro irrigation system is generally classified on the basis of its installations in the field i.e. surface method or subsurface method. The advantages of surface drip irrigation are well proved and documented. Subsurface drip irrigation is an advanced and recent revolutionary variation of traditional drip irrigation where the tubing and emitters are buried beneath the soil surface such that the wetting front lies at least as high as 45 – 60 and as low as 10 – 15 cm below the soil surface. Besides having all the benefits of surface drip irrigation it has some additional advantages. The major advantages of subsurface drip irrigation are improvement in soil water status for crop which results in faster maturity of crops, saving of scarce precious water and improving irrigation efficiency by about 30 per cent over conventional drip irrigation. Weed problem is almost nil, as the surface of the soil remains dry. Heavy textured soils are well suited for subsurface drip irrigation where applicability of surface drip irrigation has been found to be difficult. Soils having very high water in take rate and stones in substratum are not suitable for subsurface drip irrigation. In subsurface drip system flow in a medium to heavy textured soils remain spherical for a sufficiently long time. Frequency of irrigation is quiet high ensuring the spherical flow geometry to be sufficient for emitter spacing and lateral depth calculation. The subsurface drip has got additional advantage of applying domestic effluent with least contamination risk of agricultural produce and field workers. Hence subsurface drip irrigation with domestic wastewater is a promising option nowadays. It also holds the promise of reducing weed growth, fertilizer and chemical use, labour requirement and optimizing water use.

Root intrusion and severe clogging problems have caused this approach of subsurface drip to be limited in its application in the past. However new strategies like biobarrier technologies are currently available seem to have overcomed this obstacle making subsurface drip irrigation a viable alternative.

The products being used today as subsurface drip irrigation come in four basic configurations viz porous tubing, hard hose, drip tape and inline drippers. The inline dripper commercially known as J- turbo line inline dripper commonly available from Jain irrigation is selected in this study as the subsurface drip irrigation system.

However, efficiency of water application under any system of micro irrigation suffers from non-uniformity of water distribution caused due to faulty design. The design of micro irrigation system must be in accordance with the crop demand, soil type and agro climatic characteristics of the place, for achieving the maximum productivity of quality produce including conservation of precious water and land resources. Relationship between dripper discharge and operating pressure, horizontal and vertical movement of soil moisture under the system, etc provides superior criteria for designing an efficient and economic system. This in turn requires knowledge of the factors and process that control the movement and storage of water in the soil and crop response to different soil moisture conditions. For uniform out flow from emitters, however information on their hydraulic characteristics is also very vital. In view of all the above facts this study has undertaken to evaluate the performance of subsurface drip irrigation for ladies finger (okra) in sandy loam soil with the following specific objectives:

1. To study the hydraulics of a subsurface drip irrigation system
2. To study the soil moisture distribution of the selected system in bare soil
3. To study the effect of depth of installation of subsurface drip irrigation on crop performance
4. To quantify the irrigation requirement of ladies finger under subsurface drip irrigation.
5. To make a comparative evaluation of drip irrigation system under surface and subsurface condition

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Micro irrigation-led agriculture, armed with knowledge and technologies with farmer as centre point should be viewed as one of the eco-technological approaches to attain sustained and enhanced agricultural production and productivity. The technology is bound to maximize the synergistic interactions of improved seeds, water and fertilizer. Micro irrigation ensures the congruence of sustainability, productivity, profitability and equity. Since micro irrigation greatly enhances water, fertilizer and energy use efficiency and promotes precision agriculture, the sustainability in agriculture could be achieved without the burden of environmental degradation.

In this chapter, available literature relevant to the present study are reviewed and presented under the following subheads -

1. Types of micro irrigation systems
2. Hydraulics of micro irrigation systems
3. Soil moisture distribution under subsurface drip
4. Field performance of subsurface drip
5. Effect of depth of installation of subsurface drip on crop performance
6. Water requirement of crops under subsurface drip
7. Use of waste water in subsurface drip
8. Comparative studies on surface and subsurface drip irrigation system

2. 1. Types of micro irrigation systems

Generally the emission devices which deliver water in the following three different modes are termed as micro irrigation systems. They are

1. Drip mode: In drip mode water is applied as droplets or trickles
2. Bubbler mode: In bubbler mode water bubbles out from the emitters
3. Micro sprinkler mode: Water is sprinkled, sprayed or misted.

Burt (1998) reported that there were many variations of drip/micro irrigation systems. This classification was based on agronomic or horticulture requirements. For frost protection micro sprinkler/sprayer designs offer better climatic control than emitters. For enabling one to irrigate alternate tree rows without wetting the soil around adjacent rows, drip emitters are preferred. An orchard crop with an extensive shallow root system will perform better under micro sprinkler/sprayer than under drip. Emitters are often spaced in arid regions so that at least 60 % of the potential root zone volume is wet, which provides an adequate moisture reservoir for the periods of high evapotranspitration and as insurance against several days of breakdowns.

He also reported three major categories of above ground drip viz. [1] Drip tape: Thin walled hose with integral emitters built into the walls or seams of the tape [2] Disposable tape products for one or two seasons [3] Totally portable systems. Regarding subsurface there are two main categories for row crop viz. [1] One crop buried drip system: The tape is buried 10 – 25 cm [2] Permanently buried drip on row crops: The tape is buried 20 – 40 cm below the ground surface and is designed to remain in place for 6 – 10 years.

Singh (2005) described the different types of micro irrigation systems in another way. Accordingly, the micro irrigation system is generally classified on the basis of its installations in the field. i.e. surface method or subsurface method. In surface method the drip lateral is laid along with the row of crop on surface ground and the drippers/ micro-sprinklers/micro-sprayers are installed as per layout and designs. The system has an advantage, when the short duration crops are grown i.e. vegetables/ cash crops. It can be rolled back when not required for irrigation activity. The subsurface installations are generally preferred in semi permanent/permanent installation, particularly for orchards. For orchards when drip laterals are used with online drippers, the laterals are laid 45-60 cm below soil surface, to avoid any damage during intercultural operations.

According to Lal and Sharma (1998) subsurface drip laterals are placed at such a depth that wetting front lies at least 10 to 15 cm below the soil surface thus applying water directly into the root zone and leaving top 10 to 15 cm surface profile dry.

Marais (2005) reported that there are three different positions for placing the subsurface drip irrigation system.

Shallow: 0.5 -10 cm deep

Medium: 10-25 cm deep

Deep : deeper than 25 cm

Normally a thinner wall thickness of 0.15 to 0.6 mm dripper lines are used in subsurface drip irrigation but in surface drip irrigation, the thickness is 0.6 to 1.2 mm.

According to Marais (2005), turbulent flow path types are more resistant to clogging than dripper with laminar flow path. The wider, deeper and shorter flow path in the dripper, the less the chances of clogging. Pressure compensating drippers and lower discharge rate drippers allow longer runs of laterals, while staying within the design norms. Drippers with a flapper split opening are prone to lesser suck back for sand and mud into subsurface drip system.

2. 2. Hydraulics of micro irrigation systems

Hills *et al.* (1989) studied the hydraulic considerations for compressed subsurface drip tape. Compression produced certain head loss in the lateral as well as some reduction in average emitter flow rate. Results indicated that in order to maintain a desired pressure variation, the lateral length should be shortened in accordance with the degree of deformation.

Mizyed and Kruse (1989) conducted studies on emitter discharge evaluation of subsurface trickle irrigation systems. The study revealed that the capacity of the field system was decreased about 20 % after 4 years of use because of plugging and ageing components. He developed a computer model to determine the discharge of the system. The computer program can simulate performance of each trickle set, gives information on outlet hydraulics, manufactures plugging coefficient of variation, piping sizes, lengths and elevations. Moreover he found that uniformity coefficient is used as an evaluation criterion for performance of trickle irrigation system.

Wu and Irudayaraj (1989) conducted sample size determination for evaluating drip irrigation systems. An equation was developed based on energy gradient and energy changes due to slope conditions. The result showed that the variation of calculated coefficient of variation of emitter flow using different sample sizes can be presented by statistical confidence limits for samples taken from normal distribution.

Hanson (1994) reported that 'drip tape' is a key component in the drip irrigation system. He found that the drip tape selection depends on desired level of emission uniformity, manufacturing coefficient of variation, sensitivity of emitters, discharge rate to pressure changes, clogging sensitivity and cost of the system. According to his study, the emission uniformity of permanent drip systems was greater than 80 %. Manufacturing Coefficient of Variation (Cv) showed that if the value is less than 0.05, it was considered as excellent, value in between 0.05 to 0.1 considered as good and value greater than 0.2 is considered as unacceptable. The study also revealed that the sensitivity of the emitter discharge rate to pressure changes and was described by the emitter discharge exponent. An exponent equal to'one' means that emitter is completely sensitive to pressure changes, an exponent equal to 'zero' means that the emitter is pressure compensating or the discharge rate is not affected by pressure changes.

Shani *et al.* (1996) conducted studies on subsurface emitters and pressure measurements and reported that when predetermined discharge of the emitter was larger than the infiltration capacity, water pressure at the emitter outlet increases. This pressure build up in the soil decreases the pressure difference across the emitter and subsequently decreases the trickle discharge. The extent of flow decrease depends on the soil type (lower the soil conductivity, the larger the decrease), the dripper discharge (larger decrease occur for higher nominal discharge), possible cavities near the dripper outlet (a larger cavity decreases the back pressure) and the drip system hydraulic properties.

Warrick and Shani (1996) did experiments on soil-limiting flow from subsurface emitters and its effect on uniformity. The study revealed that the soil properties affect the flow from the subsurface trickle emitters. This is due to the building up of pressure in the soil. When the design flow volume increases or the hydraulic conductivity of the soil decreases, the pressure head of the soil next to the emitter increases which reduces the flow rate. He also found that the calculated ratio of the actual discharge to the designed discharge was 0.905, 0.825 and 0.704 for designed discharges of 1, 2 and 4 lph respectively. Corresponding coefficients of variability were 0.072, 0.124 and 0.195 respectively and the Christiansen's uniformities were 0.95, 0.91 and 0.85 respectively.

Bagerello *et al.* (1997) carried out an experimental investigation to deduce an evaluating procedure of local losses due to protrusion of emitter barb in to the flow in drip irrigation lines. Local losses corresponding to different pipe online emitter systems were measured for different Reynolds number values.

Hassan (1997) evaluated the emission uniformity for micro irrigation system. He found that the emission uniformity is a sound indicator of the efficiency of micro irrigation system. The emission uniformity values for systems operating in one or more than one seasons are excellent if the value is greater than 90 %, good-80-90 %, fair-70-80 % and poor-less than 70 %. The study revealed that poor emission uniformity would lead to over irrigation, resulting in low efficiency and excessive energy consumption at the pump, resulting in contaminating ground water and leaching of fertilizers below the root zone. High emission uniformity is a prerequisite for efficient irrigation. Study also revealed that the pressure variation between the inlet to the manifold and the end of the farthest lateral on the manifold should not exceed 20 % and 10 % for turbulent and laminar flow emitters respectively to maintain high emission uniformity. This would result in variation in discharge rate of 10 % for both types of emitters.

Atre *et al.* (1998) conducted experiments on hydraulics of drip tubing. The study includes pressure discharge relationships and values of friction factors for the design of drip irrigation system. The discharge studies at different operating heads in 20, 40 and 60 m drip tubing showed that pressure increases with increase in discharge. But the discharge decreased with increase in length of drip tubing as number of outlets increase with increase in length. The pressure discharge relationship was explained by power function. The discharge exponent ranged in between 0.46 to 0.64, indicating the emitters of drip tubing are partially pressure compensating. The various friction factors were evaluated. Hazen Williams's 'C' and Darcy-Weisbach friction factor, 'f 'were found to be 112.8 and 0.593 respectively and Fanning's (F_f) and Blassius (F_b) friction factors were 0.0374 and 0.0367 respectively. The uniformity values were computed by Christiansen, Wilcox and Keller-Karmelli formulas. The values of emission uniformity computed by Keller- Karmelli were logical and ranged from 96 to 98 %.

Lal (1998) conducted studies on subsurface drip irrigation system by using surface drip laterals. Results indicated that the number of emitters on surface drip laterals should be increased by 26 % if they are to be used as subsurface drip lateral without altering emitter discharge rate. Discharge rate of surface drip lateral should be doubled when they are used as subsurface drip lateral without changing the number of emitters on lateral.

Jaiswal *et al.* (2001) conducted a study to determine the optimal length of lateral line for various discharge and emitter spacing .The results revealed that for a discharge of 4 lph emitter at 0.6, 1.2, 1.8 and 2.4 m emitter spacing, optimum lengths of lateral were 28.76, 59.7, 78.8 and 107.1 m respectively. At 10 % flow variation observed pressure variation for 0.6, 1.2, 1:8 and 2.4 m emitter spacing were 19.7, 22.89, 22.45 and 24.66 % respectively. For 8 lph emitter at 0.6, 1.2, 1.8 and 2.4 m emitter spacing optimum length of lateral were 20.2, 33.6, 49.8 and 63.8 m respectively. At 10 % discharge variation pressure variation at 0.6, 1.2, 1.8 and 2.4 m emitter spacing were 22.6, 18.2, 14 and 17.3 % respectively. It showed that flow and pressure variation along the lateral is directly proportional to number of emitter openings and emitter discharge rate.

Reddy *et al.* (2001) conducted an experiment to evaluate the barb losses for 8 types of online trickle irrigation emitters of 3 familiar brands with rated discharges ranging from 2 to 8 lph. In this study the average value of Darcy's friction factor 'f ' was found to be 0.026 for 12 mm trickle lateral pipe for operating pressure range of 0.62 to 1.1 kg/cm^2. Moreover he noticed that an increase in the energy loss of about 25 %, in case of 12 mm lateral with emitters compared to the same diameter plain pipe without emitters.

Kirnak *et al.* (2004) conducted a study to determine the hydraulic performance of trickle irrigation emitters used in irrigation systems in the Harran Plain. In this study the discharge rates and coefficients of Manufacturing Variation values were compared with test results for various types of inline emitters. A total of 9 drip irrigation lines comprising 7 non-compensating and 2 compensating emitters were tested at 50, 100, 150 and 250 KPa pressures. Compensating emitter exponents ranged from 0.02 to 0.05 while non compensating emitter values varied between 0.6 and 0.85.Test results showed that only 1 of the 7 compensating emitters and both compensating emitters had flow rates within ± 10 % of manufacture's reported values.

Lesikar *et al.* (2004) conducted experiments to evaluate the application uniformity of subsurface drip Irrigation systems. Flow rates were determined for emitters from three separate lateral lines at three locations and found that the mean emitter flow rate was 2.34, 2.4 and 1.89 lph for the three different sites. Uniformity also varied widely within individual lateral and between sites. This is due to lack of normal operating pressure in the drip laterals .These low operating pressure might be attributed to design and installation problems.

Habtamu *et al.* (2005) conducted a study to hydraulically characterize different sizes and lengths of micro tubes. For different flow regimes, equations were developed for operating pressure in terms of discharge, length and diameter of micro tube. The developed equations predict the measured discharge or operating pressure with sufficient accuracy.

Howell and Hiller (2005) reported that the flow conditions in the sub main and laterals of a drip irrigation system can be considered as steady and spatially varied with lateral outflows. The flow from the sub mains into the laterals or the outflow of each emitter from a lateral is controlled by the pressure distribution in the sub main and lateral lines. The variation of discharge from emitters along a lateral line is a function of the total length and inlet pressure, emitter spacing and total flow rate.

Kishor *et al.* (2005) tested the hydraulic performance of market available drippers. He used an automatic dripper testing set up for the study. The drippers were tested for pressure and discharge relation, pressure and coefficient of manufacturing variation, barb losses and uniformity coefficient. The pressure and discharge relations were developed for all drippers by fitting power equation to the data. The drippers had the Cv less than 5 % indicating the good performance, 5 to 10 % indicating the average performance while CV more than 10 % indicated the unacceptable range of performance. The uniformity coefficient of dripper was found to be more than 95 % at all operating pressure from 50 to 300 KPa.

Joseph *et al.* (2006) conducted studies on hydraulics and field performance of subsurface inline drip irrigation system. The average discharge at different operating heads (0.5 to 1.2 kg/cm^2) showed that as the pressure increases, discharge also increases. The power function was found to be good in explaining the discharge exponent in deciding the flow regime. The value of exponent in the power function was found to be 0.534 which suggest an orifice type emitter for the inline dripper. Moreover the EU values of the system were found to range between 90 to 95 % showing uniformity in the class excellent. As the pressure increases from 0.5 to 1.2 kg/cm^2, the CV value was found to be decrease from 7.865 to 4.565 % indicating average performance. The average value of friction factors C, F_b, F_f (Hazen William Formulae, Fanning's equation, Blassius equation) were found to be 100, 0.1019, 0.1188 respectively for 12 mm inline lateral. The approximate water application efficiency was found to vary from 89 to 94 % as the pressure varies from 0.5 to 1.2 kg/ cm^2.

2. 3. Soil moisture distribution under subsurface drip

Camp *et al.* (1989) conducted an experiment to evaluate the three micro irrigation lateral placements and two irrigation allocation modes for Corn in Coarse Textured Southeastern Coastal Plain Soil. Tubing placements were Surface in row (SIR), Subsurface in Row (SSIR) and Surface Alternate Middle (SAM). Analysis on tensiometer data showed that consistent difference in wetting patterns between SAM and other two placements. Wetting patterns also indicated that no difficulty for the SSIR treatment in delivery of water upwards from the emitter to higher portions of the root system.

Hernandez *et al.* (1991) evaluated the difference between surface and subsurface fertigation with respect to root, water and nutrient distributions in the soil and their effect on Sweet Corn yield. Emitters are placed 30 cm below the soil surface. It was found that at distances of 10 and 25 cm from the emitter, two pronounced minimum water content were observed both in the surface and subsurface emitter placements: at the 60-70 and 0-10 cm soil layers. Water content at a lateral distance of 40 cm (midway between the emitters) was significantly lower at any depth than moisture content at distances of 25 and 10 cm from the emitter. Further he concluded that the higher moisture content at a radius and depth of 10 and

30 cm, respectively, in the subsurface treatment (near the trickle) than in the surface fertigation treatment, may have contributed the higher root density observed in that region in the subsurface treatment.

Plaut *et al.* (1996) conducted studies on root and shoot response to subsurface drip irrigation due to partial wetting of upper soil profile in Cotton .Here the plants were grown in 60 cm high soil columns, the bottom 15 cm of which was kept wet by frequent drip irrigation, while the upper 45 cm was wetted three times per week up to 20, 40, 60, 80 or 100 % of pot capacity. Studies revealed that a significant rise in root length density was found at all moisture contents above 20 % in the two deepest soil segments. At 40 % the rise was from 0.2 to 0.8 cm cm^{-3}, due to the development of secondary roots at the wetted bottom of the column. When only 20 % of the root capacity was maintained in the top 45 cm of the profile, almost no roots reached the wetted soil volume, and root length density was very low.

Nassar and Jaikumaran (1998) conducted studies on soil moisture distribution pattern under subsurface pad irrigation system. The study revealed that the moisture distribution pattern under subsurface pad irrigation system (SSPIS) indicated that water is held for a longer period in the root zone under this system. The surface 0-15 cm soil layer contributed nearly $2/3^{rd}$ of the total moisture use by the crop without much variation between the methods of irrigation. In case of subsurface pad irrigation, the 15-30 cm soil layer contributed 24-29 % of total consumptive use where as in surface irrigation it was 22-23 %. Soil moisture was distributed rapidly in case of surface irrigation where as moisture distribution was gradual in case of SSPIS.

Powar *et al.* (2001) conducted a study on cane wall of 15.87 mm inner diameter and placed at 15 cm beneath soil surface for different length of 25, 50, 75 and 100 m with the outlet spacing of 30 cm to evaluate moisture distribution pattern and moisture advance under different rates of discharge (3, 4 and 5 lph/m) at different irrigation intervals (1, 2 and 3 days) 0, 24 and 48 hrs after irrigation. The experiment was performed in vertisol. The vertical and radial movement of moisture decreased with increase in discharge rate and increased with irrigation interval. The radial movement of moisture was observed maximum 24 hr after irrigation. About 30 % moisture contour moved faster in first 24 hrs compared to the next 24 hrs. Also that advanced in 48 hrs for 3 days irrigation interval vertically and radially up to 75 cm and 60 cm respectively. Vertical and radial movement of moisture were observed up to 85,80 and 75 cm and 54, 45 and 45 cm in 48 hrs at 3,4 and 5 lph/m discharge respectively. The radial and vertical spread of moisture was more for 3 lph/m than 4 and 5 lph/ m as the time of application of irrigation was more for the same volume of water applied. The vertical movement of moisture decreased with increase in discharge rate of cane wall and increased with irrigation interval.

Sakellariou-Makrantonaki *et al.* (2002) conducted a study to evaluate the subsurface drip irrigation (SDI) application effects on Sugar Beet Crop Performance. During this study, soil moisture distribution before and after irrigation were noted and showed that 15 cm below the soil surface in the SDI blocks is dry, so no evaporation occurs in comparison to surface irrigation blocks. The soil moisture at the depth 30 to 60 cm was higher in SDI blocks. Soil moisture values at the same depth in the surface system were lower than the field capacity.

Visalakshi *et al.* (2005) conducted studies on the flow phenomenon under surface and subsurface drip irrigation by observing the wetting pattern of the soil surface and soil profile under the system. The wetting pattern of emitter flow were studied with emitters of 2, 4, 6 and 8 lph discharge rates applied at the surface and 30 cm below the surface of soil. Generally an inverse relationship was observed between discharge rates and area wetted. The subsurface application resulted in an increase in soil moisture retention of 3 to 4 % at the point of application compared to that of the surface application. The pattern of moisture distribution was almost the same under both the locations of drip emitters.

Reddy *et al.* (2005) conducted a study on effect of subsurface Vs surface drip irrigation on soil moisture distribution pattern and found that the soil moisture status was significantly influenced by subsurface system.

Singh and Rajput (2005) found that wetted depth and widths under SDI were higher and lower respectively than under surface drip. With increase in depth of SDI laterals, wetted soil depths also increased. However it did not increased in same amount as depth of SDI laterals. Depth of soil wetting below emitters was lower than that under surface drip. Maximum soil wetted width of 0.68 m was observed under SDI with 0.05 m depth of lateral for which wetted width was 0.49 m.While maximum wetting depth of 0.61 m with 0.58 m wetted width was found under SDI with 0.15 m lateral depth 7 hours after water application.

Joseph *et al.* (2006) conducted studies on subsurface drip irrigation and found that the soil moisture distribution pattern was found to follow a bulb shape in all the contours. The surface soil appears to be almost dry, the moisture content beneath the surface was observed to maintain relatively high moisture content with an average of 26 %.The higher moisture content was observed at 15 cm below the soil surface where the emitter was placed. The average moisture content at the point of application was 25.7 % and 24.7 % respectively, for immediately after irrigation and 24 hrs after irrigation. The moisture content was found to decrease with depth beyond 45 cm. The vertical movement was more pronounced than the horizontal movement. As the radial distance from the emitter points increased up to 30 cm, the moisture content were found to decrease gradually.

2. 4. Field performance of subsurface drip

Phene *et al.* (1985) reported that the yield, quality and evapo transpiration of tomatoes are not affected by the depth of placement (surface Vs deep surface) of trickle laterals when irrigated volumes and frequencies were the same. The reported marketable yield of hand harvested tomatoes as 114,121 and 126 t/ha for low frequency surface drip, high frequency subsurface and high frequency surface drip respectively.

Plaut *et al.* (1985) reported that in spite of the high productivity of the drip irrigated cotton, the high cost and low durability of system as well as the labor involved in annual installing and dismantling are serious limitations. Subsurface drip irrigation over comes many of these problems as it can be installed once for many years. They found that the evaporation losses under surface drip was as high as 20 % where as negligible quantity was lost from the soil surface in case of subsurface drip. Cotton yield was unaffected by location of drip line. The subsurface irrigation was more efficient when limited quantities of water were applied as deep percolation was minimal and plant stress was prevented.

Tollefson (1985) reported that the subsurface drip irrigated cotton out yielded the conventional furrow irrigated fields by an average of 30 %. Yield of cotton was in the range of 8.75 to 10 bales/ha when irrigated with subsurface drip comparing favorably to the long-term average of 5.35 bales/ha. Cotton yield in subsurface irrigated plot declined after wards due to continuous cropping of cotton in comparison to furrow irrigated fields where crop was rotated

Oron *et al.* (1991) conducted experiments on cotton, corn, wheat and peas which were irrigated by surface and subsurface drip using effluent water. They reported that higher cotton yield was obtained under subsurface drip irrigation but more data are still needed to draw definite conclusions. Corn yield was also improved by subsurface drip but the wheat yield was better for surface drip. The pea yield was higher for subsurface drip irrigation.

Camp (1998) analyzed subsurface drip irrigation system and found that crop yield obtained from subsurface drip irrigation was greater than or equal to that for other irrigation methods and the system uses less water in most cases. The system provides facilities for injection of nutrients, pesticides and other chemicals to modify water and soil conditions. This system can also be used for waste water application for turf and landscape plants.

Singh (1998) sited that subsurface drip irrigation is advantageous in reducing the weed growth, fertilizer and chemical use, labour requirement and optimizing water use. This is due to the absence of surface evaporation, maintenance and injury are less than surface drip irrigation. Besides having all the benefits of surface drip irrigation it has some additional advantages. The water and nutrients are virtually hand fed directly into the roots of the plants. It is due to the fact that a more favorable root zone is created by maintaining relatively constant soil moisture.

Breazeale *et al.* (2000) conducted studies to determine the feasibility of subsurface drip irrigation for Alfalfa. He found that the use of subsurface drip irrigation in Alfalfa increases the yield as well as water use efficiency.

Gutal *et al.* (2005) in his study on scheduling of irrigation for strawberry through drip found that the amount of water to be applied at alternate day to strawberry crop through drip method of irrigation with 85 % of 2 days pan evaporation gave higher water use efficiency and significant higher fruit yield over other treatment.

2. 5. Effect of depth of installation of subsurface drip on crop performance

Hernandez *et al.* (1991) conducted experiments on Sweet Corn and reported that when the subsurface laterals are placed at a depth 30 cm below the soil surface gives marketable and total ear yields of about 3.22 and 4.9 kg/m^2. Total fresh weight; dry matter production and plant height during the growing season were also high at this depth. Moreover phosphorous and potassium content significantly increased at the centre of the root zone which in turn facilitated the higher dry matter production and commercial yield.

Phene *et al.* (1991) reviewed the effect of high frequency subsurface drip irrigation on root distribution of Sweet Corn. Study revealed that the root extension continued at depths in excess of 2 m and the root length density was higher at a depth of 30 to 45 cm.

Hutmacher *et al.* (1996) conducted studies on subsurface drip for improving Alfalfa irrigation in West. Here the subsurface drip lateral spacing of 40 inch and 80 inch installed at an average depth of 16 inches below the bed centers were evaluated. The yield obtained during the first one and one-half years of operation of experiment was 22 % higher in the drip plots than the furrow plots during the first phase of the experiment. When the drip laterals were buried under 25 to 28 inch depth, yield obtained was 26 to 35 % higher in subsurface drip irrigation plots.

Plaut *et al.* (1996) conducted experiments on Cotton root and shoot response to subsurface drip irrigation and partial wetting of the upper soil revealed that capillary rise of water from the subsurface source is minimal. Even the rate of root growth of a young seedling at this moisture content would be lower than that at higher moisture content, but would still be sufficient to reach wet soil at a depth of approximately 45 cm, where the subsurface system was placed. The plant growth is reduced under restricted soil water content, prior to the proliferation of the root system in wet soil. This is very significant at early stages but will be partially compensated at later stages. Hence this study revealed the potential use of subsurface drip irrigation of cotton when the surface soil layer has moisture content below field capacity.

Steele *et al.* (1996) evaluated the subsurface drip irrigation for Sweet Corn, Winter Squash and in Cabbage. Here the laterals were placed at 1.2 m apart and buried at 0.28 m depth on sandy loam soil. The marketable and total Sweet Corn yields averaged 6.2, 6.65 ton/acre respectively. Total yields for Winter Squash were 7.90, 3.03 and 14.23 ton/acre and for Cabbage, average yield was 43.7 ton/acre.

Howell *et al.* (1997) conducted a study to evaluate surface and subsurface micro irrigation on Corn Yields. Here subsurface drip laterals were placed 0.3 m below the surface with emitters spaced 0.45 m apart and drip lines were placed 1.5 m apart. Corn yield exceeding 1.4 kg/m^2 were achieved in 1994, and yields exceeding 1.3 kg /m^2 were even achieved with the late planting date and the insect problems in 1993.

Camp (1998) reviewed the subsurface drip irrigation and reported that lateral depth was seldom a treatment variable because crop yield varies with lateral depth. For installations where multiple year use and tillage were a consideration, lateral depth varied from 0.02 m to 0.70 m. Where tillage was not a consideration (turf grass, Alfalfa) depths were sometimes less (0.10 to 0.40 m) depending on crop rooting depth and soil. Seed germination, seedling establishment and growth were other factors affecting lateral depth. In general, the reported information suggested that lateral be placed as shallow as tillage practices allow for coarse textured soils and at the appropriate depth to prevent or minimize surface wetting in all cases. The existence of confining soil layers that interfere with upward water movement must also be considered.

Hutmacher *et al.* (1996) compared the subsurface drip and furrow irrigation with Alfalfa in the Imperial Valley. The study was conducted in silt loam soil .He found that when the subsurface drip laterals were placed at a depth of 40 cm below the bed centers, approximately 20 % higher yields were achieved with 94 % of the water application amounts used in the furrow irrigated plots. Also when the laterals were placed at a depth of 63 to 70 cm, the applied water and ET were similar in drip and furrow irrigated plots while yields averaged between 19 and 35 % higher in subsurface drip irrigated plots.

Reddy *et al.* (2005) conducted a study on effect of subsurface v surface drip irrigation on soil moisture distribution and growth of mango varieties. Four treatments via, subsurface irrigation with dripper at 20 cm, 30 cm depth, drip line at

30 cm depth with emitter in surface and subsurface drip line were arranged .Results indicated that plants height, stem growth, number of branches and plant spread were not influenced by the system of irrigation whereas soil moisture content at 50 cm away from the emitter was higher with subsurface drip irrigation than with surface drip irrigation at 60 cm depth. The moisture content at 100 cm away from the dripper with subsurface dripper at 30 cm depth was high at 60 cm soil depth directly vertical to the dripper than surface drip irrigation. The relative water content of leaf was higher with surface irrigation than subsurface drip irrigation.

Singh and Rajput (2005) studied the response of subsurface drip irrigation lateral depth on Okra. The study indicated that Okra yield increased significantly due to subsurface placements of laterals. The maximum yield increase was found to be 5.22, 13.48 and 11.56 % under 0.05, 0.1 and 0.15 m depths of lateral placement respectively compared to that of surface drip. Thus it was recommended that lateral of subsurface drip irrigation should be placed between 0.1 to 0.15 m depth below soil surface for higher yield in Okra.

2. 6. Water requirement of crops under subsurface drip

Tollefson (1985) reported that wheat under subsurface drip irrigation yielded 7625 kg of grain /ha on 46 cm of water compared to 6725 kg/ha on flood irrigated fields using 203 cm of water per year. The study was done for a double crop system of wheat and cotton. Subsurface irrigated grain out produced flood irrigated grain by 82 %. The yields of subsequent cotton crops planted after grain harvest were increased by 50 % on drip Vs furrow.

Camp *et al.* (1989) conducted an experiment to evaluate three micro irrigation lateral placements and two irrigation application modes for corn in a coarse textured Southeastern Coastal Plain Soil. Tubing placements were Surface in Row (SIR), Subsurface in Row (SSIR) and Surface Alternate Middle (SAM).study reveals that the yields were significantly lower for Surface Alternative Middle (SAM) irrigation treatments and for the Surface Alternative Middle (SAM) pulsed application mode treatment. The SSIR treatment required the least amount of irrigation water of about 0 to 50 mm out of about 350 mm annual requirement in each year. The SIR and SAM treatments required the 38 mm and 25 mm more irrigation than SSIR treatment during the year 1985, 1986 and 1987. For the three years, the maximum differences in irrigation amounts were 38, 50 and 25 mm respectively. The corn yield was also high in SSIR.

Hernandez *et al.* (1991) evaluated the difference between surface and subsurface fertigation with respect to root, water and nutrient distributions in the soil and their effect on Sweet Corn Yield. Emitters are placed 30 cm below the soil surface. It was found that at distances of 10 and 25 cm from the emitter, two pronounced minimum water content were observed both in the surface and subsurface emitter placements at the 60 to 70 cm and 0 to 10 cm soil layers .Water content at a lateral distance of 40 cm (midway between the emitters) was significantly lower at any depth than moisture content at distances of 25 and 10 cm from the emitter. Further he concluded that the higher moisture content at a radius and depth of 10 and 30 cm respectively in the subsurface treatment than in the surface fertgation treatment may have contributed to the higher root density observed in that region in the subsurface treatment.

Caldwell *et al.* (1994) conducted a study to evaluate the frequency of irrigation for subsurface drip irrigated corn. Four-time based treatments and four soil-water depletion based treatments were used to evaluate the effect of irrigation frequency on the production of subsurface drip irrigated corn. The corn yield obtained were 12.9 to 14.1 t/ha. He found that frequency of irrigation has no effect on Corn yield as long as average available soil water deficit is less than 20 %.The time based irrigation of seven days and depletion based irrigations of 50.8 mm lead to less drainage below the root zone and higher irrigation water use efficiencies than more frequent irrigations. Frequency of irrigation has no effect on crop water use efficiency.

Lamm *et al.* (1995) conducted studies to determine the water requirement of subsurface drip irrigated Corn in North West Kansas. The soil was Silt Loam with five irrigation treatments and dry land control. Analysis of the seasonal progression of soil water revealed that the well watered treatments (75 to 125 % of ET treatments) maintained stable soil water levels above approximately 55 to 60 % of field capacity for the 2.4 m soil profile, while the deficit irrigated treatments (no irrigation to 50 % ET treatments) mined the soil water. Corn yields were highly linearly related to calculated crop water use, producing 0.048 Mg/ha of grain for each millimeter of water used above a threshold of 328 mm. Analysis of the calculated water balance components indicated that careful management of subsurface drip irrigation system can reduce net irrigation needs by nearly 25 %, while still maintaining top yields of 12.5 Mg/ha.

Hutchmaker *et al.* (1996) conducted a study to focus on the comparison of crop response and irrigation water requirements as affected by subsurface drip versus furrow irrigation for Alfalfa (forage crop). The average yield obtained was 26 to 35 % higher in subsurface drip irrigation plots. Also there was no problem with excessive or low emitter rates and no evidence of root intrusion into the drip lines. An increase in water use efficiency in the order of 20 % was noted with subsurface drip irrigation.

Sakellariou-Makrantonaki *et al.* (2002) conducted a study to evaluate the surface and subsurface drip irrigation application effects on Sugar Beet Crop performance under two levels (100% and 80%) of water application depth. Lateral were buried 0.45 m under the ground and the soil moisture measurements were taken up to 75 cm depth. The results indicated that 80% and 100% subsurface drip irrigation treatments produced similar root yield, but the first saved 16.6 % irrigation water. Also 83.3 % of applied water may produce 22.2% more yield if water is applied as subsurface drip irrigation rather than surface drip. Furthermore there was little difference in sugar content between the 100 % and 80 % of subsurface drip irrigation treatments.

Colaizzi *et al.* (2004) compared the performance of SDI, Low–Energy Precision Application (LEPA) and Spray Irrigation. The study was conducted in Pullman Clay Loam Soil at Bush land Texas, in the Southern High Plains. Here each irrigation method was compared at five irrigation levels: 0 %, 25 %, 50% 75 % and 100 % of crop evapo transpiration. The study revealed that SDI had greater yield, water use efficiency, and irrigation water use efficiency than other irrigation methods within an irrigation level in most cases, but SDI and LEPA appeared to provide more water to transpiration and less to soil evaporation, which could enhance grain yield. The study also revealed that the largest water use efficiency occurred at 50 % and 75 % of full irrigation and the smallest Water Use Efficiency occurred for dry land. The highest Irrigation Water Use Efficiency (IWUE) occurred at 50 % of full irrigation.

Prakunhungsit *et al.* (2005) conducted a study on water application for Sugarcane U-Thong 3 variety by using ET/E ratio and subsurface drip (ET-water requirement of sugarcane and E-average evaporation data). The soil was clay loam with available moisture content of 10.8 %.The sugarcane was irrigated every seven days by subsurface drip with the discharge of 1.6 lph dripper at 1.0 bar. The result showed that the subsurface drip can be used well with sugarcane planting. The sugarcane can get water evenly as planned and for the average yields of 5 treatments were 170,140,140,100 and 110 t/ha respectively which the sugarcane received total water in five treatment were 1680,1440,1214,938 and 1122 mm with the average of 5.33,4.58,3.85,2.98 and 3.56 mm/day and the water use efficiency or harvested yield per unit of water were 10.31,9.52,11.33,10.31 and 9.86 kgs/m^3 respectively.

Reddy *et al.* (2005) conducted a study on effect of subsurface Vs surface drip irrigation on growth on mango revealed that plant height, stem girth ,number of branches and plant spread were not influenced by the system of irrigation.

Joseph *et al.* (2006) evaluate the performance of subsurface drip irrigation on Okra and found that the fruit yield was obtained as 0.54 kg/plant (18 t/ha), water applied was 1.8 lit/ day / plant. Analysis showed, the soil water content was very low in the upper 15 cm, but increased towards the bottom. Also the horizontal and vertical movement of water in the root zone was found to be 44 cm and 55 cm.

2. 7. Use of waste water in subsurface drip irrigation

Ben-David *et al.* (2001) conducted a study on subsurface drip irrigation of secondary waste water with minimal risks and he found that under subsurface drip irrigation the soil performs as a complementary biofilter, an extra stage in the conventional process of the domestic waste water treatment. The results indicated that improved yields are obtained under SDI. In addition the health and environmental risks diminished due to minimal contact of disposed effluent with surface agro technology activities. No specific problems of emitter clogging were encountered due to adequate filtering of the effluent at the head control.

Choi and Suarez –Rey (2004) conducted studies on SDI for Bermuda grass with reclaimed water. Studies revealed that no emitters were completely clogged, and emitter clogging was not serious enough to impact visual quality. Statistical uniformity of emitters were reduced from 91.8 % (for new emitters) to 85.3 % after the first year and 86.2 % after the third year, while flow rates remained at 3.75, 3.78 and 3.89 lph respectively. Moreover he found that SDI with reclaimed water creates a soil envelope surrounding the subsurface emitters which acts as a biological filter, enhancing the degradation of pathogens contained in the applied effluent. Also potential risk of disease caused by bacteria and viruses can be substantially reduced when treated effluent is distributed below ground for turf irrigation. He also observed that a dry surface reduces weed problems and improves the overall aesthetics of turf landscape.

Pandey (2005) conducted an experiment to see the possibility of subsurface drip irrigation so that the safe use of domestic waste water could be made. The performance of subsurface drip irrigation was compared with the surface drip irrigation. The soil surface in the case of subsurface drip irrigation was free from pathogens, whereas it was contaminated in the case of surface drip irrigation. The crop produce were found free from pathogens. The yield of ladies finger was obtained as 152 quintal/ha in the case of subsurface drip irrigation whereas it was 98 quintal/ha in case of surface drip irrigation. The yield of cabbage obtained was 214 quintal/ha in the case surface drip irrigation whereas it was obtained as 182 quintal/ha in the case of subsurface drip irrigation.

Taylor *et al.* (2006) conducted an experiment for assessing the effectiveness of subsurface drip line to apply treated wastewater for Turf irrigation in Western Australia. He found that subsurface drip line tubings are best suited for irrigating municipal parks and gardens with treated waste water.

2. 8. Comparative evaluation of surface and subsurface drip irrigation

Camp *et al.* (1989) compared the subsurface and alternate middle micro irrigation for the Southeastern Coastal Plain. Tubing placements were surface in row (SIR), subsurface in rows (SSIR) , surface alternate middle (SAM).The study revealed that there were no difference in corn grain yield except during moderate to severe drought.Yieds were significantly lower for the SAM treatments and for the SAM pulsed application mode treatments. There was a small difference in irrigation water among the three tubing placement treatments. The SSIR treatment required the least amount of irrigation water each year. Also wetting pattern indicated that no difficulty for the SSIR treatment in delivery of water upwards from the emitter to higher portion of the root system.

Hernandez *et al.* (1991) conducted a study to evaluate the effect of surface and subsurface drip fertigation on sweet corn rooting, uptake, dry matter production and yield. Study revealed that marketable and total year yield were higher for emitter placed 30 cm below the soil surface (3.22 and 4.9 kg/m^2 respectively) than on the surface (2.86 and 4.3 kg/m^2 respectively). Total fresh weight, dry matter production and plant height during the growing season were also greater for subsurface emitters. Subsurface drip fertigation significantly increase phosphorus and potassium content at the centre of the root zone. Moreover the root activity is high in subsurface than surface fertigation

Oron *et al.* (1991) conducted experiments on cotton, corn, wheat and peas which were irrigated by surface and subsurface drip using effluent water .They reported that higher cotton yield was obtained under subsurface drip irrigation but more data are still needed to draw definite conclusions. Corn yield was also improved by subsurface drip but the wheat yield was better for surface drip. The pea yield was higher for subsurface drip irrigation.

Phene *et al.* (1991) evaluated the effect of high frequency surface (S) and subsurface (SS) drip irrigation on root distribution of Sweet corn at three levels of phosphorous. Root sampling at the end of growing season indicated that root extension continued at depths in excess of 2 m in both the surface and subsurface drip at all phosphorus levels and greatest difference between SS and S treatments were observed in the top 45 cm depth. Higher root length density was observed in the surface 30 cm in S plots while the sweet-corn in the SS plots had greater root length density than S plots below 30 cm.

Hanson *et al.* (1997) compared furrow, surface drip and subsurface drip irrigation on lettuce yield and applied water. The overall performance showed similar lettuce yield for the furrow and subsurface drip methods, but a smaller yield for the surface drip method. Applied water for the drip method ranged between 43 and 74 % of of that of the furrow method. Spatial variability of plant mass along transects in each plot showed different patterns of variability between the furrow and drip transect. Variability in the plant mass of the furrow transect appeared unrelated to variability in both soil texture and soil water content. Less variability in the plant mass and yield occurred for the drip plots than for the furrow plots.

Comparison between surface and subsurface irrigation system made by Lal (1998) is as shown below.

Particulars	Surface	Subsurface
Wetted soil volume	small	large
wetted change of soil water content	large	Small
Surface evaporation	large	Small
Total transpiration	small	large
Irrigation efficiency	low	high

Moreover subsurface drip may improve irrigation efficiency by 30 % over surface drip .As far as the flow geometry is concerned, surface drip follows a hemispherical shape .But in the case of subsurface drip the flow geometry is a complete sphere.

Lal and Sharma (1998) reported that the major advantages of subsurface drip irrigation are improvement in soil water status for crop, saving of scarce precious water and improving irrigation efficiency by about 30 % over conventional drip irrigation. They also found that subsurface drip irrigation system is best suited for heavy textural soils. The system is not suitable for soils having very high intake rate and stones in the substratum. This system has got additional advantage of applying domestic effluent with least contamination risk of agricultural produce and field workers.

Hutmacher *et al.* (1996) compared the subsurface drip and furrow irrigation with Alfalfa in the Imperial Valley. The study was conducted in silt clay loam soil. He found that by using subsurface drip irrigation the water use efficiency was increased 20 % higher than with furrow irrigation method. Because of this higher water use efficiency the yield was also increased. When the applied water and ET were similar (within 5%) in drip and furrow irrigated plots, while yield averaged between 19 and 35 % higher in subsurface drip irrigated plots during two periods of the study.

Neufeld (2001) reported that SDI is a best method for water conservation. Studies revealed that out of eight irrigation methods, SDI had the higher water use efficiency. Since these drip tubes are placed 0.45 m below the soil surface, soil water remains in the root zone for utilization by growing plants, not lost to deep percolation. Problems with gravity irrigation systems that can be substantially reduced with SDI include erosion within the field, loss of nutrients and sediment from the field to drains or streams, washing of bacteria from fields to runoff water.

Whitaker *et al.* (2001) conducted studies on yield, quality and profitability of cotton produced with subsurface drip irrigation vs overhead sprinkler irrigation systems. The subsurface drip irrigated plots matured more quickly than the overhead irrigation.

Colaizzi *et al.* (2004) held a comparative study between SDI, LEPA and Spray irrigation performance for grain sorghum. The study was conducted at Bushland, Texas in Southern High Plains of a slowly permeable clay loam soil. Here each irrigation method was compared at 5 irrigation levels: 0 %, 25 %, 50 %, 75 % and 100 % of crop ET. The study revealed that SDI had greater yield, Water Use Efficiency (WUE), Irrigation Water Use Efficiency (IWUE) than other irrigation methods at 50 % irrigation.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter describes the materials used and the methods employed for the study entitled "Subsurface Drip Irrigation of Ladies Finger in Sandy Loam Soil" conducted at the Instructional Farm Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Malappuram, Kerala during the period of 2005-2007.

3.1 Location and Climate

The experiment was conducted in the Instructional Farm, KCAET, Tavanur, in Malappuram district, Kerala. The place is situated at 10^0 52' 30" North Latitude and 76^0 East longitude. The total area of KCAET is 40.99 ha, out of which total cropped area is 29.65 ha. Agro climatically, the area falls within the border line of Northern zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon. The average annual rainfall of the region varies from 2500 to 2900 mm. The climatological data of the experimental area is shown below.

Mean maximum temperature	: 32.5 ^{0} C
Mean minimum temperature	: 22 ^{0} C
Average relative humidity	: 83 %
Average annual rainfall	: 2000 mm
Mean evaporation	: 7 mm / day
Mean solar radiation	: 85 W/ m^2 / day

3.2 Evaluation of Soil Physical Properties

The soil properties like texture, structure, bulk density, porosity, water content, field capacity, permanent wilting point and infiltration capacity are the dominant factors which determine the availability of oxygen in the soil, the mobility of water through the soil, availability of water to the crop and ease of root penetration. Texture is an important soil characteristic since it affects the infiltration rate, water storage in the soil, ease of tilling the soil, the amount of aeration and influence of soil fertility. Knowledge of the bulk density is of particular importance in the determination of moisture content and other chemical and physical properties of the soil. It can be used to estimate the differences in compaction of the soil. The infiltration process influences run off, and determines the water content of the soil. Permeability (hydraulic conductivity) is proportional to the square of average particle size in a soil. The field capacity and permanent wilting point are the upper and lower ranges of moisture available to the plant which will influence the plant water uptake.

3.2.1 Soil texture

The particle size analysis, for finding out the percentage of various sizes of particles in a dry soil can be performed in two stages, sieve analysis for coarse grained fraction and sedimentation analysis for fine grained fraction.

In this study, composition of soil was determined by sieve analysis and hydrometer method. The soil was collected from the experimental field at a depth of 75 cm from the soil surface by using an auger. The soil sample was oven dried and passed through a set of IS sieves of size 4.75 mm, 2 mm, 1 mm, 600 micron, 425 micron, 300 micron, 212 micron, 150 micron and 75 micron for sieve analysis. The percentage finer was calculated on the basis of percentage of soil retained in each sieve.

For particles finer than 75 micron, sedimentation analysis was done using density hydrometer. The calibration of hydrometer was done. Sodium hexametaphosphate solution of 100 ml was added to the dry soil sample passing through 2 mm IS sieve. It was then warmed for 10 minutes and was mixed thoroughly for 15 minutes. The soil suspension was then transferred to 75 micron IS sieve placed on a receiver and washed the soil on the sieve using a jet of distilled water. The distilled water was added to the soil suspension to make the volume exactly to 1000 ml. A rubber bung was inserted on the top of 1000 ml measuring jar containing soil suspension and shakes it vigorously. The suspension was allowed to stand for some time. The cover of the cylinder was removed and stop watch was started immediately. The hydrometer reading was taken after ½ minute by inserting the hydrometer in the solution. Similarly the readings were taken at 1, 2, 4, 8, 15, 30, 60, 120, 180 and 900 minutes. Particle size was obtained for each hydrometer reading by using the formula.

$$D=10^{-5}\,F\ \sqrt{He/t}$$

Where D - Particle size (mm)

F - A factor which depends on the specific gravity of soil and temperature of the solution.

He - Effective depth obtained from the calibration chart (cm)

t - Elapsed time (min)

The particle size distribution curve was drawn with percentage finer 'N' as the ordinate and particle diameter (mm) as abscissa.

3.2.2 Bulk Density

The core cutter method was adopted to determine the bulk density. Soil samples were collected by using core sampler. The weight (W_1) and volume (V_1) of the core cutter were noted. The sample was then over dried and weighed again (W_2). Bulk density was calculated using the relation

$$\text{Bulk density} = (W_2-W_1)/V_1$$

3.2.3 Field Capacity

For determining the field capacity a soil surface of 2 sq.m was wetted to the saturation level and was left to drain for 2 days. The surface was covered with PVC sheet to prevent the evaporation. Soil samples were collected with an auger from different depths of 15, 30 and 45 cm. The values of moisture content of two successive samples which are nearly equal to this constant value of moisture content was considered as the field capacity of the soil.

3.2.4 Wilting Point

For determining wilting point the soil sample of 20 gram were taken from different depths of 15, 30 and 45 cm respectively. The soil sample was arranged in retaining rings evenly on the porous ceramic plates and filled them uniformly. The plate was filled with distilled water and left it for few hours for complete saturation of the plates and soil samples. The excess free water was drained with pipette from around the soil samples. Gradually raised the pressure to desired level of 15 atmospheres. After 72 hrs the sample was taken and oven dried at 105 ^{0}C. Then found out dry weight of the soil and calculated the moisture content on dry weight basis which represents the wilting point.

3.2.5 Infiltration Rate

Infiltration rate was measured using double ring infiltrometer. It consists of two cylinders of 25 cm deep and was made of 2 mm rolled steel. The outer cylinder, which was 60 cm in diameter, was used to form a buffer pond to minimize the lateral spreading of water. The infiltration measurement was taken from inner cylinder of 30 cm diameter. A constant head was maintained by ponding water into the cylinder. A hook gauge measurement was taken at frequent intervals to determine the amount of water infiltrated during a particular time interval.

Water was added quickly after each measurement to maintain a constant average infiltration head. The test was replicated at different locations in the field. The average values of accumulated infiltration (y) and infiltration rate were found. Using these data an equation of following form was developed to find functional relationship

$$y = a\,t^{\alpha} + b$$

Where

y = accumulated infiltration in cm

t = elapsed time in hour

a,b, α = constants

3.2.6 Saturated Hydraulic Conductivity

An undisturbed soil sample was collected from the field. After saturating the sample in a tray of water for 1 hour, the sample was processed and placed in a constant head permeameter experimental set up. The water supply was given to constant head permeameter. The soil column length 'L' (cm) and the head of the water over the soil column, h (cm) were noted. Measuring cylinder was placed below the soil column to collect the discharge. The water was allowed to infiltrate and discharge was measured once in 10 minutes and the process was repeated till the consecutive constant values were reached. It was calculated by using Darcy's law

$$K=QL/tha$$

Where K - hydraulic conductivity (cm/sec)

Q - discharge collected (cm^3)

L - Soil column length (cm)

h - head of the water over the soil column (cm)

t - time (sec)

a - area of soil column (cm^2)

3.3 Details of field selected for the study

The selected plot for the study was located in the Northern side of the farm which was almost nearer to the Bharathapuzha river basin. The plot was bounded with coconut palms on one side and peas at the other side and the soil in the selected plot was sandy loam. The total area selected for the study was 5 cents. Here both surface and subsurface drip method were practiced. There were two water outlets near to the selected plot. Proper land preparation was done before the installation of the system in the field. The field experiment was conducted during December to June when the irrigation demands would be the highest.

3.3.1 Field Installation, Operation and Maintenance of the system

Installation of the irrigation system can be divided into three stages:

1. Fitting of the filter unit
2. Laying of the mains and sub mains
3. Laying of laterals with emitters

3.3.1.1 Components of the System

1. Control unit

A 60 mm diameter gate valve was provided at the delivery line of the main pumping system to control the discharge rate. The various operating pressures were obtained by adjusting the gate valve provided at the delivery line. A dial pressure gauge of 0 to 6 kg/ cm^2 was installed at the outlet port of the filter to note the operating pressure.

2. Screen Filter

The filter unit should be fixed in such a way that it minimizes the use of fittings and was fixed on the delivery side of the water distribution system. The filter size was selected in accordance with the capacity of the system. It consisted of a double perforated cylinder in a metallic container for removing the foreign materials. Nominal size of the filter was 2'' (50 mm) with mesh size of 100 micron (120 meshes). Nominal pressure rating was 1.5 kg/cm^2 and nominal flow rate was 18 m^3/hr. The filter used for the present study was commercially known as Jain Disc Clean Filter.

3. Ball Valve Assembly

Ball valves, each having diameter of 50 mm was used on the sub mainline to control the flow into each block (Plate 1). The time of operation of these ball valves can be controlled according to the requirement of the irrigation to the individual field.

4. Laterals

The key component of the subsurface drip irrigation system is the lateral which is placed in the crop root zone and delivers water to the field. The laterals were inline drippers manufactured from Linear Low Density Poly Ethylene (LLDPE) having nominal diameter 16 mm. End caps were provided at the end of each laterals which helps to check the proper functioning of the system. Moreover it will help for periodic flushing of the laterals. Laying of laterals in field is shown in Plate 2.

5. Inline Drippers

In inline dripper emitters are fixed within the lateral line ie. the pipe was cut and dripper was fixed in between the cut ends such that it makes a continuous flow after fixing the dripper. The inline drippers have generally a simple thread or labyrinth type flow path. With the labyrinth type flow path, it is possible to have larger cross-sectional area and turbulent flow of water to prevent clogging of drippers. The head loss is less in inline emitters as there is no barb in inline emitters. It is usually necessary to shut off flow to the lateral and cut the pipe to replace a malfunctioning in inline emitters. Specifications of the inline drip lateral used for the present study is as follows

Commercial name	: J – Turbo line
Designation	: Emitting pipe [inline]
	IS 13488- 92 16- 3- 4-2- A
Nominal diameter	: 16 mm outer dia.
Class of emitting pipe	: 2
Uniformity category	: A
Emitter type	: Orifice
Flow regime	: Turbulent
Path of flow	: Labyrinth
Nominal emission rate	: 4 lph

Pressure Rating	: 0.125 M Pa (1.25 kg/cm ^{2})
Nominal pressure	: 1.5 kg/cm ^{2}
Spacing of emitter	: 50 cm
Wall thickness	: 1 – 2 mm

6. Flushing Valve Assembly

The three sub mains were provided with flush valve at the end of the system. Periodic flushing was done to remove the mud and sandy materials.

3.3.1.2 Installation Procedure

In order to install the system in the field proper land preparation was done. After the land preparation trenches were taken at a depth of 30 cm and length of 50 cm to lay the main line. The trenches were also taken at the same depth in two rows of length 25 m for placing the sub mains. Then, the sub main pipes were placed and connected to the mains. The laterals were placed at the corresponding positions of the drilled holes. The laterals were placed at five different depths of 0, 5, 10, 15 and 20 cm below the soil surface. End caps were provided at the end of each lateral line for flushing and checking the proper functioning of the system. The system was checked for its best operation.

Plate 1. A view of ball valve assembly on sub main to control flow into each block

Plate 2. A view of subsurface inline drip and its installation in the field

3.3.1.3 Operation of the System

1. Back wash the filter till clear water comes out through its flush valve
2. Close the flush valve after the sub main is completely flushed
3. When the laterals was completely flushed close them with the help of end caps
4. Check the pressure gauge at inlet and outlet of the filter
5. Obtain the desired operating pressure by bypass valve

3.3.1.4 Maintenance of the system

1. Check for leakage of pipe, valves, fittings, filter etc regularly
2. Open the flush valve on the filter so that the dirt and silt will be flushed out. Open the filter and take out the filter element and clean it in flowing water. Take rubber seals and clean them from both the sides
3. Flush the sub mains by removing the end caps till the water going out was cleaned
4. For long years of operation acid treatment or chlorine treatment should be done.

3.4 Hydraulics of Subsurface Drip Irrigation System in the Field

Drip irrigation systems can apply frequent and small amounts of irrigation water at many points of a field at surface or subsurface near the plants. Drip irrigation with inline or online emitters is a reliable system for small farmland holding. But the efficiency of water application under this system at number of locations in field condition suffers from non-uniformity of water distribution caused due to faulty design. Dripper is a critical component of drip irrigation system. The design of dripper considers the proper material construction, its manufacturing process and hydraulic performance. Drip irrigation system is efficient in the utilization of water and energy due to low operating pressure and controlled application of water. The aim of drip irrigation design is to ensure uniform distribution of water to the crop with pre-determined rate of application of water. Therefore for uniform outflow from emitter, informations on their hydraulic characteristics are very vital. In this study the following hydraulic characteristics of inline drippers were analyzed at different lateral depths of 0, 5, 10, 15 and 20 cm in the experimental field

1. Operating pressure Vs discharge relationship of inline dripper
2. Variation in emission uniformity
3. Variability in manufacturing coefficient of variation
4. Determination of 'f' factor & Reynolds number
5. Determination of water application efficiency

Equipment needed for the hydraulic study in the actual field

1. Pressure gauge (0-6 kg/cm^2)
2. A stop watch
3. Graduated cylinder with 250 ml capacity
4. Catch cans for collecting the discharge

3.4.1 Operating pressure Vs discharge relationship of inline drippers

In order to study the hydraulic performance of subsurface drip irrigation system it was installed in the field and tested for pressure discharge relation. Testing was initiated by selecting seven operating pressures ranging from 0.3-1.8 kg/cm^2. The discharge was collected for a specific period of three minutes time in catch cans. Before starting, the catch cans were placed at different depths of 0, 5, 10, 15 and 20 cm by making small pits, where the emitters were located actually in the field. The gate valve was adjusted to maintain the required operating pressure which was monitored by the pressure gauge. A stopwatch was used to note the time. The water collected in catch can was measured by using a measuring jar. The procedure was repeated for different operating pressures. The discharge rate was determined by dividing the volume of water collected with the corresponding time. For different flow regimes the pressure and discharge relations were developed for the inline drippers by fitting power equation to the data. The developed equations predict the measured discharge or operating pressure with sufficient accuracy.

3.4.2 Variation in emission uniformity

The coefficient of uniformity is a measure of the hydrodynamic behavior of the system. It is an indicator of how equal the application rates resulting from the delivery devices are. In field, water distribution efficiency of the system is closely related to emission uniformity, which in turn determines the application efficiency. An efficient micro irrigation system must apply water uniformly through out the field.

3.4.2.1 Procedure for evaluating the emission uniformity

1. Flush the system piping and emitter laterals thoroughly, starting with larger pipes, then the smaller ones.
2. Clean the screen filters
3. Inspect the required pressure at pump discharge, across main filter and at the inlet to the main line and sub main of the lateral
4. Measure the discharge

3.4.2.2 Computation of Eu value

Add up all measured emitter discharge rates from individual emitter at a particular depth and at a particular pressure and divide the sum by number of measurements to obtain the average discharge rate. Select the lower 25 % of the measured discharge rates, i.e. if 8 measurements were made, then take the lowest two and calculate their average. This is the average of the lowest quarter.

Then,

Eu = (average of the lowest quarter / average discharge rate) x 100 [Keller & Karmelli formula]

Eu was also calculated with the following two formulae:

$$Eu = [1 - \{\Sigma X / M n\}] \times 100$$ [Christiannsen formula]

$$Eu = [1 - SD / M] \times 100$$ [Wilcox formula]

Where Eu - Emission uniformity

X - Numerical deviation of individual observations from the average application rate

SD - Standard deviation of discharge

M - Mean of the discharge

n - no. of observations

General criteria for Eu values for systems, which have been in operation for one or more seasons are as follows

Eu values greater than 90 % - Excellent

Eu values between 80 – 90 % - Good

Eu values between 70 – 80 % - Fair

Eu values less than 70 % - Poor

The variation of emission uniformity with respect to operating pressure was studied and plotted graphically.

3.4.3 Variability in manufacturing coefficient of variation

Small differences between emitters which appear to be identical may result in significant discharge variations. The manufacture's coefficient of emitter variation is a measure of the variability of discharge of a random sample of a given make, model and size of emitter as produced by the manufacturer and before any field operation of aging has taken place. The manufacture's coefficient of emitter variation (CV_m) is defined as

$$CV_m = s / q_a$$

Where

q_a - average discharge rate of emitters at that reference pressure head (lph) s - standard deviation of the emitter discharge rates at that reference pressure head (lph)

$$S = \sqrt{\sum (Xi - X)^2 / (n-1)}$$

where

X - Mean value of discharges

X_i - Discharge of i^{th} emitter

n - Number of emitters

i - a subscript identifying individual emitters.

Manufacturing precision was estimated in terms of manufacturer's coefficient of variation as follows:

If $CV_m < 5\%$, good performance

CV_m - 5-10 % average performance

CV_m - 10-15% marginal performance

CV_m >15% unacceptable

The present inline drippers were tested for pressure and coefficient of manufacturing variation relationship at laterals placed at different depths of 0, 5, 10, 15 and 20 cm and the results are tabulated and are presented graphically.

3.4.4. Determination of 'f' factors and Reynolds number for inline dripper

The determination of 'f' factor for calculating the total head loss along a multiple outlet pipes is of much value for proper design of the system. The emitters were operated under pressures ranging from 0.3 to 1.8 kg/cm^2 at different depths of 0, 5, 10, 15 and 20 cm. So the values of 'f' factors were determined by the following equations

Fanning's equation

$$F_f = 0.0056 + 1 / (2\ Re^{0.32})$$

Blassius's equation

$$F_b = 0.316 / Re^{0.25}$$

Re – Reynolds's number

$$Re = V\ d / \nu$$

Where V - velocity through the pipe in m/s

d - diameter of the lateral in m

ν - kinematic viscosity in m^2/s

3.4.5 Determination of water application efficiency at different operating pressures

The adequacy of soil moisture distribution and resulting application efficiency are the two very important components of a complete micro irrigation system evaluation. Plant root zone, irrigation application rate, water application uniformity and allowable irrigation deficit affect the application efficiency. So the application efficiency was calculated by

$$Ea = q_{min} / q_{avg} \times 100$$

Where Ea - water application efficiency (%)

q_{min} - minimum discharge (lph)

q_{avg} - average discharge (lph)

$$q_{avg} = (q_{max} + q_{min}) / 2$$

The effectiveness of a drip system can be estimated by how much of the water is stored in the root zone and is available for consumptive use by the plant. So the water application efficiency and its variation with respect to pressure at different depths were also studied.

3.5 Soil moisture distribution under subsurface drip irrigation system in bare soil

In order to study the soil moisture distribution under subsurface inline emitter, an experiment was conducted in the bare soil of the filed to eliminate the effect of moisture removal by roots. Since the subsurface drip laterals were placed at different depths, the soil moisture distribution patterns were studied separately for different depths. The emitters were located at 0, 5, 10, 15 and 20 cm depths from the surface and they are spaced at 50 cm interval along the laterals, which are spaced at 50 cm interval. The actual discharges obtained in the field during the hydraulics study were 3.7, 4.0, 4.0, 4.3 and 4.4 lph respectively for 0, 5, 10, 15 and 20 cm depths of installations. The average discharge at 1.5 kg/cm^2 calculated from different depth of installation in the field was 4.0 lph. Hence the moisture distribution pattern was studied for the same discharge of 4.0 lph at different depth of installation. The system was operated for 64, 60, 60, 56 and 54 minutes at its recommended pressure of 1.5 kg / cm^2 to get the same emitter discharge of 4.0 lph for all depths of installation. Therefore the total quantity of water applied was 4.0 liters which remain same for all depths of installation.

Profiles were exposed by cutting the soil vertically across the centre of the point of application of subsurface drip at 0, 5, 10, 15 and 20 cm of the depth of laterals. A close view of the exposed profile is shown in Plate 3. The dimensions of the wetted profile in horizontal and vertical directions were measured and recorded by measurements and photographs. The vertical profile exposed should have a total horizontal length of 40 cm to one side of the emitter and 40 cm to other side of the emitter and a vertical length of 50 cm downwards. Soil samples at grid points of 10 cm x 10 cm were collected before irrigation, half an hour after irrigation and 24 hours after irrigation and moisture contents were determined gravimetrically. The moisture data were analyzed for distribution pattern by plotting moisture contour using the computer software package "SURFER 32" of windows version.

3.6 Field study to evaluate the effect of depth of installation and water requirement of Okra under Subsurface Drip Irrigation System

A field experiment was conducted to study the effect of depth of installation and water requirement for the crop okra and the same was compared with surface system. A field layout with plants is shown in Fig.1.

3.6.1 Crop and variety

Vegetables such as tomato, brinjal and okra are closely spaced and these plants cover the entire soil surface on maturity. They respond favorable under low soil water tension. Okra being one of the most popular vegetable crops of Kerala, grown in tropical and subtropical regions for its tender green fruits. Hence this particular study selected this crop, for evaluation. The variety was *Salkeerthi*. Crop spacing is 50 x 50 cm with a root zone depth of 45 cm. The total duration of the crop was 120 days.

Plate 3. A close view of the exposed profile in the bare field

3.6.2 Statistical Design for the Study

The statistical design selected for the study was Randomized Complete Block Design (RCBD) with 15 treatments and three replications. The overall size of the experimental plot selected for the study was 23 x 6.5 m^2 consisting of 45 plots arranged in three blocks. Each block contains 15 plots length wise and the treatments includes 5 depths of placement of laterals (0, 5, 10, 15, 20 cm) and three levels of irrigation water (1.0, 1.5, 2.0 liters/day/plant). So there were a total of 45 plots with 540 plants. The area of each plot was 1.5 x 1.0 m^2 with 12 plants in each plot at a spacing of 50 cm. The treatments were as follows

Table 1. Details of Treatments

Treatment	Name	Area (m^2)	Depth of Installation (cm)	Irrigation Applied (lit/day/plant)
T_1	D_1I_1	1.5	0	1
T_2	D_2I_1	1.5	5	1
T_3	D_3I_1	1.5	10	1
T_4	D_4I_1	1.5	15	1
T_5	D_5I_1	1.5	20	1
T_6	D_1I_2	1.5	0	1.5
T_7	D_2I_2	1.5	5	1.5
T_8	D_3I_2	1.5	10	1.5
T_9	D_4I_2	1.5	15	1.5
T_{10}	D_5I_2	1.5	20	1.5
T_{11}	D_1I_3	1.5	0	2
T_{12}	D_2I_3	1.5	5	2
T_{13}	D_3I_3	1.5	10	2
T_{14}	D_4I_3	1.5	15	2
T_{15}	D_5I_3	1.5	20	2

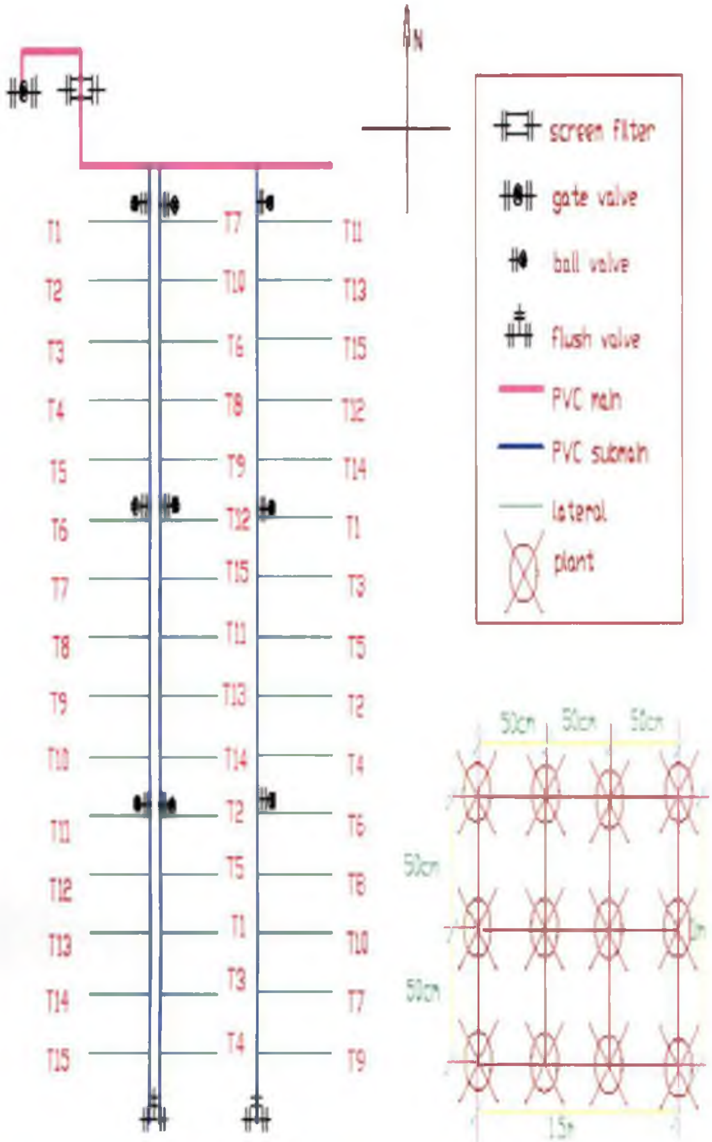

Fig.1 Field layout with plant

plan of indidual plot

3.6.3 Sowing

A few days before sowing, the seed bed was prepared and herbicides were applied. Sowing was done in February with a target population of 8 plants/ m^2. So each plot consists of 12 plants. The seeds were soaked in water one day before sowing for enhancing the germination. The soaked seeds were put at a distance of 5 cm from the pre marked emitter positions.

3.6.4 Estimation of Crop Water Requirement

Water requirement of crops (WR) is a function of plants, surface area covered by plants and evapotranspitration rate. Irrigation water requirement has to be calculated for different season. The maximum discharge required during any one of the three seasons is adopted for design. The daily water requirement for fully-grown plants was calculated as under

$$V = E_p \times K_c \times K_p \times W_p \times S_p$$

If there is rainfall, the net depth of irrigation to be applied is

$$V_n = V - (R_e \times S_p)$$

Total water requirement of the farm plot = V_n x no. of plants

The values of the various parameters used for estimating the water requirement of okra in the present case is shown in bracket against each parameter explained

V - water requirement in litre/day/ plant

E_p - maximum pan evaporation in mm / day (10 mm/day)

K_c - crop factor. The value of crop factor depends on foliage characteristics, stage of growth, environment and geography ($K_c = 1$)

K_p - pan coefficient (0.7)

W_p - wetted area, which is shaded due to canopy. Canopy cover when the sun is over head, which depends on the stage of crop growth. This is other wise known as canopy factor (W_p = 1) for a matured okra plant.

S_p - spacing of crops in m^2 (50 x 50 cm)

R_e - effective rainfall in mm (Nil)

Therefore the estimated water requirement was found to be 2 litres/ day/ plant.

3.6.5 Scheduling of Irrigation

As the roots were so short during the seedling stage manual watering was done for a period of one week to ensure that the roots get enough water to survive. Irrigations were scheduled based on the daily crop water requirement of the crop in Tavanur region of Malappuram district in Kerala, as estimated above. In order to determine the optimum water requirement for the crop, three irrigation levels were adopted which was 50, 75 and 100 % of water requirement of okra. Accordingly the three levels of irrigation were selected as 1.0, 1.5 and 2.0 litres/ day/ plant respectively. The discharge rate of the emitter was 4 lph at a nominal pressure of 1.5 kg/cm^2. So daily irrigation was applied for a time period of 15, 23 and 30 minutes to obtain a discharge rate of 1.0, 1.5 and 2.0 litres/ day/ plant.

3.6.6 Fertilizer and Pesticide application

Fertilizers were applied based on the package of practices recommendations of KAU. Farm Yard Manure (FYM) was applied as basal dose @ 12 t/ha. At the time of sowing, N, P_2O_5 and K_2O @ 25, 9 and 25 kg/ha were applied. After that 16 kg rajphos, 8 kg urea and 25 kg potash were applied one month after planting. Necessary plant protection methods were also done at the proper time.

3.6.7 Weeding

Weeds interfere with the growth of the crop by absorbing water and nutrients. Therefore periodical removal of the weeds was essential to maintain an optimum growth rate for the crops. Manual weeding was done on weekly basis and the weed count in a representative plot was noted for the highest irrigation level of 2 litre /day/plant

3.7 Parameters Evaluated to Study the Depth of Installation and Levels of Irrigation

The performance of the system was evaluated under the following sub heads.

1. Yield
2. Biometric observations
    a. Height of the plant
    b. Girth of plant
    c. Number of leaves
3. Water use efficiency
4. Weed infestation
5. Pinching of the hose by roots & root intrusion into the emitter
6. Root proliferation and water distribution under subsurface inline dripper in the crop root zone

3.7.1 Yield measurements

First harvesting was done in the middle of April 2007. Afterwards harvesting was done on alternate days. Yield was recorded separately for each treatment. Yield data were evaluated to know how evenly the water and nutrients were being distributed in the plot.

3.7.2 Biometric observations

Biometric observations were taken one, two and three month after planting. From each plot one plant was selected randomly and measurements of height, girth and number of leaves of the plant were made.

3.7.2.1 Height of the plant

The height of the selected plant grown under each treatment was taken. The measurement was taken from the ground surface to the shoot tip for the selected crop.

3.7.2.2 Girth of the plant

One month after planting the thickness of the stem was measured on the selected crop at intervals of one month. The reading was taken 2.5 cm above the ground level.

3.7.2.3 Number of leaves

The numbers of leaves were counted for the selected crop in each treatment

3.7.3 Determination of Water Use Efficiency

Water use efficiency was calculated for each treatment. It is the ratio of the yield of the crop in kg/ha and total water applied in mm.

$$Ew = Y/Wu$$

where,

Ew = water use efficiency (kg/ha mm)

Y = yield of the crop in kg/ha

Wu = Total water applied, mm

3.7.4 Root proliferation and water distribution under subsurface inline dripper in the crop root zone

The root length and root zone length were measured at the end of the crop period before removing the crop. Root zone was the area in which the maximum root hairs which assist in the absorption exist and was measured laterally. The maximum length of the roots was called the root length and was measured vertically. The distribution of water within the root zone of the crop was also studied at the time of crop removal.

3.8 Statistical Analysis for yield and biometric observations

An ANOVA test was performed to find out the significance of difference between group means. The ANOVA analysis does not indicate between which means there is a significance difference. An ANOVA test, Tukey's test was necessary to find out between which means there is a significant difference. The Tukey's test is designed to perform a pair wise comparison of the means to see where there is significance difference. The minimum pair wise difference needed for significance

$$Xmax - Xmin \qquad T\ (error\ (df))\ X \sqrt{EMS / R}$$

3.9 Comparison with surface and subsurface drip irrigation

Based on the above observations a comparison was made between surface and subsurface drip irrigation systems.

RESULTS AND DISCUSSION

CHAPTER IV
RESULTS AND DISCUSSION

An experiment was conducted to evaluate the hydraulics and field performance of subsurface drip irrigation of ladies finger in sandy loam soil. The hydraulic characteristics such as pressure discharge relationship, variation in emission uniformity, manufacturing coefficient of variation, friction factors, Reynolds number and application efficiency were assessed. The field performance of the system was tested for the crop ladies finger on growth and yield characteristics. The subsurface drip irrigation system was also evaluated for different depths of installations and different levels of irrigation.

The results obtained from the study were analyzed to provide basic information of soil moisture movement under subsurface drip irrigation and its performance on growth and yield of crop. The results of the study were discussed in this chapter under the following sub heads.

4.1 Evaluation of Soil Physical Properties

The following basic soil properties which influence the performance of the system were determined.

4.1.1 Soil texture

The results of the soil textural analysis are shown in APPENDICES I and II. The results of the mechanical analysis (both sieve and sedimentation) were plotted to get particle size distribution curve. In this curve, percentage finer "N' was taken as ordinate and particle diameter (mm) as the abscissa on logarithmic scale. The resulting curve is shown in Fig. 2. The figure showed that the soil sample consisted of 79.9 % sand having size range 2 to 0.05 mm, 16.69 % silt (0.05 to 0.002 mm) and the remaining part 2.41 % clay. As per the USDA classification chart, the textural class of the soil was found to be sandy loam.

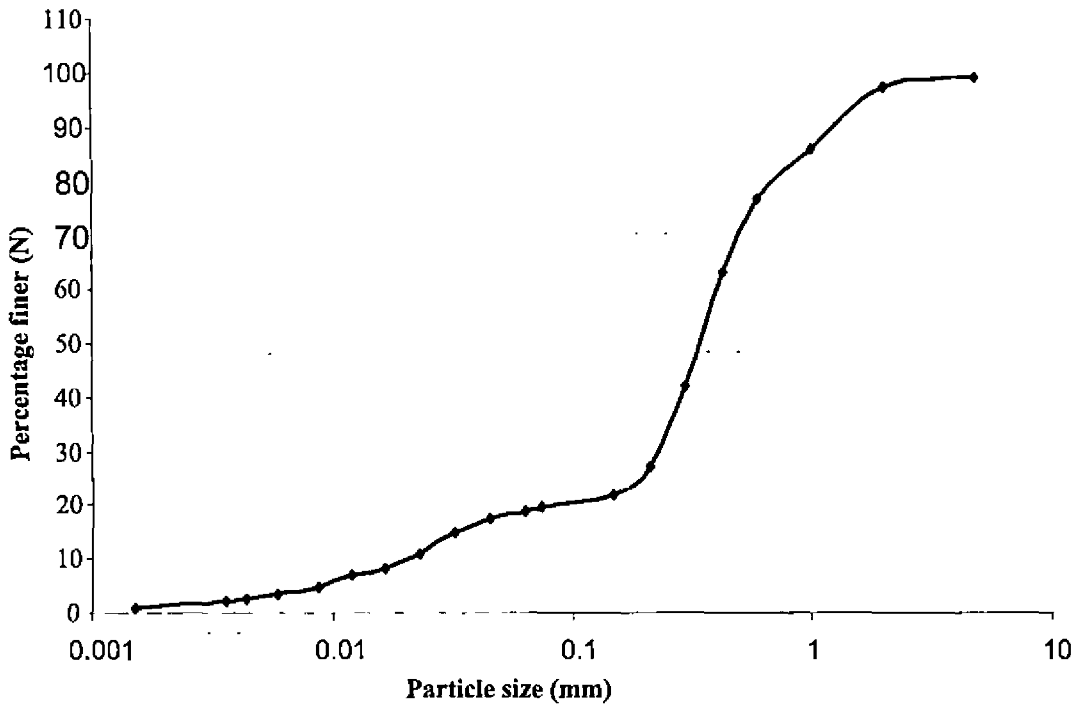

Fig. 2. Particle size distribution curve

4.1.2 Bulk Density

The bulk density of the soil in the experimental field was found by core cutter method. The weight and volume of core cutter and weight of soil samples are given in APPENDIX III. The mean bulk density of the soil was found to be 1.7 g/cm^3 which lie within the range of 1.5 to 1.8 g/cm^3 for sandy loam soil.

4.1.3 Field Capacity

Soil samples were taken for determining the field capacity. It was found that the soil reached field capacity, 24 hours after saturation. The field capacity was determined as 10 % for the soil and the value is within the standard limit of 3 to 15 % for sandy loam soil.

4.1.4 Wilting Point

The average wilting point of the soil is determined as 5.7 % which is in conformity with the standard range of 3 to 8 % for sandy loam soil.

4.1.5 Infiltration Rate

A double ring cylinder infiltrometer test was conducted to determine the infiltration rate of the soil as the performance of the system was influenced by the infiltration properties of the soil. The field data on cylinder infiltrometer is given in APPENDIX IV. The functional relationship between accumulated infiltration and time was fitted as

$$y= 0.42\, t^{0.79} + 0.54$$

The basic infiltration rate of sandy loam soil ranges between 6.5 to 12.5 cm/hr. The average basic infiltration rate of the soil was found to be 8.1 cm/hr.

4.1.6 Saturated Hydraulic Conductivity

The subsurface movement of water is greatly influenced by the hydraulic conductivity of soil. Hence the hydraulic conductivity was experimentally found out and the data were given in APPENDIX V. The corresponding value obtained as 2.05×10^{-4} cm/sec.

4.2 Design and Installation of the System in the Field

The system was designed and installed in the field.

4.2.1 Description of irrigation system

a) Mainline

Material	: PVC
Size	: 60 mm
Length	: 0.5 m
Installation depth	: 0.3 m

b) Sub main

Material	: PVC
Size	: 50 mm
Length	: 25 m
Lateral spacing	: 1.5 m
Installation depth	: 0.3 m

c) Lateral line

Material	: LLDPE
Size	: 16 mm
Emitter spacing	: 50 cm
Installation depths	: 0, 5, 10, 15 and 20 cm

d) Emitter

Type	: inline dripper
Manufacturer	: Jain irrigation
Discharge	: 4 lph
Operating pressure	: 1.5 kg /cm ^{2}
Time of irrigation	: 15, 23 and 30 minutes to get three different levels of irrigation 1.0, 1.5, 2.0 litre /day/plant respectively.

e) Filter

Type of filter	: Jain Disc Clean Filter
Nominal flow rate	: 18 m^3/hr

4.2.2 Hydraulics of Subsurface Drip Irrigation System

The drip irrigation system offers the highest irrigation uniformity compared with other methods of irrigation. Success of micro irrigation system depends on the physical and hydraulic characteristic of the drip lateral. Hence the following hydraulic characteristics of the lateral were studied in the field at different depth of installations.

4.2.2.1 Operating pressure Vs discharge relationship of subsurface inline drippers

The pressure discharge relationship is useful to know the head requirement to operate the emitter at the prescribed flow rates and design the lateral diameter and length to keep the pressure variation along the lateral within limits. The discharges observed at different operating pressures at different lateral depths were shown in APPENDIX VI and the mean discharge is tabulated in Table 2. The pressure discharge relationship was described by fitting power functions to the data and is shown in Fig.3.

Table 2. Pressure- Discharge Relationship

Sl.No	Pressure (kg/cm^2)	Discharge (lph)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	1.1	1.3	1.6	1.8	1.9
2	0.6	1.4	1.5	2.0	2.1	2.3
3	0.9	1.9	2.6	2.9	2.9	3.0
4	1.0	2.2	2.8	3.1	3.1	3.2
5	1.2	2.8	3.2	3.5	3.5	3.6
6	1.5	3.7	4.0	4.0	4.3	4.4
7	1.8	4.0	4.4	4.4	4.5	4.7

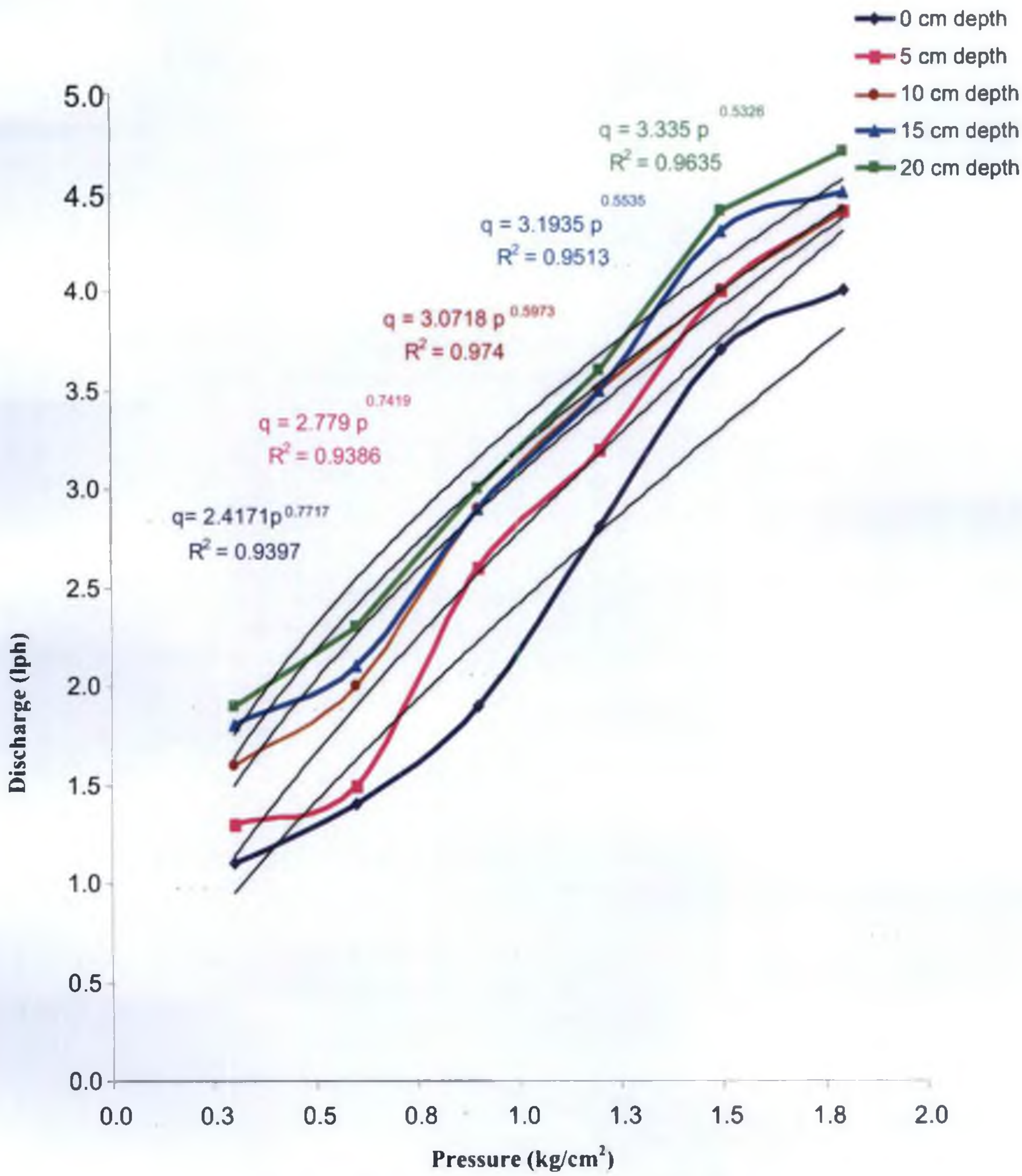

Fig. 3. Variation of discharge with pressure

The average discharge for different operating pressures (0.3 to 1.8 kg/cm^2) at different lateral depth showed that as pressure increases the discharge also increases irrespective of the depth of installation. This indicates that the emitter discharge rate depends on the pressure (*Atre et al., 1998*). It was also observed that for same pressure, the discharge was found to increase as depth of installation increases. The increase in discharge with pressure is comparatively less at zero depth of installation than at 5, 10, 15 and 20 cm depths. This may be due to the fact that the weight of the overlying soil layer would have an impact on discharge as the depth of installation increases. The actual discharges obtained in the field were 3.7, 4.0, 4.0, 4.3, and 4.4 lph at 0, 5, 10, 15 and 20 cm of depth of installation respectively at the nominal operating pressure of 1.5 kg/cm^2. Hence an average discharge of 4 lph was used for scheduling irrigation for the crop. Among the different functional relationships tested for pressure discharge relation, the power function was found to have the best correlation.

The power function also explained the role of discharge exponent in deciding the flow regime. In this study the power function was found to be good in explaining the pressure discharge relationship. The general form of the power function is

$$q_e = K_d H^a$$

where q_e – emitter flow

H – head causing flow

K_d, a – constants for specified emitter

Lower the discharge exponent, lower will be the effect of pressure variation on discharge. The point source emitters are classified as long path, orifice and pressure compensating emitters depending upon the value of the exponent. When 'a' approaches 1 the emitter is considered a long path or laminar flow type emitter. An orifice type point source emitter has 'a' of about 0.5 indicates turbulent flow while 'a' for a pressure compensating emitter it is positive and nearly zero. Vortex emitter has an 'a' value of 0.4. Thus the exponent provides a great deal of insight into the performance characteristics of the emitter that it describes. If the discharge and operating pressure are linearly related, the discharge of these emitters is sensitive to fluctuations in operating pressure. When the flow through an emitter is a turbulent or fully turbulent emitter discharge is not as sensitive to operating pressure and viscosity. The degree of pressure compensation increases as 'a' approaches zero. The performance of the emitters may vary with the type of flow through them. If the flow is laminar it is susceptible to clogging. If the flow is turbulent the opportunity of clogging is less. Therefore the developed equations given below predict the measured discharge or operating pressure with sufficient accuracy. The value of emitter exponents at different lateral depths are shown in Table 3. The value of the exponent suggested that this is an orifice type emitter.

Table 3. Emitter exponents at different lateral depths

Depth (cm)	Emitter exponents
0	0.7717
5	0.7266
10	0.5973
15	0.5416
20	0.5325

Lower the discharge exponent lower will be the effect of pressure variation on discharge. In the present case the values of 'a' in the power functions were found to vary between 0.5 to 0.7 at different depth of installations which indicated that a pressure variation of 20 % would result in a flow variation of approximately 10 % and the values suggested partially pressure compensating property of emitters (Kirnak *et al.*, 2004). It was also found that the value of the exponents decreased with depth.

4.2.2.2 Variation in emission uniformity

The losses or efficiencies in drip irrigation are more influenced by the emission uniformity (Eu) rather than runoff or deep percolation losses. Emission uniformity is a function of variation in flow between the emitters due to the pressure variation in the pipe network normally expressed in percentage. In simple words emission uniformity is the ratio of minimum rate of discharge to the average rate of discharge.

The variations of emission uniformity with respect to pressure were studied at different lateral depths by varying pressure from 0.3 to 1.8 kg/cm^2. The averages of the values estimated by Keller- Karmelli formula, Christiansen formula and Wilcox formula are shown in Table 4 and the same is shown in Fig. 4. The calculated values by the individual formula are shown in APPENDIX VII. This indicated that emission uniformity was very much influenced by the pressure variation. The correlation of power equation was noted and the best correlation was found at 15 cm depth of the laterals.

The emission uniformity was computed using all the three formulae to have a comparison and is shown in Table 5. The emission uniformity computed by Christiansen formula was found to be higher than the other two formulae. Further investigations were needed to suggest which formula is more logical.

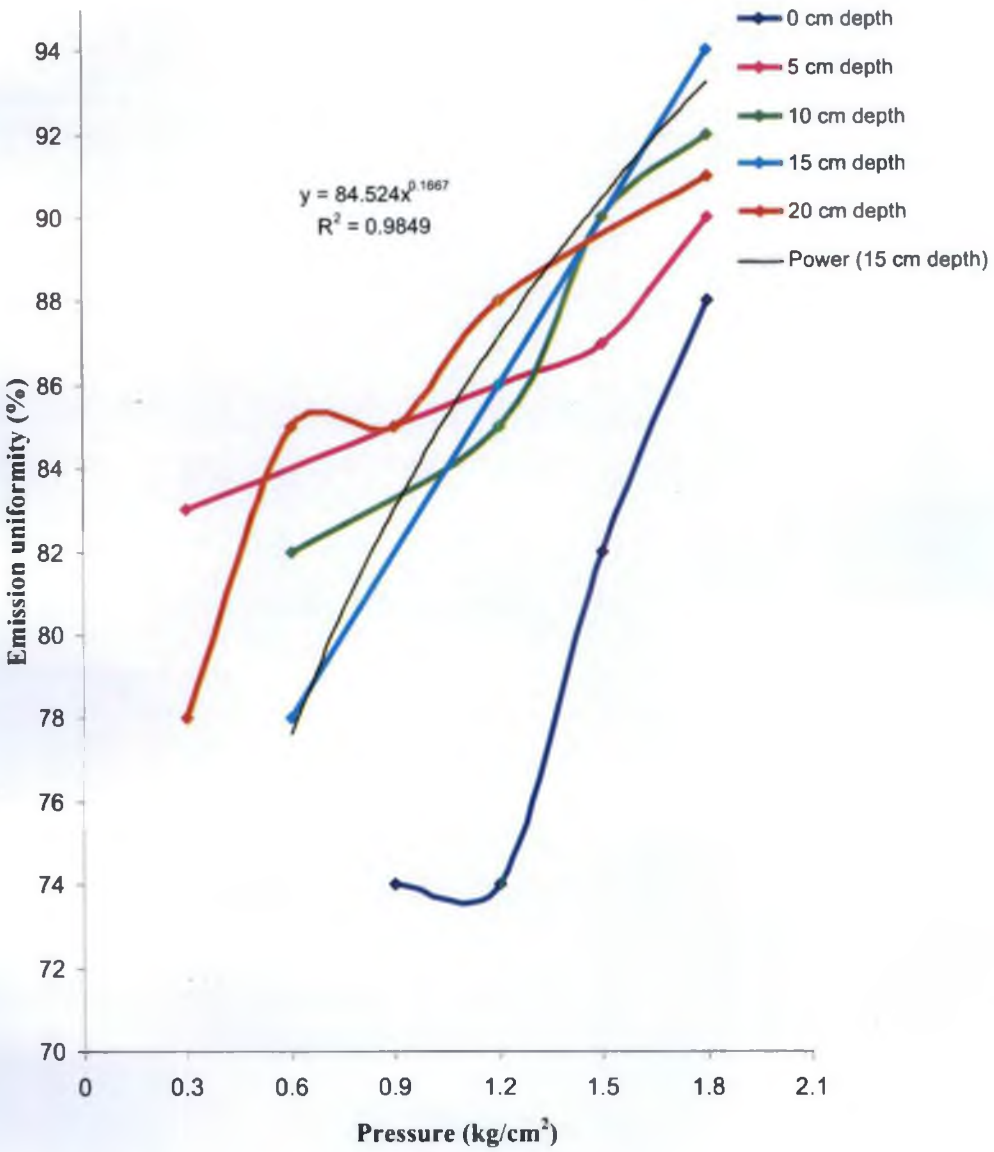

Fig. 4. Variation of emission uniformity with pressure

Table 4. Variation of emission uniformity with pressure at different depths

Sl.No	Pressure (kg/cm^2)	Emission uniformity Eu (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	92	83	91	89	78
2	0.6	82	81	82	78	85
3	0.9	74	89	92	89	85
4	1.0	93	97	96	95	97
5	1.2	74	86	85	86	88
6	1.5	82	87	90	80	84
7	1.8	88	90	92	94	91

Table 5. Emission uniformity at nominal operating pressure of 1.5 kg/ cm^2

Sl.No	Equation	Uniformity coefficient (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	Keller and Karmelli	86	83	86	77	86
2	Christiansen	81	92	93	80	78
3	Wilcox formula	79	85	90	83	88

The Eu values of the system were found to range between 74 to 94 % for a pressure variation of 0.3 to 1.8 kg/cm^2 and at different depth of installation. This means that some emitters have a uniformity more than 90 %, which are excellent, some of them have values between 80 to 90 %, come under the category of good and others come under the category of fair with an average uniformity of 70 to 80 %.This values shows that systems operating for more than one year with Eu in the excellent and good ranges indicates a satisfactory maintenance practice. However poor or near poor Eu (70 % or less) usually indicates clogged, gradual clogging or deteriorating emitters problems with pressure regulation.

The Eu values of the system were found to increase with increase in pressure and it also increases with increase in depth. This may be due to increase in discharge with increase in depth. The better uniformity was obtained at 10 to 15 cm lateral depth. The variation in emission uniformity may be due to the defects in manufacturing the emitter, uneven pressure distribution and manual control of the operating conditions in the field.

Low emission uniformity (Eu) will mean applying more water to satisfy the need of plants. Consequently plants previously having too little water will get enough while the rest will receive too much. If irrigation efficiency is defined as the percentage of applied water that is stored in the root zone, then poor Eu will lead to over irrigation, resulting in low efficiency and excessive energy consumption at the pump. It will also result in contamination of ground water and inefficient use of fertilizer as it will be leached below the root zone by the excessive amount of applied water.

Evidently high emission uniformity is a pre requisite for efficient irrigation. High Eu is achieved by maintaining a limited variation in discharge rate among system emitters. Proper maintenance of filters is also vital for preserving system Eu. Emitter clogging and uneven pressure distribution are the major factors contributing disparity in discharge rate and poor uniformity. Upgrading Eu to 90 % could save on water, power and fertilizer bills, improve irrigation efficiency and crop yield, preserve the environment and enhance grower's net profit.

Annual evaluation of Eu is recommended for monitoring system performance and pinpointing problems. It is also advisable to evaluate newly installed system to establish a base line for future evaluation. Thus it was observed that the emission uniformity is a sound indicator of the efficiency of the micro irrigation system.

4.2.2.3 Variability in manufacturing coefficient of variation

The inline drippers were tested for pressure and coefficient of manufacturing relation and are given in Table 6. The test results are compared with BIS and ASAE standards and it was rated as average (5 to 10 %) and marginal performance (10 to 15 %) emitters. The relationship between Cv and pressure were developed by fitting power equation and the variation of Cv with pressure at different depth is shown in Table. 6 and the same are plotted in Fig. 5. From the figure it could be seen that as pressure increases the Cv value was found to decrease indicating good performance. The performance at 1.5 kg/cm^2 was found to be satisfactory.

Table 6. Manufacturing coefficient at different operating pressures and depths

Sl.No	Pressure (kg/cm^2)	Manufactures coefficient Cv (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	7.7	16.4	10.2	10.7	12.5
2	0.6	17.2	14.7	12.2	20	12.5
3	0.9	11.2	11.9	8.0	10.9	13.5
4	1.0	7.4	2.8	4.6	4.9	4.1
5	1.2	11.7	14.6	13.0	14.0	12.5
6	1.5	8.8	12.4	9.9	15.0	11.9
7	1.8	8.0	11.0	7.6	6.2	8.0

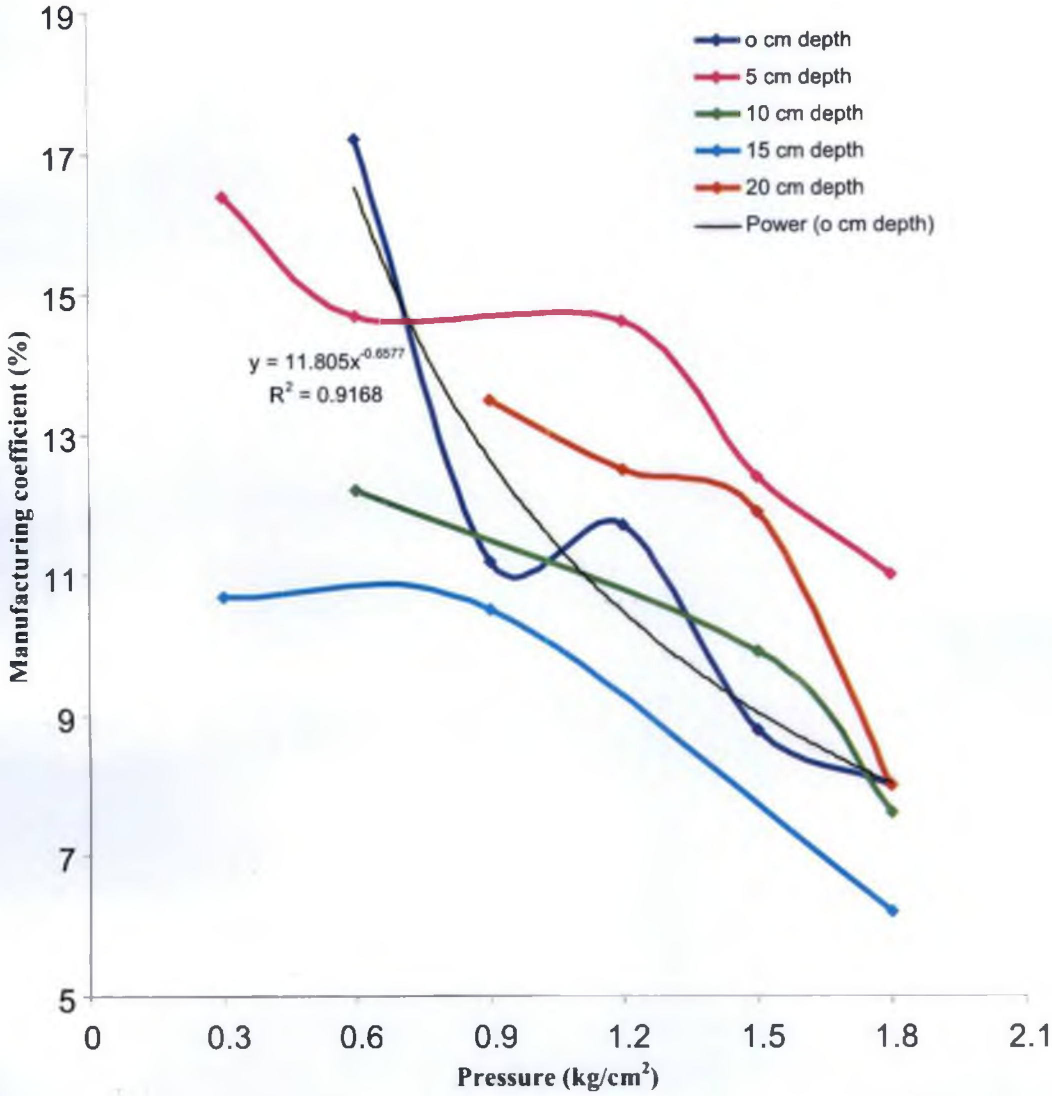

Fig. 5. Variation of manufacturing coefficient with pressure

The high variation in values of coefficient of variation indicates an intrinsic variability of the product. The manufactures variation was mainly caused by pressure and heat instability during emitter production. In addition the high Cv values could occur due to a heterogeneous mixture of the materials used in the production of emitters. The high Cv values implies that there is no possibility of uniform water distribution with variation in pressure (Kirnak *et al., 2004*).

4.2.2.4 Determination of 'f' factors and Reynolds number for inline dripper

The data were analyzed systematically to estimate the Reynolds number for inline drippers by varying the operating pressure at different lateral depth and is shown in Table 7 and is presented in Fig.6.

Table 7. Variation of Reynolds Number with pressure at different depths

Sl. No	Pressure (kg/cm^2)	Reynolds No				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	1460	1725	2123	2389	2521
2	0.6	1858	1990	2654	2789	3052
3	0.9	2521	3450	3848	3848	3981
4	1.0	2929	3715	4133	4113	4246
5	1.2	3715	4246	4644	4644	4777
6	1.5	4909	5308	5308	5706	5839
7	1.8	5308	5839	5839	5971	6237

The Reynolds number increased from 1460 to 6237 for the lateral pipe size of 16 mm with increase in inlet pressure from 0.3 to 1.8 kg/cm^2 and it also increased with increase in depth. This confirms that the turbulence of flow increase with increase in pressure. If the values of Reynolds number is less than 2000, the flow is said to be laminar, if the Reynolds number is greater than 4000 the flow is said to be turbulent and if it ranges from 2000 to 4000 the flow changes from laminar to turbulent. (*Benzal ., 2000*). So the analysis on Reynolds number indicated that both laminar and turbulent flow pattern is seen in the emitter discharges.

The data were also analyzed for frictional factor based on the Reynolds number. The frictional factors were calculated at five different lateral depths of 0, 5, 10, 15 and 20 cm by using Fanning's formula and by using Blassius formula and the calculated values are shown in APPENDIX VIII. The average of the calculated values of friction factor is shown in Table 8. The average values decreased from 0.0526 to 0.0359 with increases in pressure from 0.3 to 1.8 kg/cm^2 and also decreased with depth from 0 to 20 cm. Analysis showed that as the pressure increases the friction factor decreases. Studies conducted by *Atre et al. 1998* found that the average values of Fanning's friction factor and Blassius friction factor for 16 mm drip tubing were 0.0374 and 0.0367 respectively. The friction factors obtained from this study is in conformity with this result. The plot of Reynolds number with pressure showed the same trend of variation in all the depth of installation.

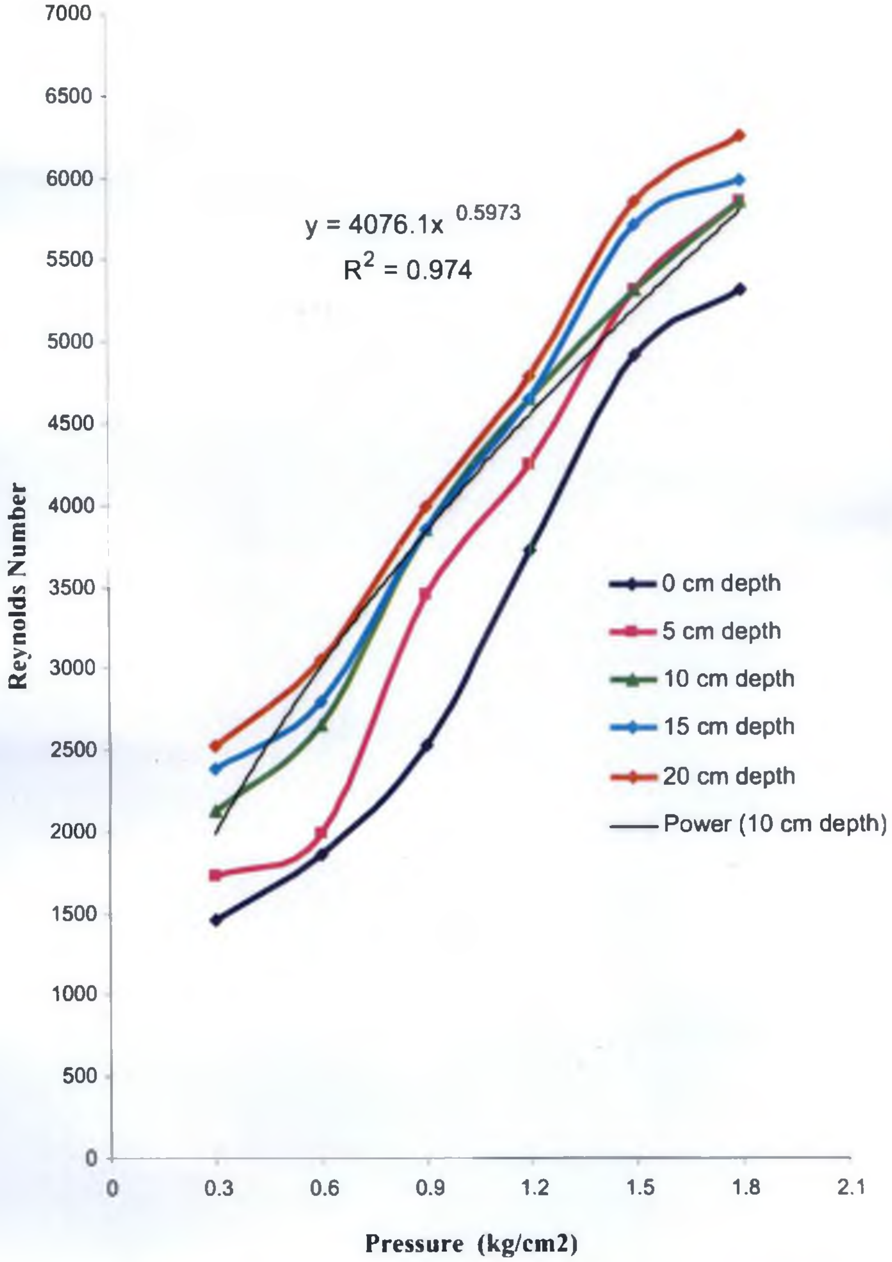

Fig. 6. Variation of Reynolds Number with pressure

Table 8. Average value of Friction factor at different operating pressures and depths

Sl.No	Pressure (kg/cm^2)	Friction factor				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	0.0526	0.0483	0.0477	0.0462	0.0455
2	0.6	0.0494	0.0485	0.0449	0.0443	0.0433
3	0.9	0.0455	0.0408	0.0407	0.0407	0.0399
4	1.0	0.0440	0.0404	0.0400	0.0400	0.0397
5	1.2	0.0411	0.0396	0.0387	0.0387	0.0393
6	1.5	0.0382	0.0374	0.0374	0.0367	0.0365
7	1.8	0.0381	0.0365	0.0365	0.0363	0.0359

4.2.2.5 Determination of water application efficiency at different operating pressures

The effectiveness of drip system can be estimated by how much of water can be stored in the root zone. Considering the minimum water discharged as the water that can be stored in the root zone and the maximum discharge as the water delivered for consumptive use, the value of water application efficiency of the system was calculated at different depths and also at varying pressures as shown in APPENDIX IX and its variation with respect to the operating pressure is shown in Fig.7. The power function was found have a good correlation as compared to other functions and is represented in the figure and the best correlation was found at a depth of 15 cm. From the figure, it could be seen that as the pressure increases the application efficiency was found to increase. In all the five depths application efficiency increases with pressure and it is not affected by depth of installation of laterals and finally reaches a value between 88 to 90 %.

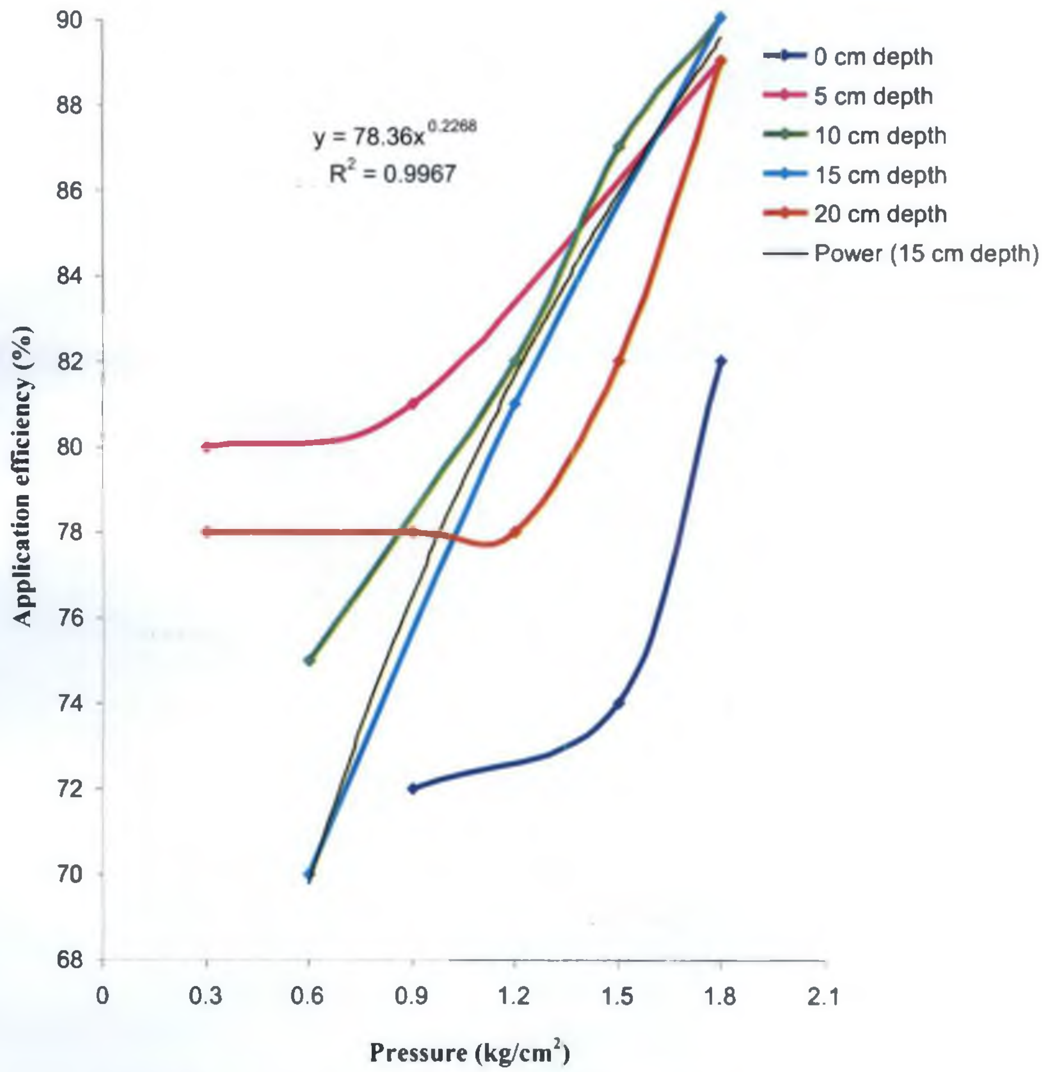

Fig. 7. Variation of application efficiency with pressure

4.3 Soil moisture distribution under subsurface drip irrigation system in bare soil

An experiment was conducted to evaluate soil moisture distribution pattern of the inline drippers in the bare field. The emitters were located at 0, 5, 10, 15 and 20 cm depth from the surface and they were spaced at 50 cm interval along the laterals, which were spaced 50 cm apart. The actual discharges obtained in the field during the hydraulics study were 3.7, 4.0, 4.0, 4.3 and 4.4 lph respectively for 0, 5, 10, 15 and 20 cm depth of installations. The average discharge at 1.5 kg/cm^2 calculated for different depths of installation in the field was 4.0 lph. Hence the moisture distribution pattern was studied for the same discharge of 4.0 lph at different depths of installation. The system was operated for 64, 60, 60, 56 and 54 minutes at its recommended pressure of 1.5 kg / cm^2 to get an emitter discharge of 4.0 lph for 0, 5, 10, 15 and 20 cm depth of installation from the surface. Thus the total quantity of water applied for studying the moisture distribution in the bare soil was 4.0 litres which remain same for all treatments.

The profiles were exposed by cutting the soil vertically across the centre of the point of application of emitter. Soil samples were collected from this vertical profile at grid points (10 cm x 10 cm) and moisture content was determined gravimetrically. The calculated value of moisture content is shown in APPENDIX X. The moisture data were analyzed for distribution pattern by plotting the soil moisture contour as shown in Figs. 8, 9, 10, 11 and 12. The contours were drawn for before irrigation, half an hour after irrigation and 24 hours after irrigation.

When emitter was placed below the soil surface and water was allowed to flow, a saturated sphere of small diameter was found to develop first, which keeps on growing till the unsaturated water flow rate from the surface of saturated sphere becomes equal to the emitter discharge rate i.e. the wetting front reaches a steady state condition when the unsaturated flow rate from the saturated peripheral area of the bulb becomes equal to the emitter discharge rate. The pattern of distribution was found to follow a bulb shape in all the contours.

The surface soil appears to be almost dry in higher depth of installation say 15 and 20 cm as seen from the data obtained from the field. The maximum moisture content was observed around the emitter position. The maximum moisture content observed at 0, 5, 10 , 15 and 20 cm depth of installation were 19, 24, 25, 22 and 22 % respectively half an hour after irrigation. The corresponding values 24 hours after irrigation was found to be almost same in all the depth of installation as seen from the Table 9.

Table 9. Maximum value of observed moisture content at different emitter positions

Depth of installation (cm)	Maximum Moisture content (%) at the emitter position		
	Before irrigation	half an hour after irrigation	24 hours after irrigation
0	4	19	10
5	6	24	13
10	6	25	12
15	14	22	14
20	11	22	13

While observing the profile cut half hour after irrigation it was found that the radius of saturated water entry zone was increasing very fast initially and after sometime the lateral advancement of the wetting front restricted, but the downward movement continued. The water advance rate was found to increase as it moves away from the emitter and reaches a steady state.

The wetted profiles were also observed half an hour after irrigation and 24 hrs after irrigation and are shown in Plate 4. At the wetting front the moisture content was equal to the initial moisture content present in the soil. There was significant horizontal movement. This significant horizontal or lateral movement of water may be due to the slow and frequent application of water through the emitter. The minimal evaporation loss may also favor the water front advance. The maximum horizontal & vertical water front advance were measured and recorded as shown in Table 10. Based on the maximum horizontal and vertical water front advance, the spacing of emitters could be adjusted to wet the soil adequately. This observation on water front advance ensured that the horizontal and vertical movement reaches the effective root zone. This would ensure that the moisture distribution definitely covers the entire root zone of the crop. The vertical movement should not go beyond the effective root zone depth to avoid the percolation losses.

Table 10. Moisture front advance from the point of application of the emitter

Depth of installation (cm)	Moisture front advance (cm)	
	Horizontal advance(cm)	Vertical advance (cm) measured from surface
0	32	55
5	50	76
10	50.5	77
15	52	80
20	55	82

The moisture front advance data from this study revealed that the horizontal and vertical movement of water go beyond the lateral spacing and root zone depth in bare soil. But the extraction pattern may be different in actual cropped field. Therefore the moisture front advance has to be studied with standing crop too.

Plate 4. Wetted profiles observed half an hour after irrigation and 24 hours after irrigation

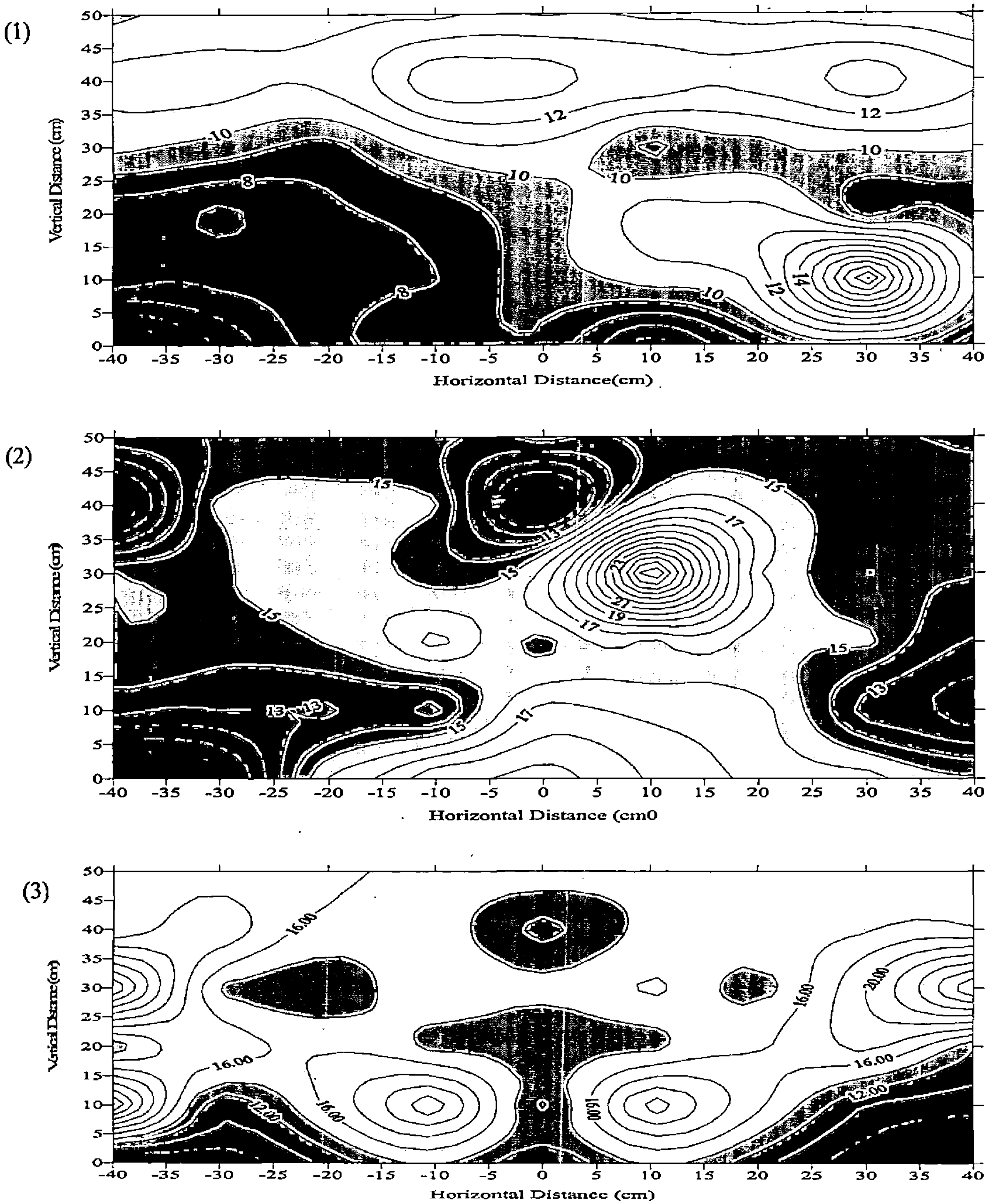

Fig. 8. Soil moisture distribution pattern at 0 depth: before irrigation (1) half an hour after irrigation (2) and 24 hours after irrigation (3). (Emitter position 0, 0)

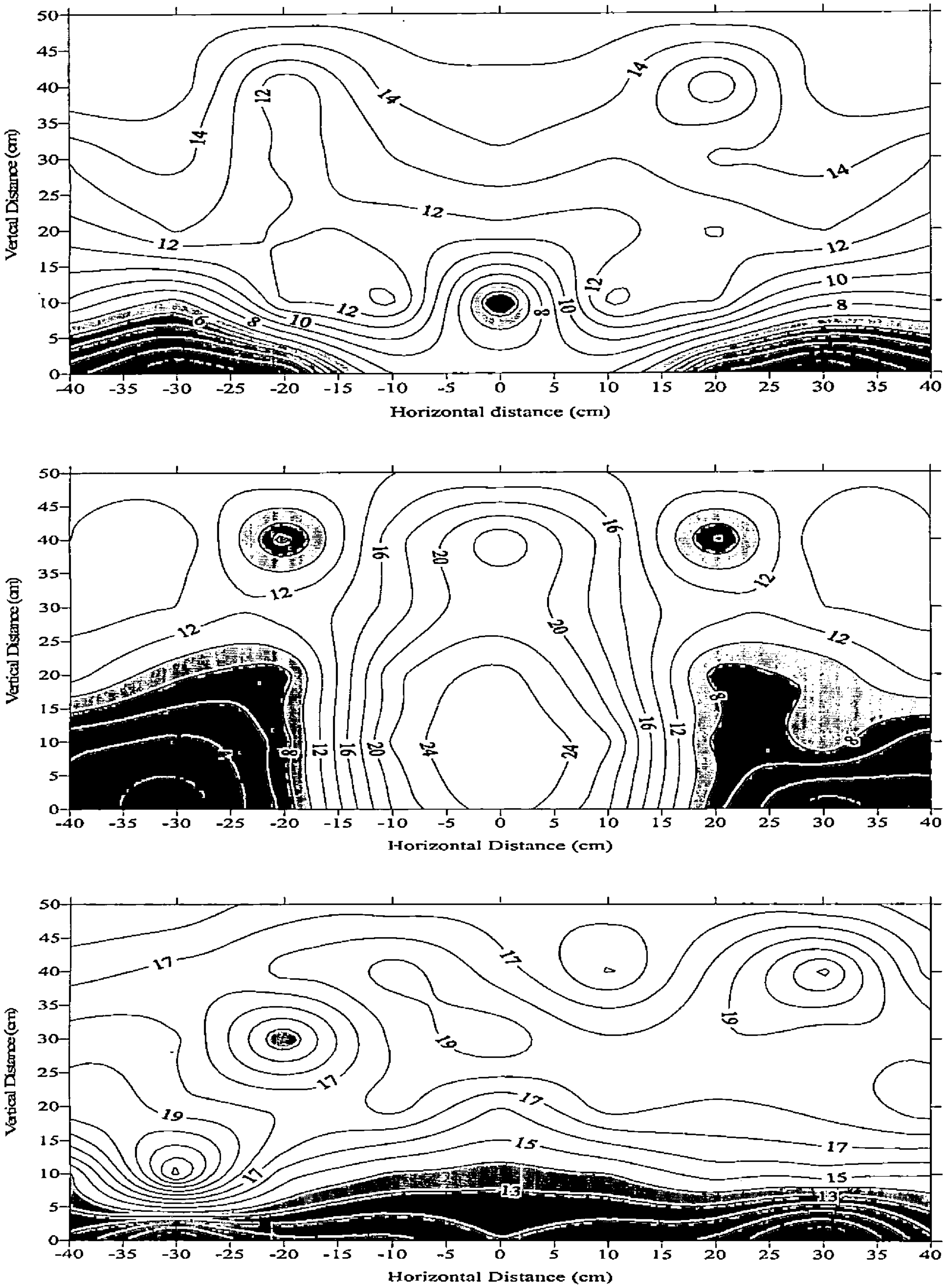

Fig. 9. Soil moisture distribution pattern at 5 cm depth before irrigation, half an hour after irrigation, 24 hours after irrigation. (Emitter position 5, 0)

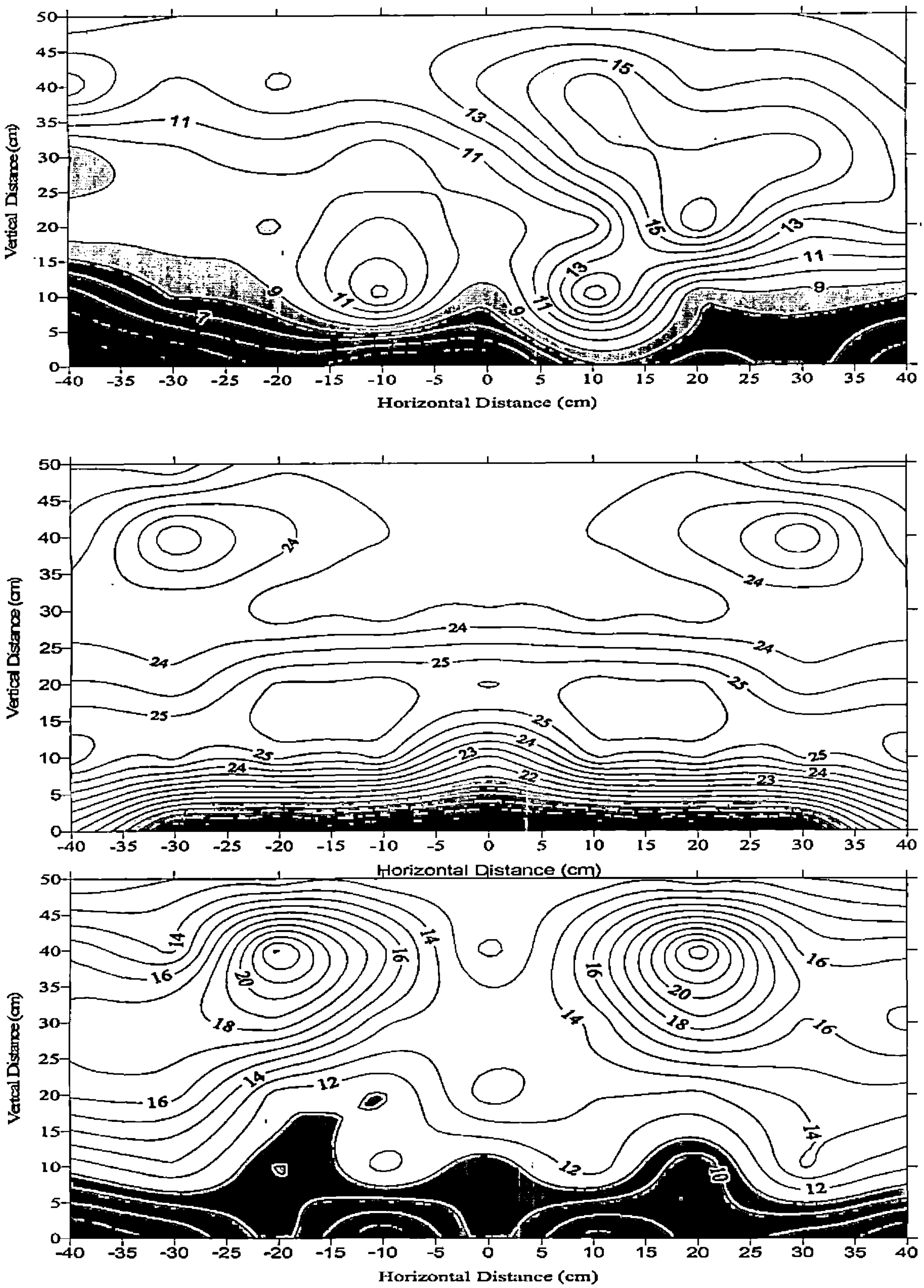

Fig.10. Soil moisture distribution pattern at 10 cm depth (before irrigation, half an hour after irrigation and 24 hours after irrigation. (Emitter position 10, 0)

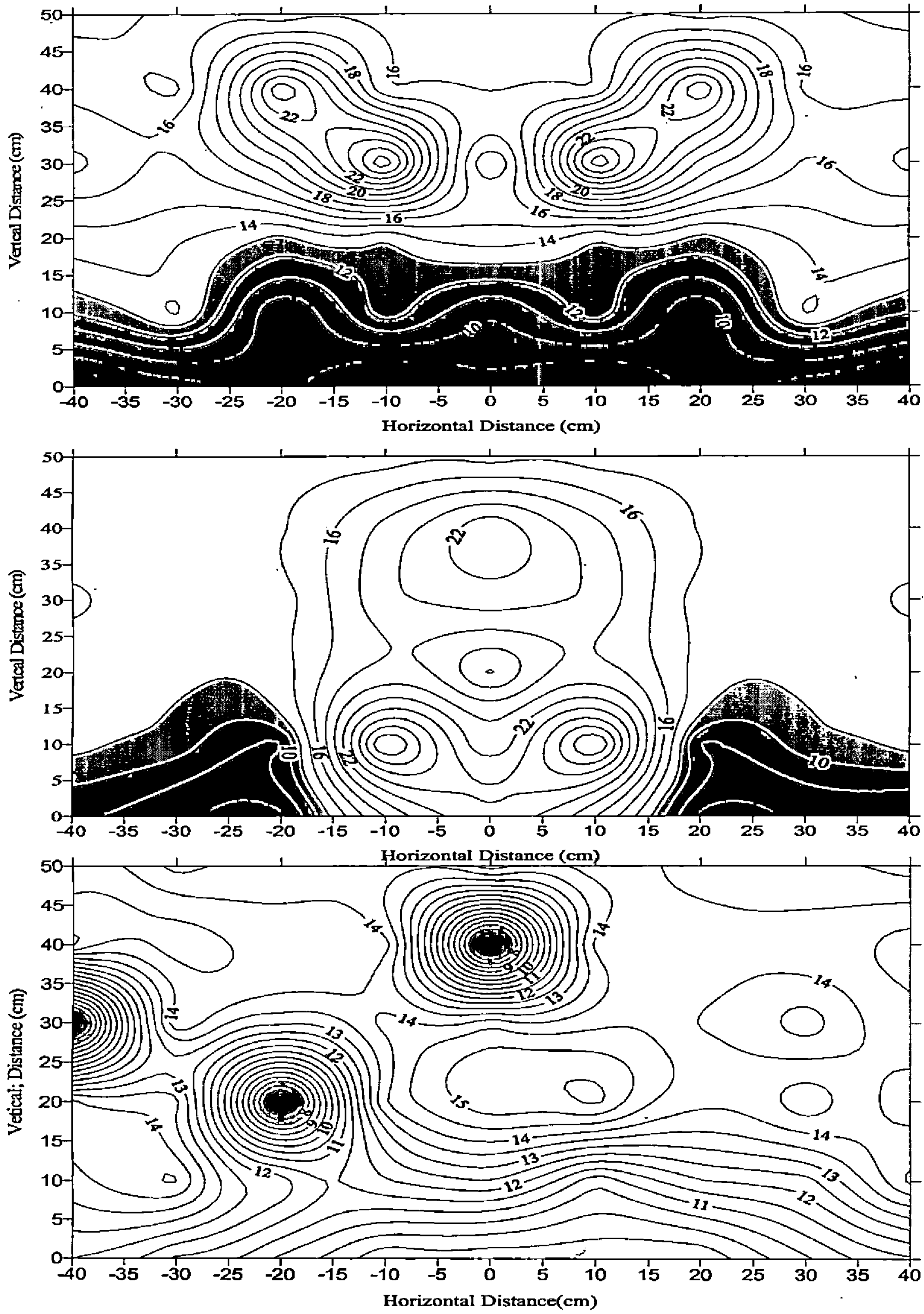

Fig.11. Soil moisture distribution pattern at 15 cm depth (before irrigation, half an hour after irrigation and 24 hours after irrigation (Emitter position 15, 0).

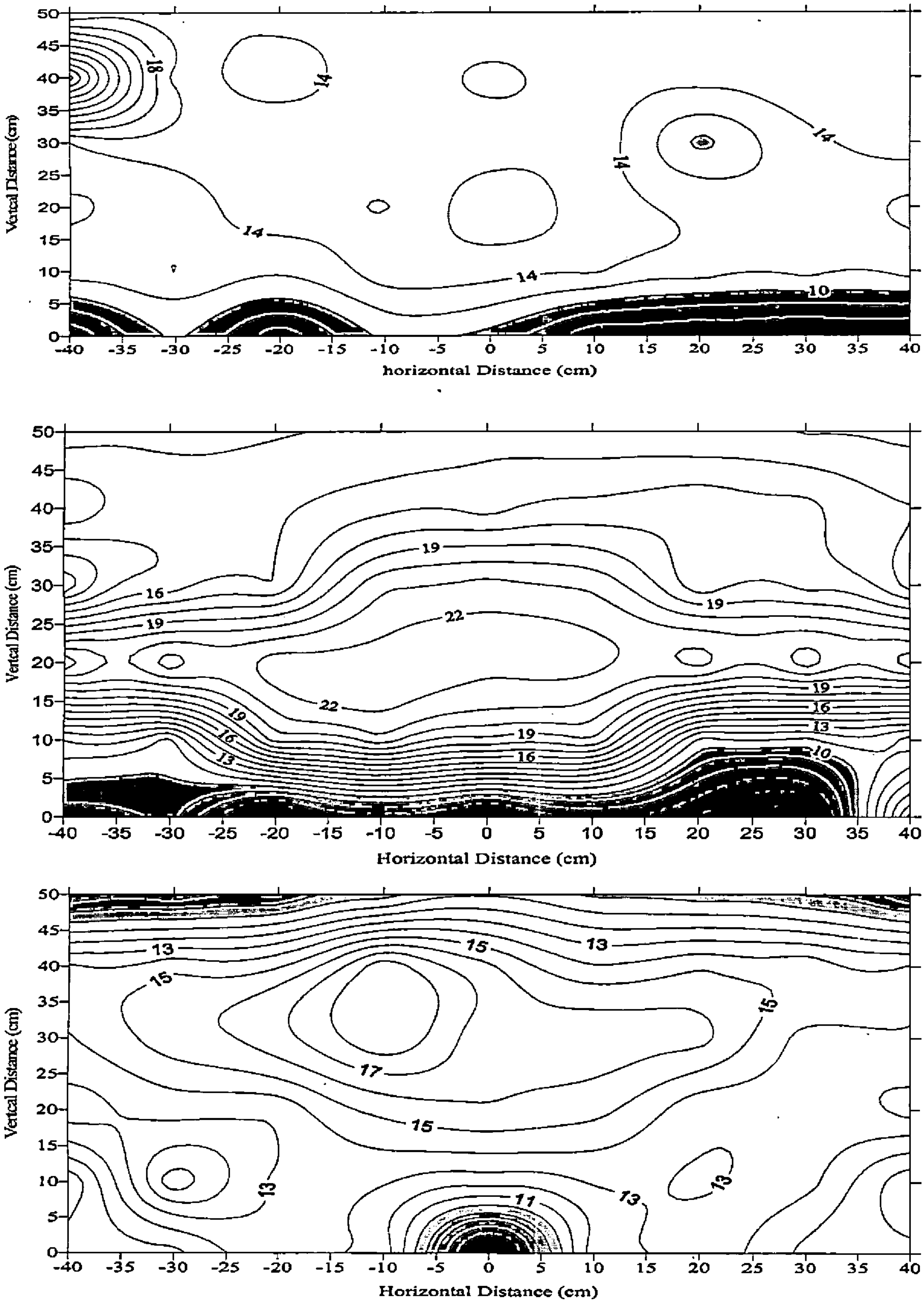

Fig.12. Soil moisture distribution pattern at 20 cm depth (before irrigation, half an hour after irrigation and 24 hours after irrigation. (Emitter position 20, 0)

While analysing the soil moisture contour plotted for different depths of installation, the maximum depletion was found at zero depth of installation, while the same was considerably reduced in the deeper installation. This may be due to the high evaporation and infiltration from the surface. The moisture content observed 24 hours after irrigation was found to be higher in deeper installation. While analysing the contours of all the five depths of installation, the moisture content was evenly distributed 24 hrs after irrigation at 5, 10, 15 and 20 cm depth from the surface. The best distribution was observed at 10 and 15 cm depth of installations, after 24 hrs of irrigation

The uneven distribution and concentrated contour indicated some barriers or impermeable layers which prevent the proper movement of water in the soil. This was due to some patchy laterite formations below the soil surface here and there. The higher moisture content values seen at a farther distance away from the emitter was due to the overlapping of moisture from the nearby emitters, because emitters were spaced at 50 cm interval in the lateral and laterals were laid at 50 cm interval in the plot and was also laid at different depths of installation. Further study is needed to explain the overlapping effect of the nearby emitters.

4.4 Field study to evaluate the effect of depth of installation and levels of irrigation on growth and yield of ladies finger under Subsurface Drip Irrigation

4.4.1 Estimation of water requirement of ladies finger

The crop water requirement as per theoretical calculation based on evaporation data of Tavanur region was estimated as 2.0 litre/ day/ plant. According to the code of practice, the application of water below the soil surface through emitters with discharge rates should generally be in the same range as that of drip irrigation. The estimated water requirement was found to be in conformity with water requirement of crops under drip irrigation estimated by CWRDM Kozhikode, Kerala and PFDC centre of KCAET which is 1- 2 litre/ day under drip irrigation and 4 - 8 litre/ day/ plant under surface methods.

After the soil moisture distribution studies in the bare soil, the crops were raised in the field to study the effect of depth of installation and irrigation levels on growth and yield of crop ladies finger. The system was installed at 5 different depths of 0, 5, 10, 15 and 20 cm and irrigation was given in three levels viz, 1.0 litre/day, 1.5 litre/day and 2.0 litre/day. These values were 50, 75 and 100 % of the estimated water requirement of ladies finger in Tavanur region of Malappuram District in Kerala. The performances were studied based on the following observations.

4.4.2 Yield of Crop

The crop started yielding two months after planting. A close view of the standing crop is shown in Plate 5. The yields under different treatments were compared to find out the effect of depth of installation of laterals and levels of irrigation in subsurface drip irrigation system. Three replications were done for all the treatments. Results of the yield obtained from the field for various treatments were tabulated in Table 11 and the same are presented in Fig.13.

Plate 5. A view of the standing crop in the field under subsurface drip irrigation system

Table 11. Mean yield of ladies finger as affected by various treatments

Treatment	Name	Area (m^2)	Yield (kg)	Yield(kg/ha)
T_1	D_1I_1	1.5	0.69	4582.72
T_2	D_2I_1	1.5	0.77	5140.74
T_3	D_3I_1	1.5	1.12	7481.48
T_4	D_4I_1	1.5	1.01	6755.56
T_5	D_5I_1	1.5	0.95	6335.80
T_6	D_1I_2	1.5	0.75	5012.35
T_7	D_2I_2	1.5	0.87	5777.78
T_8	D_3I_2	1.5	1.21	8093.83
T_9	D_4I_2	1.5	1.04	6928.40
T_{10}	D_5I_2	1.5	1.01	6740.74
T_{11}	D_1I_3	1.5	0.72	4809.88
T_{12}	D_2I_3	1.5	0.80	5328.40
T_{13}	D_3I_3	1.5	1.17	7767.90
T_{14}	D_4I_3	1.5	1.07	7145.68
T_{15}	D_5I_3	1.5	0.96	6424.69

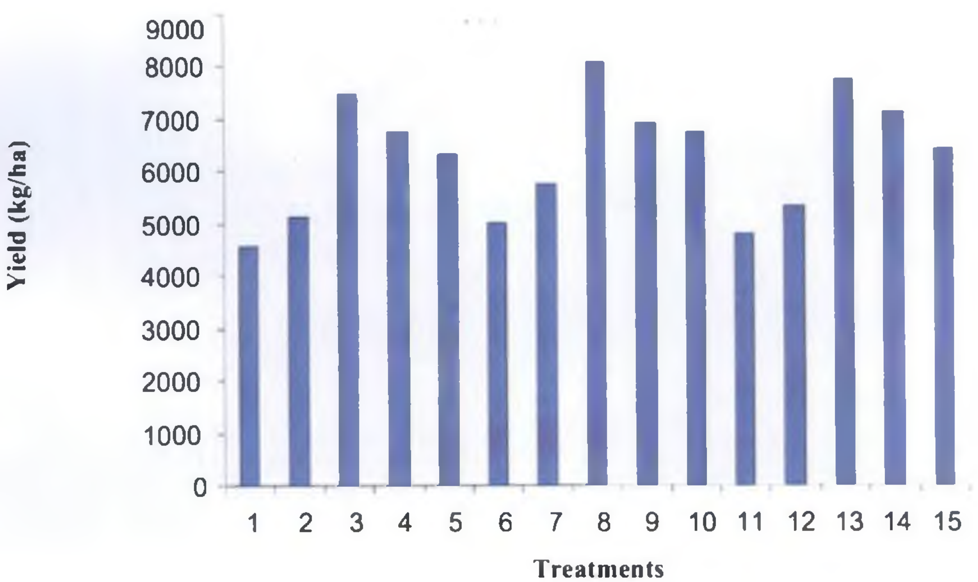

Fig.13. Yield Chart

From the table of yield data, it is cleat that the maximum yield obtained was 8.1 t/ha for the treatment D_3I_2 (T8). D_3I_2 is the treatment with lateral depth 10 cm and the level of irrigation 1.5 lit/day. INCID (Indian National Committee on Irrigation and Drainage) 1994, Drip irrigation in India, New Delhi reported the yield of ladies finger in conventional and drip method of irrigation as 15.3 t/ha and 17.7 t/ha respectively. While comparing the yield of this study with that of the INCID report the yield obtained is only 50 % of the national average, owing to the serious attack of mosaic disease for the crop in the middle of the cropping season.

The statistical analysis using two way ANOVA with interaction and without interaction was made. Also for comparing the significance of yield between any two means of the treatments, Tukey's test, a post ANOVA test was performed. The results are given in Table 12.

Table 12. ANOVA Table for yield: Two way ANOVA without interaction

Source of variation	d. f	S.S	M.S.S	F cal	F(tab)	
Replication	2	1.621333	0.81066667	4.42872	F(2,28) =5.45	NS
Treatment	14	2417.085	172.648952	943.1915	F(14,28)=2.75	**
Error	28	5.125333	0.18304762			

**represents the value is significant at 1 per cent significance level

NS – Non significant

From the table it can be seen that

1. There is no significant difference between replications for the yield parameter at 1 per cent significant level.
2. There is highly significant difference among the 15 treatments tested for the yield parameter.

For analysing the interaction between depths and irrigation levels ANOVA test with interaction was done and is shown in the Table 13.

Table 13. ANOVA Table for yield: Two way ANOVA with interaction

Source of variation	d. f	S.S	M.S.S	F cal	F(tab)	Inference
Replication	1	1.621333	1.62133333	4.42872	F(1,11) =241	NS
Treatment	14	2417.085	172.648952	471.5957	F(14,11)=2.6	*
irrigation	2	13674.29	6837.14611	18675.87	F(2,11)=19.4	*
depth	4	13857.93	3464.48199	9463.335	F(4,11)=14.55	*
I*D	8	41405.22	5175.65218	14137.45	F(8,11)=5.26	*
Error	14	5.125333	0.36609524			

* represents the value is significant at 5 per cent significance level

From the table it can be seen that

1. There is no significant difference between three replications for the yield at 5 per cent significance level
2. There is significant difference among treatments for yield at 5 per cent significance level
3. It is also seen that there is significant difference among the five depths of placement of laterals for the yield parameter at 5 per cent level of significance
4. There is significant difference among three irrigation levels for yield at 5 per cent level of significance
5. Analytical results also showed that there is interaction between irrigation, depth of installation and yield at 5 per cent level of significance.

Tukey's test for all possible pair wise difference for the yield

This test is used to study the significant difference between mean values of yield of various treatments and is presented in Table 14.

From the Table 14. it can be seen that the differences between the mean values of yield are always greater than 1.52 except T9 and T14, T9 and T10, T4 and T10, T15 and T5, T12 and T2, T2and T6, T6 and T11. The final result as given under the table indicates that the same letters as superscripts represent treatments having no significance difference.

4.4.3 Biometric Observations

Biometric observations such as height of the plant, girth of the plant and number of leaves were taken one month, two months and three months after planting and are tabulated in Table 15.

The biometric properties directly affect the yield of the crop, so the maximum value on height, thickness and number of leaves were obtained for the treatment 8 (D_3I_2) ie, 10 cm depth of installation and irrigation level 1.5 litre/ day/ plant)

Table 14. Difference between the mean values of yield for different treatments

	T8	T13	T3	T14	T9	T4	T10	T15	T5	T7	T12	T2	T6	T11	T1
T1	23.7	21.5	19.57	17.3	15.84	14.67	14.57	12.44	11.84	8.07	5.04	3.77	2.9	1.54	
T11	22.16	19.96	18.03	15.76	14.3	13.13	13.03	10.9	10.3	6.53	3.5	2.23	1.36^{NS}		
T6	20.8	18.6	16.67	14.4	12.94	11.77	11.67	9.54	8.94	5.17	2.14	0.87^{NS}			
T2	19.93	17.73	15.8	13.53	12.07	10.9	10.8	8.67	8.07	4.3	1.27^{NS}				
T12	18.66	16.46	14.53	12.26	10.80	9.63	9.53	7.40	6.80	3.03					
T7	15.63	13.43	11.50	9.23	7.77	6.60	6.50	4.37	3.77						
T5	11.86	9.66	7.73	5.46	4.00	2.83	2.73	0.60^{NS}							
T15	11.26	9.06	7.13	4.86	3.40	2.23	2.13								
T10	9.13	6.93	5.00	2.73	1.27^{NS}	0.10^{NS}									
T4	9.03	6.83	4.90	2.63	1.17^{NS}										
T9	7.86	5.66	3.73	1.46^{NS}											
T14	6.40	4.20	2.27												
T3	4.13	1.93													
T13	2.20														
T8															

NS=No significant difference

TsqrtEMS/r = 1.52

Final result

$T8^{a}$ $T13^{b}$ $T3^{c}$ $T14^{d}$ $T9^{d}$ $T4^{de}$ $T10^{de}$ $T15^{f}$ $T5^{f}$ $T7^{g}$ $T12^{h}$ $T2^{h}$ $T6^{hi}$ $T11^{hi}$ $T1^{j}$

Table 15. Biometric observations

Treatment	R1			R2			R3		
	One month after planting			Two months after planting			Three months after planting		
	Height	Girth of the plant	No of leaves	Height	Girth of the plant	No of leaves	Height	Girth of the plant	No of leaves
T_1	21.87	2.75	5	42.00	2.80	9	60.50	3.13	14
T_2	22.37	2.81	5	42.50	2.85	9	61.10	3.21	13
T_3	25.02	3.00	7	44.50	3.02	10	63.37	3.31	16
T_4	24.97	2.94	6	44.23	3.00	11	62.50	3.26	16
T_5	22.90	2.74	5	42.23	2.81	9	61.50	3.23	15
T_6	22.80	2.79	5	42.47	2.9	11	62.10	3.23	15
T_7	22.87	2.82	5	43.00	2.85	11	63.10	3.52	14
T_8	**25.90**	**3.10**	**8**	**45.10**	**3.15**	**12**	**64.10**	**4.10**	**18**
T_9	25.63	2.95	8	45.07	3.00	12	62.90	3.75	18
T_{10}	23.28	2.75	5	43.03	2.8	11	62.53	3.61	14
T_{11}	22.30	2.76	4	42.07	2.79	1	61.30	3.21	15
T_{12}	22.53	2.83	4	42.37	2.85	11	62.27	3.32	15
T_{13}	25.43	3.05	6	44.20	3.06	10	63.43	3.45	16
T_{14}	24.77	2.97	6	44.13	2.98	10	62.83	3.41	16
T_{15}	22.33	2.86	5	42.13	2.90	9	62.30	3.38	15

4.4.3.1 Plant Height

The height of the plants under different treatments were analysed using ANOVA with two way interaction between depth of installation and levels of irrigation.

Table 16. ANOVA Table without interaction for plant height

Source of variation	d.f	S.S	M.S.S	F cal	F(tab)	Inference
Replication	2	0.040444	0.02022222	0.330566	F(2,28) =5.45	NS
Treatment	14	39.85111	2.84650794	46.53088	F(14,28)=2.75	**
Error	28	1.712889	0.0611746			

**represents the value is significant at 1 per cent significance level

From the table it can be seen that

1. There is no significant difference between replications for the height of the plant at 1 per cent significant level.
2. It is also seen that there was highly significant difference among the 15 treatments tested.

Table 17. ANOVA Table with interaction for plant height

Source of variation	d.f	S.S	M.S.S	F cal	F(tab)	Inference
Replication	1	0.040444	0.0404444	0.330566	F(1,11) =241	NS
Treatment	14	39.85111	2.8465079	23.26544	F(14,11)=2.6	*
Irrigation(I)	2	29413.57	14706.786	120203.4	F(2,11)=19.4	*
Depth(D)	4	29134.6	7283.6501	59531.65	F(4,11)=14.55	*
I*D	8	87684.93	10960.616	89584.69	F(8,11)=5.26	*
Error	14	1.712889	0.1223492			

* significance at 5 per cent level of significance

1. There is no significant difference between three replications for the height of the plant at 5 per cent significance level
2. There is significant difference among treatments regarding the height of the plant at 5 per cent significance level
3. It is also seen that there is highly significant difference among the five depths of placement of laterals for the height of the plant at 5 per cent level of significance
4. There is significant difference among three irrigation levels for plant height at 5 per cent level of significance

5. Analysis also showed that there is interaction between irrigation, depth of installation and height of the plant at 5 per cent level of significance

4.4.3.2 Thickness of the Stem

The thickness of the stem of plants grown under different treatments was analyzed and it was found maximum at D_3I_2 (depth of installtion-10 cm and level of irrigation-1.5 lit/day/plant) (Table.16). The corresponding value is 4.1 cm for D_3I_2 followed by 3.75 cm for D_4I_2 (depth of installation -15 cm and level of irrigation -1.5 lit/day/ plant).

4.4.3.3 Number of leaves

The number of leaves of the plants were also noted and it was found maximum at D_3I_2 (depth of installtion-10 cm and level of irrigation-1.5lit/day/plant) with 18 numbers of leaves (Table 15). The analysis of the data indicated that there is not much variation among the treatments.

The correlations between yield, plant height, thickness of the stem and number of leaves were tested with Pearson Correlation Coefficient and are presented in Table 18.

Table 18. Correlations between yield and biometric observations

		Plant Height	Girth	Number of leaves	Yield
Plant Height	Pearson Correlation	1.000	0.753**	0.675**	0.848**
Girth	Pearson Correlation		1.000	0.654**	0.667**
Number of leaves	Pearson Correlation			1.000	0.700**
Yield	Pearson Correlation				1.000

** Correlation is significant at 0.01 level

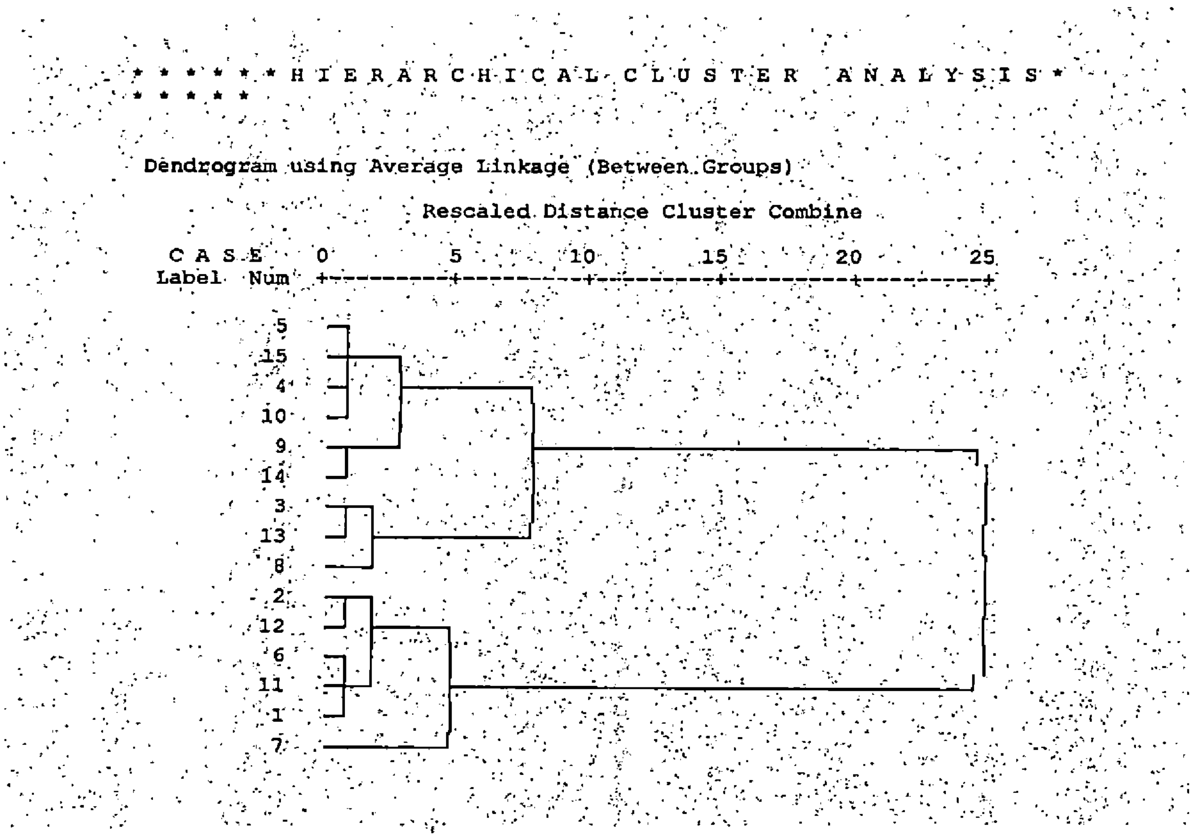

Fig. 14. Dendrogram using average linkage between groups

The analysis done by the dendrogram showed that the treatments have similar properties is clustered together. The same was also supported by the Tukey's test too.

4.4.4 Determination of Water Use Efficiency

The water use efficiency at different treatments were calculated and is given in Table 19 and the same is plotted in the Fig.15. The highest water use efficiency was noted for the treatment D_3I_1 (depth of installtion-10 cm and level of irrigation-1.0 litre/day/plant) with a value of 15.59 kg/ha mm followed by the treatment D_4I_1 (depth of installtion-15 cm and level of irrigation-1.0 litre/ day/ plant) with a value of 14.07 kg/ha mm. For the best treatment D_3I_2 (depth of installtion-10 cm and level of irrigation-1.5 litre/day/plant) the water use efficiency was 11.24 kg/ha mm for the yield.

The variation of water use efficiency may be due to the influence of pest and diseases control, choice of the crop and genetic improvement (by selection and breeding) of its productivity and adaptation to the particular environment as well as by improvement of the water, air and nutrient supply to the roots, and of light and carbon dioxide supply to foliage.

Table 19. Water use efficiency as affected by different treatments

Treatment	Name	Area (m^2)	Yield (kg/ha)	Water applied/ plot (liters)	Water applied/ ha (lit)	water applied/ ha (mm)	Water use efficiency (kg/ha mm)
T_1	D_1I_1	1.5	4582.72	1440	4800000	480	9.55
T_2	D_2I_1	1.5	5140.74	1440	4800000	480	10.71
T_3	D_3I_1	1.5	7481.48	1440	4800000	480	15.59
T_4	D_4I_1	1.5	6755.56	1440	4800000	480	14.07
T_5	D_5I_1	1.5	6335.80	1440	4800000	480	13.20
T_6	D_1I_2	1.5	5012.35	2160	7200000	720	6.97
T_7	D_2I_2	1.5	5777.78	2160	7200000	720	8.02
T_8	D_3I_2	1.5	8093.83	2160	7200000	720	11.24
T_9	D_4I_2	1.5	6928.40	2160	7200000	720	9.62
T_{10}	D_5I_2	1.5	6740.74	2160	7200000	720	9.36
T_{11}	D_1I_3	1.5	4809.88	2880	9600000	960	5.01
T_{12}	D_2I_3	1.5	5328.40	2880	9600000	960	5.55
T_{13}	D_3I_3	1.5	7767.90	2880	9600000	960	8.09
T_{14}	D_4I_3	1.5	7145.68	2880	9600000	960	7.44
T_{15}	D_5I_3	1.5	6424.69	2880	9600000	960	6.69

The low water use efficiency in the study may be due to the yield reduction caused by the mosaic disease for the crop.

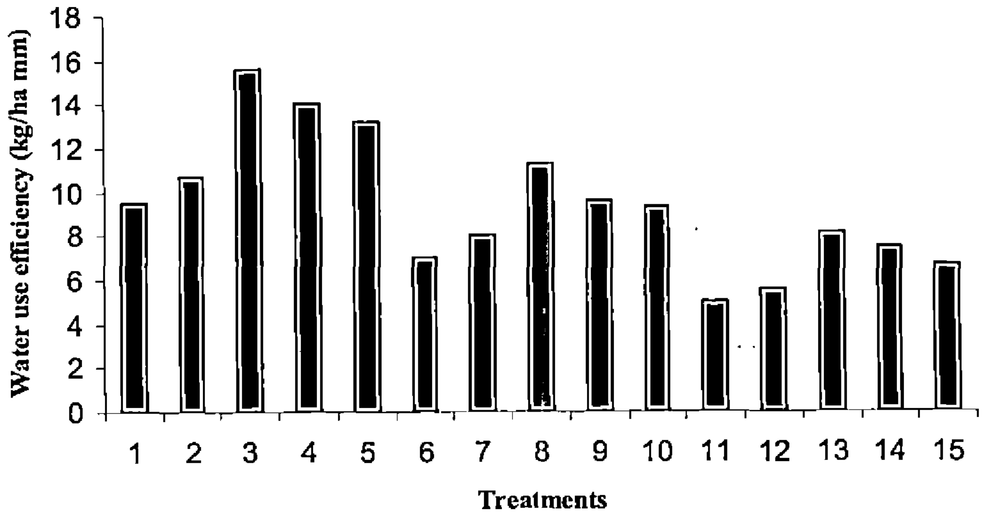

Fig. 15. Variation of water use efficiency with treatment

4.4.5 Weed infestation

Weeds were a major problem in the area causing absorption of water and nutrients available to the plants. But the subsurface drip irrigated plots showed substantial reduction in the weed count. The cumulative weed growth was shown in the Table 20.

Table 20. Cumulative weeds count from 1 m^2 area at different depth for irrigation @ 2.0 lit/ day/plant

Date	Depth of installation				
	0 cm	5 cm	10 cm	15 cm	20 cm
20/02/2007	0	0	0	0	0
24/02/2007	5	4	4	3	2
28/02/2007	11	10	9	8	6
4/3/2007	15	13	11	10	9
8/3/2007	21	19	16	14	11
12/3/2007	26	23	19	18	15
16/3/2007	30	28	24	20	17
22/3/2007	34	30	22	21	18
26/3/2007	38	34	30	25	20

From the Table 20 it can be concluded that the weed infestation was less in deeper installation. This may be due to the fact that the surface soil remains dry in deeper installation as the water is applied at deeper depth.

4.4.6 Pinching of the hose by roots and root intrusion into the emitter

The pinching of the hose by roots and root intrusion into the emitter was studied by exposing vertical profile in the field and it was found that there was no evidence of pinching of the hose by roots or root intrusion into the emitter (Plate 6). This may be due to the use of inline drippers with turbulent flow emitters and thick walls of 'bio barrier technology' which keep roots from growing into drip emitters. Thus the recently developed subsurface drip irrigation technology overcomes the operational barrier of root intrusion and root impinching experienced in the past.

4.4.7 Root proliferation and water distribution under subsurface inline dripper in the crop root zone

The root distributions were studied at different treatments and are presented in Table 21. A significant increase in root length was found due to subsurface irrigation and the root length and root zone length was found maximum at D_3I_2 with a maximum root length of 40.5 cm and root zone length of 15.5 cm. A comparative view of root development in surface and subsurface irrigation is shown in plate 7.

Plate 6. A view of rooting pattern showing no evidence of root impinching and root intrusion

Surface drip **Sub surface drip**

Plate 7. Comparative view of root development in surface and subsurface drip

Table 21. Root zone length, root length and moisture front advance observed for various treatments

Treatment	Name	Root zone length (Horizontal) (cm)	Root length (Vertical) (cm)	Moisture front advance in the root zone	
				Horizontal Distance (cm)	Vertical Distance (cm)
T_1	D_1I_1	6.33	31	29	35
T_2	D_2I_1	7.67	33.50	32	49.5
T_3	D_3I_1	8.67	34.93	32.5	50
T_4	D_4I_1	10.83	35.57	34	50
T_5	D_5I_1	12.50	33.47	37	52
T_6	D_1I_2	9.50	32.5	31	36.5
T_7	D_2I_2	11.50	36.50	33	50.5
T_8	D_3I_2	15.50	40.50	35	51
T_9	D_4I_2	14.17	38.50	35.5	50
T_{10}	D_5I_2	13.43	35.50	37.5	52.5
T_{11}	D_1I_3	10.50	32.1	30	35
T_{12}	D_2I_3	12.83	34.50	31	51
T_{13}	D_3I_3	14.50	38.77	31.5	50
T_{14}	D_4I_3	13.43	34.83	32	50
T_{15}	D_5I_3	11.50	33.67	38	53

It is clearly seen that the water has distributed all along its roots. The maximum vertical root length was found to be 40.50 cm at the 10 cm depth of placement of laterals followed by a root length of 38.50 at 15 cm depth of placement. In both the cases the level of irrigation was 1.5 litres/ day/ plant. At zero depth of placement of laterals the root length was less as compared to the subsurface placements. It was also seen that, more number of roots had been grown to deeper layers to get water. The moisture distribution along the vertical soil profile taken at the centre of the crop before and after irrigation is shown in Plate 8.

Plate 8. A view of the root zone immediately after irrigation

By analyzing the moisture front advance the maximum vertical and horizontal movements were 52.5 cm and 37.5 cm respectively observed at 20 cm depth of placement of laterals. Moisture movement was observed to go beyond the maximum vertical and lateral spread of roots as observed from the photographs (Plate 7) and Table 21. Hence it has been concluded that roots never experience any water stress under subsurface installations as the water front covers the entire root zone.

Combining all the above results the following conclusions were made from the field study to evaluate the crop performance.

The yield was found to be maximum for the treatment D_3I_2. This was followed by the treatment D_3I_3 (Table 11). The analysis on biometric observations also showed that the height, girth of the plant and number of leaves are found to be high at D_3I_2. Hence the subsurface drip irrigation with 10 cm depth of placement of laterals and 1.5 litre/day of irrigation was considered the best for ladies finger in sandy loam soil of Tavanur region of Malappuram District.

The maximum yield at 10 cm depth may be due to the maximum absorption of moisture from the first half of the effective crop root zone depth. Since a major portion of water and nutrient absorbing roots are distributed at a distance of 10 cm from the surface. It may be seen that about 70 % of the total moisture used is extracted from the first half of the root zone depth .The remaining 30 % is distributed in the next half of the root zone. The increase in yield was also due to the negligible effects of non beneficial components such as runoff, soil evaporation and long term drainage.

The analysis showed that the optimum water requirement of ladies finger in subsurface drip irrigation system is 1.5 litre /day, which offers a 25 % saving of water than surface drip irrigation methods. This implied that subsurface drip irrigation save water to some extent. As the crop was attacked by mosaic disease, this has to be further investigated for another crop with an expectation of 50 % saving in water.

The practical implications of the present study favour the use of subsurface drip irrigation, generally placed at a depth of 10 cm below the soil surface for the crop ladies finger. So the crops would benefit from such an irrigation system even if the upper layers of the soil profile have low moisture content, insufficient capillary rise, limited residual water, and lack of surface irrigation or rainfall.

4.5 Comparison with surface and subsurface drip irrigation

Based on the results obtained above a comparison was made between surface and subsurface drip systems.

The average yield obtained from surface drip was found to be 4.8 t/ha where as the best subsurface treatment yield was 8.1 t/ha which is 60 % higher than the surface drip irrigation (Table 11). The higher yield in subsurface drip may be due to the following reasons.

1. Increased wetted soil volume
2. Decreased rate of redistribution of soil moisture
3. Decreased surface evaporation
4. Increased total transpiration
5. Increased Irrigation efficiency

The biometric observations such as height of the plant, thickness of the stem and number of leaves were less in surface drip compared to the subsurface drip (Table 15). This may be due to the higher water use efficiency of subsurface drip irrigation. Since these drip tubes are placed below the soil surface, soil water remains in the root zone for utilization by growing plants.

The distribution of root length and root zone length differed significantly between surface and subsurface drip irrigation methods as shown in the

Table 21. The maximum root zone length of 15.50 cm and root length of 40.50 cm were observed in D_3I_2. It was also found that in all the treatments as the root zone length increases the root length also increases. While comparing the root distribution in the subsurface placements, the corresponding values obtained for the surface treatment was found to be only 6.33 cm and 31 cm respectively which is comparatively less. This is mainly due to the less moisture availability at the surface due to the high rate of infiltration at the top dry layers. Moreover the atmospheric interactions are high at the surface as compared to the subsurface.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMERY AND CONCLUSION

The study entitled "Subsurface Drip Irrigation of ladies finger in Sandy Loam Soil" was aimed to assess the hydraulic characteristics of inline dripper in the field, soil moisture distribution and effect of depth of installation and levels of irrigation on growth and yield of crop. This study has also made a comparison between surface and subsurface drip.

The average discharge for different operating heads ranging from 0.3 to1.8 kg/cm^2 showed that as the pressure increases, discharge also increases and the same was also tested at 0, 5, 10, 15 and 20 cm of depths of installation. Studies revealed that as depth of installation increases the discharge also increases. The actual discharges obtained in the field were 3.7, 4.0, 4.0, 4.3, and 4.4 lph at 0, 5, 10, 15 and 20 cm of depth of installation respectively at the nominal operating pressure of 1.5 kg/cm^2. The power function was found to be good in explaining the discharge exponent in deciding the flow regime. The values of the exponent in the power function was found to be 0.7717, 0.7266, 0.5973, 0.5416 and 0.5325 respectively for 0, 5, 10, 15 and 20 cm depths which suggested an orifice type (turbulent flow) emitter for the present inline dripper.

The emission uniformity (Eu) of the system were found to range from 74 to 94 %. This meant that some emitters have a uniformity more than 90 %, which are excellent, some of them have values between 80 to 90 %, come under the category of good and others come under the category of fair with an average uniformity of 70 to 80 %. The manufacturing coefficient (Cv) was found to vary between 6.2 and 20%, as the pressure varied from 0.3 to 1.8 kg / cm^2. This indicated an average to marginal performance of the inline dripper. The Reynolds number was increased from 1460 to 6237 for the lateral pipe size of 16 mm with increase in inlet pressure from 0.3 to 1.8 kg/cm^2 and it was also increased with increase in depth. This confirmed that the turbulence of flow increases with increase in pressure. The average values of friction factor decreases from 0.0382 to 0.0365 for the same pressure of 1.5 kg/cm^2 as the depth increases from 0 to 20 cm. It was also found that as the pressure increases the friction factor decreases. The application efficiency increased with pressure and was not much affected by depth of installation of laterals.

An experiment was conducted to evaluate soil moisture distribution pattern of the inline drippers in the bare field. The emitters were located at 0, 5, 10, 15 and 20 cm depth from the surface. The soil moisture distribution pattern was found to follow a bulb shape in all the contours. The maximum moisture content observed at the emitter position were 19, 24, 25, 22 and 22 % respectively for 0, 5, 10 , 15 and 20 cm depths of installation half an hour after irrigation. The maximum depletion was found at zero depth of installation after 24 hrs of irrigation, while the same was considerably reduced in cases of the deeper installation. The best moisture distributions were observed at 10 and 15 cm depth of installations after 24 hours of irrigation. The moisture content observed 24 hours after irrigation was found high in deeper installations. The maximum horizontal and vertical water front advance observed at 20 cm depth was found to be 55 cm and 82 cm respectively. The vertical movement was more pronounced than the horizontal movement.

A field study was conducted to study the effect of depth of installation and levels of irrigation on growth and yield of ladies finger in sandy loam soil. The highest fruit yield of 8.1 t/ha was obtained for the treatment D_3I_2 ie, for the depth of installation 10 cm and the level of irrigation 1.5 litre/day/plant. Water use efficiency was found 11.24 kg/ha mm for the treatment D_3I_2. The analysis on biometric observations also showed that the height, thickness and number of leaves of the plant were found high at D_3I_2. Hence the subsurface drip irrigation with 10 cm depth of placement of laterals and 1.5 lit/day/plant of irrigation was considered as the best treatment for okra in sandy loam soil.

Weed count data revealed that the weed infestation was less in deeper installation of emitters. There was no evidence of pinching of the hose by roots or root intrusion into the emitter. Moisture movement was observed to go beyond the maximum vertical and lateral spread of roots which indicated that the plant never had any water stress during the crop period under subsurface drip.

The studies conducted to evaluate the growth and development of roots, revealed that there was a significant rise in root length under subsurface drip irrigation and the root length and root zone length was found maximum for the treatment D_3I_2 (depth of installation -10 cm and level of irrigation-1.5 lit/day/plant) with a value of 40.5 cm and 15.5 cm respectively. The maximum horizontal and vertical water front advance in the root zone was found 37.5 cm and 52.5 cm respectively.

While comparing surface and subsurface drip irrigation on crop performance, the average yield obtained under surface drip was found to be 4.8 t/ha where as the yield under best subsurface treatment was 8.1 t/ha which is 60 % higher than the surface drip irrigation. The biometric observations such as height of the plant, thickness of the stem and number of leaves were less in surface drip compared to the subsurface drip. This may be due to the higher water use efficiency of subsurface drip irrigation than surface drip. The average water use efficiency for the surface drip and the best subsurface treatment were 7.18 kg/ha mm and 11.24 kg/ha mm respectively. The distribution of root length and root zone length differed significantly between surface and subsurface drip irrigation. The moisture distribution was also found better in subsurface than surface treatments.

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APPENDICES

APPENDIX 1

Grain Size Distribution of the Soil (Coarse Fraction)

Sl.No	IS sieve	Particle Size D(mm)	Mass retained (g)	% retained	Cumulative % retained	Cumulative % finer
1	4.75	4.75 mm	3.50	1.17	1.17	98.93
2	2	2 mm	4.80	1.60	2.77	97.23
3	1	1 mm	42.90	14.30	17.07	82.93
4	0.60	0.6 mm	18.57	6.19	23.26	76.74
5	0.425	0.425 mm	40.40	13.47	36.73	63.27
6	0.3	0.3 mm	63.32	21.10	57.83	42.17
7	0.212	0.212 mm	52.20	18.40	76.23	23.77
8	0.15	0.15 mm	35.20	11.73	87.96	12.04
9	0.075	0.075 mm	24.00	8.00	95.96	4.04
10	pan	pan	4.25	1.42	97.38	2.62

APPENDIX 11

Grain Size Distribution of the soil (Fine fraction)

Mass of dry soil sample (M) =300 g

Mass of fraction passing 2 mm sieve (M') =260 g

Mass of dry sample taken from minus 2 mm sieves (Md) =50 g

Specific gravity of soil particles of minus 75 micron, G =2.65

Date	Time	Elapsed Time	Temperature	Hydrometer reading	Rh	Effective Depth	Factor M	Particle Size, D(mm)	% finer (N)based on Md	% finer based on whole N=N,xM'/M
20-1-06	11.05am	½	32	6.75	7.25	14.2	1193	0.064	21.68	18.79
	11.06am	1	32	6.20	6.70	14.5	1193	0.045	19.92	17.33
	11.08am	2	32	6.25	6.75	14.6	1193	0.0322	20.08	17.47
	11.12am	4	32	5.00	5.50	14.8	1193	0.023	16.06	13.97
	11.18am	8	32	3.00	3.50	15.2	1193	0.0164	9.64	8.39
	11.33am	15	33	2.50	3.00	15.8	1180	0.0121	8.03	7.22
	12.03pm	30	33	1.75	2.25	16.0	1180	0.0087	5.63	4.89
	1.03pm	60	33	1.25	1.75	16.3	1180	0.0059	4.02	3.5
	3.03pm	120	36	1.00	1.50	16.5	1144	0.0044	3.21	2.79
	6.03pm	180	33	0.75	1.25	16.7	1180	0.0036	2.41	2.10
	3.05am	900	36	0.25	0.75	16.0	1144	0.0015	0.803	0.69

Calibration of Hydrometer

Volume of hydrometer (V_h) = 85 ml

Height of bulb = 14.8 cm

Sectional area of the jar, A = 29.85 cm2

Constant ½(V_h-V_h/A) = 5.98 cm

Hydrometer reading, Rh	H (cm)	Effective Depth, He (cm)
30	05	6.474
25	2.2	8.275
20	4.0	9.975
15	5.6	11.675
10	7.4	13.375
5	9.1	15.075
0	10.9	15.875
-5	12.6	18.675

APPENDIX III

Determination of bulk density by core cutter method

Sl.No	Particulars	1	2	3
1	Mass of core cutter + wet soil (W_1), g	1302	1490	1364
2	Mass of core cutter (W_2), g	636	820	841
3	Mass of wet soil (W_3), g	666	670	523
4	Volume of core cutter (V_1), g	400	344.9	344.9
5	Bulk density (W_3/V_1)	1.7	1.9	1.5

Average Bulk Density =1.7 g/cm^3

APPENDIX IV

Observations on Cylinder Infiltometer

Elapsed time (min)	Interval (min)	Distance of water surface from reference point			Infiltration during period	
		Initial depth(cm)	Final depth(cm)	Decrease in water level(cm)	Average rate (cm/hr)	Accumulated infiltration(cm)
-	-	11.0	-	-	-	-
5	5	11.0	9.10	1.90	22.80	1.90
10	5	11.0	9.40	1.60	19.20	3.50
15	5	11.0	10.20	0.80	9.60	4.30
25	5	11.0	9.50	1.50	18.00	5.80
45	20	11.0	8.11	2.89	8.67	8.69
60	15	11.0	9.00	2.00	8.00	10.69
75	15	11.0	9.00	2.00	8.00	12.69
90	15	11.0	8.30	2.70	10.8	15.39
110	20	11.0	8.30	2.70	8.10	18.09
130	20	11.0	8.30	2.70	8.10	20.79

APPENDIX V

Determination of Coefficient of Permeability by constant head permeameter

Details	Sample 1	Sample 1	Sample 1
Hydraulic head(cm)	120	107	99
Length of soil sample (cm)	12.00	12.00	12.00
Hydraulic Gradient	10.00	8.92	8.30
Cross sectional area of sample (cm^2)	78.50	78.50	78.50
Time interval (sec)	600	600	600
Quantity of flow (cm^3)	100	85	80
Permeability coefficient (cm/sec)	2.12×10^{-4}	2.02×10^{-4}	2.11×10^{-4}

APPENDIX VI

Emitter discharge for pressure 0.3 kg/cm^2

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	1.0	1.2	1.1	1.2	1.1	1.0	1.2	1.1
2	5	1.5	1.5	1.0	1.4	1.3	1.5	1.4	1.0
3	10	1.8	1.8	1.6	1.5	1.7	1.4	1.5	1.8
4	15	1.7	1.6	2.0	2.0	1.6	1.9	1.6	2.0
5	20	1.4	2.0	2.2	1.5	1.4	2.1	2.0	2.2

Emitter discharge for pressure 0.6 kg/cm^2

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	1.5	1.6	1.1	1.2	1.2	1.1	1.5	1.7
2	5	1.7	1.2	1.7	1.5	1.5	1.7	1.7	1.2
3	10	1.6	2.3	2.5	1.8	1.5	2.3	2.0	1.8
4	15	1.7	2.6	3.0	2.0	1.6	1.6	1.9	2.0
5	20	2.4	2.4	2.6	2.5	2.0	2.3	1.8	2.0

Emitter discharge for pressure 0.9 kg/cm^2

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	2.9	1.7	1.0	2.0	2.0	2.0	1.9	1.5
2	5	3.1	2.1	2.6	2.6	2.5	2.8	2.9	2.4
3	10	3.2	2.9	3.0	3.0	2.6	3.0	3.0	2.5
4	15	3.0	2.7	3.2	3.0	2.3	3.0	3.2	2.6
5	20	3.0	2.3	3.6	3.4	3.0	3.2	3.1	2.7

Emitter discharge for pressure 1.0 kg/cm^2

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	2.0	2.2	2.1	2.0	2.3	2.0	2.4	2.3
2	5	2.8	2.6	2.8	2.8	2.7	2.8	2.8	2.7
3	10	3.0	2.9	2.8	3.1	3.1	3.1	3.2	3.2
4	15	2.9	3.0	2.8	3.1	3.2	3.1	3.2	3.2
5	20	3.0	3.2	3.3	3.0	3.2	3.3	3.3	3.3

Emitter discharge for pressure 1.2. Kg/cm^2

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	3.8	2.5	2.0	2.0	3.4	2.9	3.0	3.0
2	5	3.9	2.3	3.3	3.1	3.5	3.0	3.2	3.5
3	10	4.2	3.4	2.9	3.0	3.5	3.2	4.0	3.6
4	15	3.0	3.2	3.9	3.2	3.6	2.8	4.1	4.0
5	20	3.6	3.4	3.5	3.4	3.6	2.7	4.0	4.2

Emitter discharge for pressure 1.5 kg/cm^2

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	3.2	4.8	3.2	4.0	5.1	3.4	3.2	3.0
2	5	5.1	3.4	3.5	4.1	4.3	4.3	3.2	4.2
3	10	3.4	4.4	4.4	4.0	3.5	3.9	4.0	4.4
4	15	5.1	4.8	3.1	3.5	4.0	5.1	4.4	4.2
5	20	4.9	4.1	4.5	3.4	4.3	4.9	4.9	4.1

Emitter discharge for pressure 1.8 kg/cm²

Sl.No	Depth of Lateral(cm)	Discharge collected in lph							
		Emitter 1	Emitter 2	Emitter 3	Emitter 4	Emitter 5	Emitter 6	Emitter 7	Emitter 8
1	0	2.9	4.6	4.4	4.3	4.0	4.0	4.0	3.9
2	5	4.6	5.0	4.0	4.0	5.0	4.0	4.9	4.0
3	10	4.9	4.3	4.0	4.3	4.7	4.7	4.5	4.0
4	15	4.4	4.9	4.3	4.5	4.5	4.8	4.5	4.0
5	20	4.9	4.5	5.0	5.0	4.3	4.0	4.6	5.0

APPENDIX VII

Emission uniformity (Eu) computed by Keller and Karmelli formula

Sl.No	Pressure (kg/cm²)	Emission uniformity Eu (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	91	77	94	89	73
2	0.6	79	73	80	76	83
3	0.9	68	89	90	86	83
4	1.0	92	95	95	94	97
5	1.2	71	84	86	83	86
6	1.5	86	83	86	77	86
7	1.8	85	91	91	93	89

Emission uniformity (Eu) computed by Christiansen formula

Sl. No	Pressure (kg/cm²)	Emission uniformity Eu (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	94	88	90	89	79
2	0.6	85	88	85	83	85
3	0.9	82	91	95	92	86

4	1.0	95	98	97	96	97
5	1.2	71	89	83	88	91
6	1.5	81	92	93	80	78
7	1.8	90	90	94	96	93

Emission uniformity (Eu) computed by Wilcox formula for different operating pressures

Sl.No	Pressure (kg/cm^2)	Emission uniformity Eu (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	92	84	90	89	81
2	0.6	83	82	82	76	87
3	0.9	72	88	92	89	86
4	1.0	93	97	95	95	96
5	1.2	80	86	86	86	88
6	1.5	79	85	90	83	88
7	1.8	88	89	92	94	92

APPENDIX VIII

Friction factor calculated by Fanning's formula

Sl.No	Pressure (kg/cm^2)	Friction factor				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	0.05417	0.0516	0.0487	0.0471	0.0464
2	0.6	0.0506	0.0496	0.0457	0.0451	0.0440
3	0.9	0.0464	0.0425	0.0412	0.0412	0.0408
4	1.2	0.0416	0.0401	0.0391	0.0391	0.0388
5	1.5	0.0385	0.0377	0.0377	0.0370	0.0368
6	1.8	0.0391	0.0368	0.0368	0.0365	0.0361

Frictional factor calculated by Blassius formula

Sl.No	Pressure (kg/cm^2)	Friction factor				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	0.0511	0.0450	0.0466	0.0452	0.0446
2	0.6	0.0481	0.0473	0.0440	0.0435	0.0425
3	0.9	0.0446	0.0412	0.0401	0.0401	0.0398
4	1.2	0.0405	0.0391	0.0383	0.0383	0.0380
5	1.5	0.0378	0.0370	0.0370	0.0364	0.0361
6	1.8	0.0370	0.0361	0.0361	0.0360	0.0356

APPENDIX IX

Variation of application efficiency with depth and pressure

Sl.No	Pressure (kg/cm^2)	Application Efficiency, Ea (%)				
		Depth 0 cm	Depth 5 cm	Depth 10 cm	Depth 15 cm	Depth 20 cm
1	0.3	91	80	88	89	78
2	0.6	79	83	75	70	82
3	0.9	70	81	88	90	78
4	1.0	91	96	93	93	95
5	1.2	69	74	82	81	78
6	1.5	74	77	87	76	82
7	1.8	77	89	90	90	89

APPENDIX X

Observed soil moisture content at different depths and lateral distances of considered grid points

Depth of installation 0 cm

Grid Point	Soil Moisture Content (%)		
	Before Irrigation	Immediately After Irrigation	After 24 hour irrigation
0,0	10.00	21.55	6.36
0,10	14.39	17.86	5.35
0,20	10.67	16.69	8.21
0,30	6.44	16.51	9.22
0,40	4.76	15.16	7.37
10,0	11.54	17.44	9.61
10,10	23.64	16.67	10.59
10,20	16.53	16.45	11.21
10,30	9.93	12.47	20.42
10,40	8.80	11.18	10.05
20,0	12.32	14.46	9.51
20,10	13.16	15.57	11.61
20,20	15.76	15.33	11.46
20,30	18.84	15.29	8.11
20,40	12.18	12.96	8.51
30,0	14.39	9.04	9.47
30,10	16.75	28.85	8.54
30,20	12.71	16.11	9.59
30,30	20.00	13.98	10.14
30,40	30.43	14.09	10.24
40,0	11.11	16.64	13.93
40,10	14.50	15.86	12.98
40,20	15.04	15.55	12.50
40,30	15.67	14.65	14.02
40,40	16.05	14.74	12.27
50,0	15.18	14.52	10.86
50,10	14.97	14.29	10.71
50,20	14.85	14.26	10.50
50,30	14.81	14.12	10.27
50,40	14.78	13.78	9.74
0,0	9.96	19.57	8.92
0,-10	14.29	19.01	8.78
0,-20	10.67	16.27	7.82
0,-30	6.47	9.11	5.10
0,-40	4.76	7.79	2.04
10,0	11.63	13.99	8.06

10,-10	24.07	12.45	7.91
10,-20	16.53	12.80	7.57
10,-30	9.93	13.09	7.37
10,-40	28.57	13.61	7.83
20,0	12.32	15.31	9.01
20,-10	13.16	17.56	8.34
20,-20	15.85	15.09	7.87
20,-30	17.79	14.29	6.70
20,-40	12.18	14.88	7.36
30,0	14.39	16.31	10.78
30,-10	16.34	14.20	10.51
30,-20	12.02	15.60	8.46
30,-30	13.37	14.85	9.58
30,-40	30.43	15.05	10.28
40,0	11.11	7.24	13.64
40,-10	14.98	15.27	14.01
40,-20	15.04	15.24	11.22
40,-30	19.77	15.38	11.51
40,-40	16.05	11.06	11.43
50,0	15.22	14.54	10.86
50,-10	14.93	14.16	10.71
50,-20	14.81	14.26	10.50
50,-30	14.78	14.12	10.27
50,-40	14.74	13.78	9.74

Depth of installation 5 cm

Grid Point	Soil Moisture Content (%)		
	Before Irrigation	Immediately After Irrigation	After 24 hour irrigation
0,0	12.09	25.71	8.54
0,10	11.11	20.34	8.10
0,20	10.82	6.67	2.96
0,30	7.22	0.64	0.84
0,40	11.76	3.54	3.37
10,0	13.40	24.80	4.43
10,10	13.90	22.61	13.41
10,20	15.45	7.19	12.14
10,30	15.49	9.55	8.55
10,40	15.08	4.72	8.81
20,0	15.91	24.74	11.74
20,10	18.52	18.51	11.45
20,20	17.79	7.01	11.86
20,30	18.33	8.47	13.11
20,40	19.78	12.89	11.55
30,0	19.82	22.62	13.92

30,10	18.09	16.72	13.00
30,20	18.92	12.97	14.21
30,30	18.18	14.01	14.39
30,40	18.59	14.81	13.07
40,0	17.42	23.67	14.69
40,10	14.75	17.28	14.48
40,20	18.30	5.38	10.97
40,30	22.33	15.92	15.58
40,40	16.56	14.02	15.79
50,0	16.45	13.98	15.76
50,10	16.34	13.94	15.74
50,20	16.23	13.90	15.71
50,30	16.13	13.49	15.66
50,40	15.15	13.45	15.41
0,0	12.02	25.07	8.57
0,-10	10.78	20.28	8.08
0,-20	10.82	6.64	1.96
0,-30	7.25	0.64	0.84
0,-40	11.76	3.54	3.35
10,0	12.32	28.24	4.43
10,-10	13.83	22.54	13.41
10,-20	15.45	7.14	12.11
10,-30	23.48	3.59	6.63
10,-40	13.89	4.72	8.81
20,0	13.26	28.83	11.69
20,-10	18.52	21.36	11.45
20,-20	17.87	7.01	11.82
20,-30	18.23	8.47	13.11
20,-40	19.78	12.89	11.52
30,0	19.82	20.70	13.89
30,-10	18.18	16.72	13.00
30,-20	12.90	12.92	11.68
30,-30	18.18	13.95	14.39
30,-40	18.47	14.88	13.07
40,0	17.42	23.62	14.66
40,-10	19.57	17.28	14.45
40,-20	18.39	5.13	10.97
40,-30	17.33	15.92	15.63
40,-40	16.56	13.98	15.79
50,0	16.34	13.94	15.71
50,-10	16.45	13.90	15.69
50,-20	16.34	13.49	15.66
50,-30	15.15	13.11	15.64
50,-40	15.06	13.07	15.41

Depth of installation 10 cm

Grid Point	Soil Moisture Content (%)		
	Before Irrigation	Immediately After Irrigation	After 24 hour irrigation
0,0	8.80	18.23	7.77
0,10	7.53	18.24	9.50
0,20	9.52	18.3	13.21
0,30	8.57	18.32	6.48
0,40	6.83	22.14	7.52
10,0	10.08	22.32	14.53
10,10	12.70	25.12	12.01
10,20	9.09	25.13	14.32
10,30	14.17	25.14	13.83
10,40	12.17	25.8	13.07
20,0	14.59	25.6	13.13
20,10	13.08	25.7	14.80
20,20	12.71	25.6	14.47
20,30	14.19	24.12	14.48
20,40	14.61	24.56	14.19
30,0	13.73	23.5	14.36
30,10	14.13	23.1	15.10
30,20	18.72	23.1	13.21
30,30	15.87	23.5	13.74
30,40	17.34	23.7	14.32
40,0	16.02	23.42	11.96
40,10	15.90	23.53	15.05
40,20	23.90	24.21	12.69
40,30	15.68	25.56	14.65
40,40	15.79	23.1	14.18
50,0	15.74	23.21	14.15

50,10	15.69	23.12	14.08
50,20	15.55	23.4	14.01
50,30	15.45	22	13.92
50,40	15.22	22.45	13.88
0,0	10.66	18.23	7.09
0,-10	6.95	18.24	9.50
0,-20	10.53	18.3	13.21
0,-30	8.16	18.32	6.75
0,-40	6.83	22.14	10.17
10,0	8.82	22.32	14.04
10,-10	12.47	25.12	11.04
10,-20	9.88	25.13	13.58
10,-30	12.85	25.14	14.24
10,-40	11.36	25.8	13.40
20,0	13.51	25.6	13.13
20,-10	10.77	25.7	14.80
20,-20	11.39	25.6	14.10
20,-30	16.34	24.12	29.49
20,-40	16.13	24.56	14.19
30,0	13.33	23.5	14.17
30,-10	14.13	23.1	14.77
30,-20	18.72	23.1	13.21
30,-30	17.60	23.5	13.33
30,-40	17.65	23.7	13.62
40,0	11.62	23.42	11.64
40,-10	17.31	23.53	15.05
40,-20	23.51	24.21	12.69
40,-30	13.81	25.56	14.95
40,-40	15.79	23.1	13.46

50,0	15.69	23.21	14.11
50,-10	15.74	23.12	14.05
50,-20	15.60	23.4	14.01
50,-30	15.45	22	13.88
50,-40	15.22	22.45	13.85

Depth of installation 15 cm

Grid Point	Soil Moisture Content (%)		
	Before Irrigation	Immediately After Irrigation	After 24 hour irrigation
0,0	8.80	23.91	10.49
0,10	7.53	18.03	9.16
0,20	9.52	5.42	9.06
0,30	8.57	6.40	10.41
0,40	6.83	5.71	11.40
10,0	10.08	19.95	12.50
10,10	12.70	33.02	10.61
10,20	9.09	7.97	11.98
10,30	14.17	11.35	12.31
10,40	12.17	12.67	14.60
20,0	14.59	13.22	13.78
20,10	13.08	18.67	15.68
20,20	12.71	13.16	14.11
20,30	14.19	12.64	14.88
20,40	14.61	13.24	13.66
30,0	13.73	21.08	15.25
30,10	26.09	19.57	14.36
30,20	18.72	13.04	13.95
30,30	15.87	12.35	13.19
30,40	17.34	14.35	14.40
40,0	16.02	23.72	5.23
40,10	15.90	18.65	14.29
40,20	23.90	13.83	14.36
40,30	15.68	13.70	14.32
40,40	15.79	13.01	14.80
50,0	15.69	12.98	14.78
50,10	15.64	12.91	14.29
50,20	15.45	12.84	13.61
50,30	15.22	12.59	13.50
50,40	14.78	12.52	13.29
0,0	8.73	23.76	10.51
0,-10	7.49	17.98	9.13
0,-20	9.48	5.43	9.06
0,-30	8.57	6.40	10.38

0,-40	6.83	8.38	11.40
10,0	10.04	19.89	12.50
10,-10	12.66	33.02	11.98
10,-20	9.04	7.91	11.96
10,-30	14.17	11.35	12.31
10,-40	12.12	12.67	14.57
20,0	14.59	13.22	13.78
20,-10	13.08	18.60	15.38
20,-20	12.71	13.16	14.07
20,-30	14.10	12.60	5.34
20,-40	14.55	13.24	13.66
30,0	13.67	21.08	14.11
30,-10	26.09	19.54	14.38
30,-20	18.64	13.04	14.16
30,-30	15.81	12.40	13.14
30,-40	17.34	14.35	14.40
40,0	15.95	23.79	5.22
40,-10	15.96	18.65	14.59
40,-20	23.90	13.78	14.32
40,-30	14.77	13.66	14.32
40,-40	15.79	13.01	14.78
50,0	15.74	12.93	15.03
50,-10	15.60	12.91	14.41
50,-20	15.36	12.88	13.72
50,-30	15.27	12.84	13.50
50,-40	14.78	12.59	13.31

Depth of installation 20 cm

Grid Point	Soil Moisture Content (%)		
	Before Irrigation	Immediately After Irrigation	After 24 hour irrigation
0,0	2.60	2.17	2.76
0,10	12.66	7.13	4.62
0,20	13.28	6.00	4.07
0,30	15.30	4.19	3.50
0,40	15.77	16.40	4.02
10,0	12.46	18.78	14.81
10,10	13.11	19.03	14.33
10,20	12.82	10.67	12.95
10,30	13.61	10.68	12.63
10,40	16.87	10.48	12.73

20,0	15.88	22.12	17.29
20,10	15.36	22.30	15.10
20,20	13.18	22.50	13.49
20,30	13.36	22.56	12.97
20,40	12.64	22.63	11.32
30,0	16.03	21.36	10.25
30,10	16.67	20.78	15.26
30,20	16.36	17.26	9.31
30,30	13.59	17.63	13.48
30,40	13.91	15.58	15.06
40,0	16.07	16.29	15.58
40,10	14.05	17.32	15.34
40,20	14.90	17.84	14.64
40,30	14.75	17.33	15.90
40,40	14.08	16.04	14.83
50,0	10.90	15.84	14.78
50,10	9.80	15.36	14.66
50,20	9.48	15.13	14.53
50,30	8.90	14.91	14.46
50,40	7.32	14.70	14.19
0,0	2.95	4.48	9.36
0,-10	12.72	6.65	10.52
0,-20	13.28	3.78	4.77
0,-30	15.36	9.44	10.43
0,-40	15.73	8.50	4.39
10,0	12.46	20.39	15.77
10,-10	13.11	20.73	15.22
10,-20	13.25	19.49	12.23
10,-30	10.32	10.68	14.06

10,-40	16.87	12.04	12.79
20,0	15.79	22.12	14.73
20,-10	15.30	22.30	13.76
20,-20	13.18	22.50	14.87
20,-30	13.44	22.56	13.07
20,-40	12.32	22.63	11.52
30,0	16.03	21.36	15.23
30,-10	18.93	20.78	14.77
30,-20	16.67	16.03	15.71
30,-30	15.68	15.41	15.06
30,-40	13.91	12.20	13.99
40,0	16.22	16.58	16.39
40,-10	18.82	16.72	15.22
40,-20	14.90	15.83	12.86
40,-30	14.75	15.45	15.34
40,-40	14.15	17.04	34.69
50,0	10.51	16.09	14.81
50,-10	9.48	15.13	14.68
50,-20	7.92	14.91	14.55
50,-30	7.51	14.70	14.48
50,-40	7.32	14.49	14.14

SUBSURFACE DRIP IRRIGATION OF LADIES FINGER IN SANDY LOAM SOIL

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Placing water beneath the soil surface via buried drip lines is slowly becoming the preferred choice of many farmers. No doubt the use of subsurface drip irrigation technology may well be the future of irrigation in the coming years and decades. It holds the promise of reducing the weed growth, fertilizer and chemical use, labour requirement and optimizing water use. Subsurface drip irrigation is an advanced and recent revolutionary variation of drip irrigation. The aim of drip irrigation design is to ensure uniform distribution of water to the crop with pre-determined application of water. Therefore, for uniform outflow from emitter, information on their hydraulic characteristics is very vital. The system is comparatively costly and prone to clogging. It is therefore necessary to evaluate the performance in the field and see whether their performance is meeting the design expectations. Hence the present study was undertaken to analyze the hydraulics of subsurface inline drip irrigation system, soil moisture distribution pattern, the effect of depth of installation of laterals and levels of irrigation on growth and yield of ladies finger and to compare the performance of surface and subsurface drip irrigation. In this study five depths of installations (0, 5, 10, 15 and 20 cm) and three levels of irrigation were studied (1.0, 1.5 and 2.0 lit/ day/ plant).

The subsurface drip irrigation system was tested for their hydraulic performance in the field at five depths of installations of 0, 5, 10, 15 and 20 cm in terms of pressure-discharge relation, emission uniformity, manufacturing coefficient of variation, friction factors, Reynolds number and application efficiency. The discharge from emission points were collected at seven different operating pressures ranging from 0.3 to 1.8 kg/cm^{2}. The power function was found to be good in explaining the discharge exponent in deciding the flow regime. The discharge exponent for the power function was found 0.7717, 0.7266, 0.5973, 0.5416 and 0.5325 for respectively 0, 5, 10, 15 and 20 cm which suggested an orifice type (turbulent flow) emitter for the present inline dripper. The emission uniformity values of the system were found to range between 74 and 94 % at different depths

of installation and varying pressure indicating average to excellent performance. The manufacturing coefficient value (Cv) was found to be vary between 6.2 and 20 %, as the pressure varies from 0.3 to 1.8 kg/cm^2. This indicated an average to marginal performance of the inline dripper. The Reynolds number increased from 1460 to 6237 for the lateral pipe size of 16 mm with increase in inlet pressure from 0.3 to 1.8 kg/cm^2 and it also increased with increase in depth. This confirms that the turbulence of flow increases with increase in pressure. The average values of friction factor decreases from 0.0382 to 0.0365 for the same pressure of 1.5 kg/cm^2 as the depth increases from 0 to 20 cm. It was also found that as the pressure increases the friction factor decreases. The application efficiency increased with pressure and was not much affected by depth of installation of laterals.

The soil moisture distribution pattern was found to follow a bulb shape in all the contours. The maximum moisture content observed at the emitter position were 19, 24, 25, 22 and 22 % respectively for 0, 5, 10, 15 and 20 cm depths of installation half an hour after irrigation. The maximum depletion was found at zero depth of installation after 24 hrs of irrigation, while the same was considerably reduced in the deeper installations. The best moisture distributions were observed at 10 and 15 cm depths of installation after 24 hrs of irrigation.

A field study was conducted to study the effect of depth of installation and levels of irrigation on growth and yield of ladies finger in sandy loam soil. The highest fruit yield obtained was 8.1 t/ha for the treatment D_3I_2 ie, the depth of installation 10 cm and the level of irrigation 1.5 lit/day/plant. Water use efficiency was found 11.24 kg/ha mm for the treatment D_3I_2. The analysis on biometric observations also showed that the height, thickness and number of leaves of the plant were found high at D_3I_2. Hence the subsurface drip irrigation with 10 cm depth of placement of laterals and 1.5 lit/day/plant of irrigation was considered as the best treatment for okra in sandy loam soil. The maximum horizontal and vertical movement of water front in the root zone of okra was found 37.5 cm and 52.5 cm respectively. The moisture movement was observed to go beyond the maximum vertical and lateral spread of roots which indicated that the plant never had any water stress during the crop period under subsurface drip. Therefore it is clear that the adoption of subsurface drip technology should be enthusiastically pursued as an appropriate technology to deal with increasing demand of water, environmental, ecological and economic concerns