LOW PRESSURE LOW COST (LPLC) DRIP IRRIGATION SYSTEM FOR SMALL LAND HOLDERS

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DEO NARAYAN SAH

THESIS

Doctor of Philosophy

IN

AGRICULTURAL ENGINEERING

(Irrigation Water Management Engineering)

2009

DEPARTMENT OF SOIL AND WATER ENGINEERING
COLLEGE OF TECHNOLOGY AND ENGINEERING
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR (RAJASTHAN) 313 001 (INDIA)

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Thesis

Submitted to the

Maharana Pratap University of Agriculture and Technology, Udaipur

In Partial Fulfillment of the Requirement for

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Doctor of Philosophy

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(IRRIGATION WATER MANAGEMENT ENGINEERING)

BY

DEO NARAYAN SAH

2009

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR -313 001

Dated: 15/09/2009

CERTIFICATE -I

This is to certify that **Mr. Deo Narayan Sah** has successfully completed the preliminary examination held on 22/05/2008 as required under the regulation for the degree of **Doctor of philosophy** in **Agricultural Engineering** (Irrigation Water Management Engineering).

(**Dr. R.C. Purohit**)
Head
Department of Soil and Water Engineering,
C.T.A.E., Udaipur

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY & ENGINEERING, UDAIPUR - 313 001

Dated: 15/09/2009

CERTIFICATE -II

This is to certify that this thesis entitled "**Low pressure low cost (LPLC) drip irrigation system for small land holders**" submitted for the degree of **Doctor of Philosophy** in the subject of **Agricultural Engineering** (Irrigation Water Management Engineering), embodies bonafide research work carried out by **Mr. Deo Narayan Sah,** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on date 27/08/2009.

(Dr. R.C. Purohit)
Major Advisor

(Dr. R.C. Purohit)
Head
Department of Soil and Water
Engineering, C.T.A.E., Udaipur.

(Dr. Virendra Kumar)
Dean
Collage of Technology and
Engineering, Udaipur.

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR -313 001

Dated: 11/12/2009

CERTIFICATE –III

This is to certify that this thesis entitled "**Low pressure low cost (LPLC) drip irrigation system for small land holders**" submitted by **Mr. Deo Narayan Sah,** to the Maharana pratap University of Agriculture and Technology, Udaipur in partial fulfillment of the requirements for the degree of the **Doctor of Philosophy** in the subject of **Agricultural Engineering (Irrigation Water Management Engineering)** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We therefore, recommend that the thesis be approved.

(Dr. R.C. Purohit)
Major Advisor

(Dr. Virendra Kumar)
Advisor

(Dr.R.A. Kaushik)
Advisor

(Dr. S.K. Jain)
Advisor

(Dr. M.K. Khandelwal)
External Examiner

(Dr. R.C. Purohit)
Head
Deptt. of SWE,CTAE, Udaipur.

(Dr. Virendra Kumar)
Dean
CTAE, Udaipur

Director Resident Instructions
MPUAT, Udaipur.

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY
COLLEGE OF TECHNOLOGY & ENGINEERING, UDAIPUR -313 001

Dated: 14/12/2009

CERTIFICATE -IV

This is to certify that **Mr. Deo Narayan Sah,** student of Doctor of Philosophy in Agricultural Engineering in the subject of Irrigation Water Management Engineering**,** Department of Soil and Water Engineering, College of Technology and Engineering, has made all corrections/modifications in the thesis entitled "**Low pressure low cost (LPLC) drip irrigation system for small land holders**" which were suggested by the external examiner and the advisory committee in the oral examination held on 11/12/2009, the final copies of the thesis duly bound and corrected were submitted on 14/12/2009.

(Dr. R.C. Purohit)
Major Advisor

(Dr. R.C. Purohit)
Head
Department of Soil and Water Engineering,
C.T.A.E., Udaipur.

(Dr. Virendra Kumar)
Dean
Collage of Technology and Engineering,
MPUAT, Udaipur.

ABSTRACT

A field experiment entitled "Low Pressure Low Cost (LPLC) Drip Irrigation System for Small Land Holders" was conducted during 2008-09 at Horticulture Farm, Rajasthan College of Agriculture, Udaipur. Manually operated affordable low pressure low cost (LPLC) drip system was constructed from locally available materials. The system consists of Krishak Bandhu (KB) pipes, KB pressure treadle pump with pressure drum (source), microtubes and medical infusion set as emitters. The KB pressure treadle pump is basically a foot operated, medium lift, double-stroke, vertical reciprocating and positive displacement pump. It was appropriated with non return valve with bend arrangement. The field experiments were conducted on different aspects for tomato and broccoli, such as vegetative growth parameters, hydraulic performances, crop water requirements, water use efficiency and cost economics. Sprouting broccoli (*Brassica olreacea* L. var. italica) cv. Aishwarya (F_1 - Hybrid) and tomato (*Lycopersicon esculentum* Mill) cv. Dev variety were grown. Emitters clogging which is common menace with drip systems were controlled by weekly addition of lime in storage tank. Treatments combinations were as under

T1: Broccoli grown on level ground with medi-emitters

T2: Tomato grown on 0.5 % up slope with medi-emitters

T3: Tomato grown on level ground with microtubes

T4: Broccoli grown on 0.5 % up slope with microtubes

The experiment was laid out with four treatments, which were treated as twenty-one replication (without treatment) for randomized block design (RBD). Each sub plot was comprised of 21 numbers of rows with 566 numbers of plants, out of which 5 plants were selected randomly as observational plants. Paired rows planting pattern was adopted with improved planting geometry. Row to row and plant to plant spacing was 0.60 m and 0.45 m respectively.

It was found that male can perform the pump operation more efficiently than female having same weight. Since the total lift of pump is 13 m, the farmers can use this pump for drip, sprinkler and supplemental irrigation from available source of water (ground water, pond and storage tank, etc). Its cost was Rs 2900($65). Ergonomically designed KB pressure treadle pump found to operate satisfactory, divisible and affordable for small land holders.

System was operated under 6 m pressure head, discharge of emitters and its hydraulic parameters were evaluated. The application time was calculated on the basis of Kc and pan evaporation (35 years weekly climate normal during growth period of vegetable crops, RCA). Discharge rate of emitters under 6 m head was 2.29, 2.11, 1.05 and 0.86 l/h for treatments T1,

T2, T3 and T4 respectively. Flow through medi-emitter was laminar where as flow through microtubes was turbulent. It was scheduled daily based on crop water requirement and daily soil moisture observation was recorded by AIC tensiometer at 30 and 60 cm depth of soil profile in each subplots. Soil moisture content was found closer to field capacity.

Uniformity tested under 4-8 m head, Qvar, Hvar, Cv, UCS, CUC and Ed found in the range of 8.58 to 24.29 %, 16.36 to 48.84 %, 0.0945 to 0.1675, 86.15 to 90.82 %, 85.69 to 92.44 % and 58.33 to 75.17 % respectively.

The performance of four treatments was assessed by vegetative growth parameters with four biometric parameters: crop residue (all leaves + steam but without fruit mass), fruit mass, aboveground biomass and root mass. Fruit mass was significantly different in case of treatments T2 and T3 where as insignificant in case of T1 and T4 ($p \leq 0.05$). Yield of fruit (per ha) of broccoli and tomato in treatment T1 (29.27 t/ha) followed by T4 (17.33 t/ha) and T3 (63.46 t/ha) followed by T2 (56.03 t/ha) respectively. The vegetative growth parameters were high and superior quality in treatments T1 and T3 compared with T4 and T2.

The Water use efficiency (WUE) is one of the best tools for the evaluating the performance of different irrigation treatments. As the ground water contribution was nil (GWT › 10 m), the seasonal water requirement was found to be 20.08, 19.68, 18.61 and 21.06 cm respectively for treatments T1, T2, T3 and T4 and corresponding WUE are 1.46, 2.85, 3.41 and 0.82 t/ha-cm. T1 saved the water to the extent of 4.65 per cent over T4 and T3 to the extent 5.46 per cent over T2. The overall efficiency of water use within this experiment was high.

The developed system has pay back period of one season only, benefit to cost (B/C) ratio varies from 1.52 to 5.31 (without subsidy). This design therefore presents an attractive prospect for the advancement of affordable micro irrigation technology. However, for proper functioning of the medi-emitters, require a weekly check against clogging. Thus, appropriate, affordable, accessible, low operation and maintenance cost, users friendly LPLC drip irrigation system is better alternative for small land holders. This water efficient irrigation methods (LPLC) can significantly improve food production and the livelihoods in water scarce areas of developing countries, promoting greater economic and food security.

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I- INTRODUCTION

1.1 GENERAL

Agriculture is fundamental requirement for human survival. It supports life system and generates rural employment. Irrigation water is a crucial factor in meeting the food demand of ever increasing population of the world as well as India. The major resources inherent to modern agriculture are getting exhausted. These natural resources include arable land with fertile soil and fresh water. Several hectares of farm land remain deprived of cultivation due to the irregular precipitation, falling water table and lack of irrigation facilities. Water is a precious natural resource. Therefore, the development of water resources and their effective management is quite important for survival and economic growth of the nation.

India has 2.4 per cent of land mass and 4 per cent fresh water resources of the world, but support 17 per cent of the world population. The population is growing at around 2 per cent per annum since independence. Therefore, per capita land availability has dwindled from 0.48 ha to 0.15 ha and water availability has been reduced from 5300 Cu m to 1500 Cu m. In India, 91.6 per cent of the water is used for irrigation purpose as compared to 84 per cent in Asia and 71 per cent in the world (FAO, 1999).

FAO (2003) reported that towards 2015/30 the global food production will need to increase by 60 per cent to close nutrition gaps, cope with the population growth and accommodate change in diets over next three decades. Water withdrawals for agriculture are expected to increase by some 14 per cent in that period, representing annual growth rate of 0.6 per cent, down from 1.9 per cent in the period 1963-1999. Much of the increase will take place on arable irrigated land, forecasted to expand globally from some 2 million Sq. km to 2.42 million Sq. km. In group of 93 developing countries, water use efficiency in irrigation (the ratio between water consumption by crops and the total amount of water withdrawn), is expected to grow from an average 38 per cent to 42 per cent.

Conventional surface irrigation methods supply water unevenly with respect to space and time. In addition, losses such as evaporation, percolation, conveyance and seepage are major constraints in obtaining higher water use efficiency. Thus, there is an urgent need for maximum and efficient utilization of available resources; pressurized irrigation system has assumed greater importance. The overall efficiency of drip irrigation system is about 80-95 per cent as compared to that of 30-40 per cent in case of surface irrigation systems.

Drip irrigation is the slow and regular application of water, directly to the root zone of plants, through network of economically designed plastic pipes with low-discharge emitters. It limits the irrigation water closely to the consumptive use of plants. Thus, drip irrigation minimizes the conventional losses such as deep percolation, run-off and soil evaporation. It also permits the effective utilization of fertilizer, pesticides and other water-soluble chemicals along with irrigation water with better crop response. A properly designed drip system has following advantages: It saves water, increases yield, improve quality of produce, curtails labour cost, decreases salt concentration in the root zone, permits use of water soluble chemicals/fertilizers through the system, keeps inter-row space firm and dry, permits application in greenhouse and also controls and reduces diseases.

The low cost drip irrigation in India as introduced by International Development Enterprises-India (IDEI) represents an affordable means of expanding irrigation into rainfed areas, thereby increasing land productivity. IDE has been conducting research and developing low-cost, low-pressure drip irrigation systems since 1990. A major breakthrough in low-cost drip came with the development of KB drip ("KB" stands for the Hindi words "Krishak Bandhu", which means "farmer's friend".)

Low pressure low cost (LPLC) drip system is modified form of KB drip. It is water efficient irrigation method, affordable, divisible, significantly enhances agriculture production and the livelihood in water scarce areas of developing countries promoting greater economic and food security. Manually operated drip system was constructed from locally available materials and cost was justified by designing paired-row planting system by using low cost KB pipes, KB pressure treadle pump with pressure drum (source), improved field layout. The microtubes and medical infusion set were used as emitters.

The drip irrigation technology along with KB pressure treadle pump supports the farmers against the limitations of rain fed farming and enables them to grow wider variety of crops through out the year. The farmers can apply with higher cropping intensity and do priority farming. Modern irrigation technology improved agricultural practices coupled with enhanced participation of the poor in the markets is the key to income generation. Drip system is effective and pays in 1 season only. Low pressure low cost (LPLC) drip system with operating head 13 m with 95.79 per cent field emission uniformity at 6 m head or more at more head has low operation and maintenance cost. Also the spare parts can be replaced easily. Thus, appropriate, affordable, accessible, LPLC drip irrigation system can be is better alternative for small land holders.

1.2 HISTORICAL DEVELOPMENT OF LOW COST MICRO-IRRIGATION SYSTEM

The micro-irrigation system was developed originally as a sub-irrigation system. The basic idea underlying micro-irrigation can be traced back to experiments in Germany in 1860s. The first work in micro-irrigation in USA was study carried out by House in Colorado in 1913. An important breakthrough was made in Germany back way in 1920 when perforated pipe micro-irrigation was introduced.

During early 1940s, Symcha Blass, an Israeli engineer, observed that a big tree near a leaking pipe showed more vigorous growth than other trees in the vicinity, which were not irrigated by tap water. This encourages him to develop an irrigation system that would apply water in small quantity drop-by-drop. In Israel, the first extensive research of micro-irrigation was conducted in the deserts of Arava and Negave where adverse climate conditions, very sandy alkaline soils and saline water had to be encountered. It produced effective results on crops compared to conventional methods.

In India, micro-irrigation was practiced through indigenous methods such as bamboo pipes, perforated clay pipes and pitcher/porous-cup irrigation. In bamboo micro-irrigation system, long hollow bamboo pipes of diameters ranging 50-100 mm are used as channels. In Meghalaya, some farmers have been bamboo micro-irrigation for crops betel, pepper and areca nut by diverting water streams in hilly slopes. The discharge at the head varies from 15 to 20 l/min and is reduced to 10-30 drops/min at the point of application. These methods can be advantageously used by individual farmer for small land holding.

In Maharashtra, perforated earthen ware pipes were used, their efficiency, benefit and cost ratio have been elaborated for popularizing them. Earthen pitchers and porous cups have also been used for growing vegetable crops in Rajasthan. The technique envisages embedding of earthen cups of 500 ml capacity at the site of seedlings. The cups are filled with water at 4-5 days intervals.

Clay emitter system is comparable to pitcher irrigation system, which is traditionally being used as a method of irrigation in some part of India. This system is suitable for crops which require low water requirement, because the discharge rate per emitter is only 2-2.5 l/d. The emitters are 8 cm long fired clay tubes tapered at both ends. The emitters are shaped by using moulds of 8 cm length or extruded for 30 cm length and larger volume dried in the shade and then fired to about 65^0C. According to distance between the plants, the emitters are connected serially at the specified distance with LDPE/LLDPE pipes, fixed with the help of white zinc oxide paste and laid underground in the fields. The depth varies with the type of soil and crop. A 300 liters drum filled with water is kept on a slightly raised platform to serve as reservoir (Alam and Kumar, 2001).

In India, micro-irrigation was introduced at government level in the early 1970s at the agricultural Universities and research institutions but significant development occurred only in 1980s with the establishment of the Plasticultural Development Centres and the AICRP on the Use of Plastics in Agriculture. The micro irrigation scheme has been approved for implementation during the tenth plan for covering a total area of 6.2 lakh ha involving 3.8 lakh ha under drip irrigation and 2.4 lakh ha under sprinkler irrigation (Ministry of Agriculture, 2006).

International Development Enterprises India (IDEI) promotes affordable drip irrigation technology (ADITI) in the form of package and ready-to-use kits such as bucket kit, drum kit, and customized systems which are used by farmers for growing both horticulture and cash crops have been successfully adopted by 85,000 small and marginal farmers. KB Drip utilizes lay-flat laterals (that looks like tape when it is in a roll) with a wall thickness of only 125 micron (0.125 mm) or 250 micron (0.25 mm) and is 16-mm in diameter when filled with water. The KB Drip lateral was developed from thin plastic tube used to sell cold candy (Freez-it). The machine to produce KB Drip is also less costly as compared to the regular plastic pipe extruder. Microtubes are used as emitters with KB Drip to provide uniform water application. The cost of an installed KB Drip system in India is around US$ 600 per hectare for closely spaced crops like vegetables. The inlet pressure head for the KB Drip systems can range from 0.5 to 3 meters. In view of the severe water scarcity and very low purchasing power of small farmers the performance of KB Drip systems is found to be very satisfactory. IDE developed several treadle pump models to match soil, water, and income conditions (IDE, 2007).

1.3 SYSTEM CHARACTERISTICS AND THE NEEDS OF SMALL HOLDERS

Small holder is a marginal farmer practicing a mix of commercial and subsistence production where the family provides the majority of labour and the farm provides the principal source of income. The term also embraces small commercial enterprises growing high value crops such as cut flowers and produce for export. A small holder will normally derive his/her livelihood from an irrigated holding of less than 5 ha – holdings are often less than 0.2 ha.

Small holders will aim to minimise production costs and maximise returns to inputs by increasing the quantity or quality of production. Modern irrigation technology is likely to be attractive where it can reduce high production costs. Subsistence farmers are mainly driven by the need to minimize risk and assure a food supply, rather than by market forces and a wish to maximise profit. In such cases, new irrigation technology might only be considered where it offers more secure production of basic foods and reduced risk of crop failure with minimal expenditure.

Hillel (1989) warns of a gap between modern technology systems and the needs of smallholders in arid regions of the developing countries where the benefits of drip irrigation could be remarkable. He suggests that researchers and manufacturers are fascinated by high technology, developing ever more specialized and intricate hardware. In his analysis the important attributes are low cost, simplicity of design and operation, reliability, longevity, few manufactured parts that must be imported, easy maintenance and low energy requirements. Similar characteristics are designed other irrigation technology if adopted by smallholders.

Keller (1990) reported that the principal benefits of pressurized irrigation systems are higher water use efficiency, through reduced conveyance losses and improved field application, greater control over the timing and depth of applications. Farmer can achieve higher productivity per unit of water and land by adopting a pressurized irrigation method.

In traditional irrigation methods, the productivity of water is limited by farmer's capacity to invest labour and adopt management skills in accurate land leveling and field preparation. Farmers will invest in modern technology only when the financial return is sure and certain.

1.4 RESEARCH NEEDS AND OBJECTIVES

Increasing competition for water and the need to increase food production in line with increases in population is leading national governments and international donors to re-evaluate the potential role of pressurized, “modern” irrigation technology. These technologies are small-scale and divisible, and avoid some of the problems of the large-scale; agency managed surface irrigation systems constructed in the past. It provides higher irrigation efficiency with water savings. Practically these savings may be illusive as high efficiency is achieved only where resources are available for accurate design, installation and operation of equipment. The limitations of pressurized irrigation technology must be analyzed for realistic assessment of its potential. It should be discarded for promotion when the necessary institutional, technical and financial supports are not proper. Physical factors such as climate, soil type, water quality and topography are important in determine the type of irrigation method is applicable.

India possesses 160 million ha of cultivated land (second largest in the world). More than 70 per cent of its population is dependent on agriculture. Out of 320 million work force of India, 170 million (53 per cent) are employed in agriculture (Alam and Kumar, 2001). The present productivity of irrigated command area 2-3 t/ha is compared to 4-6 t/ha of food grains in research farms. The food production has become almost stagnant where as the population of the country have exceeded 1000 million marks. Agriculture is by far the biggest user of water accounting for more than 70 per cent of water utilization world wide and 90 per cent of water utilization in the developing countries. Irrigation is the largest consumer of fresh water. Therefore the aim should be to get optimal productivity per unit of water. Scientific water management, farm practices and drip irrigation method should be adopted wherever feasible (Alam and Kumar, 2001).

The drip systems require intensive capital due to sophisticated technology. Therefore, it is beyond the capacity of the most farmers in India. Therefore if the drip system could be made affordable and within the reach of small and marginal farmers in India, it will definitely increase the productivity and income of the farmers. Also, conserve the scarce precious water in the country. Further this will also enhance the farmer's capability relevant to soil, water and crop management to obtain maximum yield, because it is suitable for versatile topographical and agro climatic conditions for various type of crops and soil.

IDE has developed a low cost drip irrigation system and this affordable drip system has extensively field tested to advance this technology accessible to small and marginal farmers. The cost of system is being reduced by eliminating sophisticated components. These are replaced by low cost substitutes maintaining the quality and performance. IDE has reduced the cost by 80 per cent by making the system portable by shifting the lateral lines and excluding emitters/drippers but using holes and socket or microtubes to receive water from the lateral tubes. Low cost filters are used. If system is not portable, due to the height or coverage of crop there is 50-60 per cent cost is reduced by irrigating 4 or 6 rows of crop from each lateral line. It can be afforded by the farmers even without subsidy. It is difficult and cumbersome for the small and marginal farmers to get subsidy from the Government. IDE affordable micro irrigation technology supports small and marginal farmers of India. It has working head 0.5-3 m with 73-84 per cent distribution uniformity (Polak *et al.*, 1997).

Numerous studies have been conducted on drip irrigation system to optimize hydraulic parameters of lateral and microtubes, productivity of different crops, performance, economy and suitability of system. The results indicate application of irrigation water operating head of more than 3 m is recommended for uniformity in (Anonymous, 2005; Bralts *et al*, 1993; Keller and Karmeli, 1974; Mofoke *et al.*, 2004; Wu and Gitlin; 1973; Savva, 2001; Sivanappan, 1978; Yadav, 1998). However, no low cost drip irrigation system has been developed more than 3 m head. An attempt has been made to develop LPLC drip irrigation system more than 3 m head.

The objectives of present investigation are to develop an efficient low pressure low cost (LPLC) drip irrigation system, with locally available materials and that would be adoptable and affordable for small land holders. Higher head in KB drip system with increasing height of source is difficult to maintain and costly also. It is not transferable. In the areas with a high density of small farmer with scarcity of water, the low cost drip irrigation system would promote water saving irrigation technology which is divisible and affordable on small scale. This system would suit areas where water and crops are valuable and where higher capital input of existing drip irrigation technology limits its adoption. In India the low cost drip system must be popularized to solve many problems facing the country.

Drip irrigation is suitable for vegetables and orchards but it gives maximum return for vegetables within a season. Tomato (*Lycopersicon esculentum* Mill) cv. Dev is one of the most popular and important commercially grown vegetable. It is in demand throughout the year. It is liked in one or other form and therefore, it is popular vegetable both among the growers and consumers.

Sprouting broccoli (*Brassica olreacea* L. var. italica), cv. Aishwarya (F_1 - Hybrid) is an important cruciferous winter season rare vegetable. Now a day in India, the popularity of broccoli is on increasing trend in star categories and heritage hotels among affluent society due to its nutritional superiority, however, its cultivation is negligible. Owing to promotion to tourism, the scope of broccoli is very bright in Udaipur.

In the light of above considerations, a field experiment entitled "Low Pressure Low Cost (LPLC) Drip Irrigation System for Small Land Holders" was proposed with following specific objectives:

(i) To design a low pressure low cost (LPLC) drip irrigation system.

(ii) To analyze the hydraulic parameters of the designed system, micro-tubes and medi-emitters.

(iii) To assess crop water requirement and water use efficiency for micro-irrigated crops.

(iv) To evaluate the performance of the LPLC drip irrigation system and its cost effectiveness.

1.5 PROLOGUE

The draft of the thesis has been divided in five parts, which are given below

(i) Introduction

(ii) Review of literature

(iii) Materials and methods

(iv) Results and discussion

(v) Summary and conclusions

II- REVIEW OF LITERATURE

An extensive review of literature has been done on the lines of objectives contemplated to facilitate devising an appropriate methodology towards accomplishing the relevant to the present research. The use of drip irrigation, particularly in areas having water scarcity and salinity problem is gaining popularity now days. This chapter deals with the work done on design of low cost drip irrigation system, hydraulics, design of emitters, fertigation, uniformity, crop water requirement, performance and economy of the system.

2.1 DRIP IRRIGATION SYSTEM: STATUS AND ISSUES

The status and prominent issues of microirrigation systems have been studied by researchers on various crops. These studies have been reviewed and presented as under:

In India, research experiments on drip irrigation were conducted in the early seventies in many States, Agricultural Universities and Research Organizations. The researches accelerated after the establishment of the Plasticultural Development Centres and the coordinated research project on the Use of Plastics in Agriculture. The urge and progress were remarkable during the last decade, when it covered an area of 0.3 million ha (Rao, 2002). The highest coverage was in the state of Maharashtra followed by Karnataka, Tamil Nadu, Andhra Pradesh and Rajasthan (Kumar and Singh, 2002).

According to Sivanappan (1999 a) area of about 28.5 m ha can be brought under drip irrigation by 2020-25. However, at the present compound growth rate of 12 per cent per annum, 8 years would be required to bring additional one million hectare area under drip irrigation.

The drip irrigation system is needed in areas of acute water scarcity and where commercial cultivation of cash or horticultural crops is practiced. Research has been conducted all over the country on various crops to quantify the advantage of drip irrigation with enhanced production in order to saving (Padmakumari and Sivanappan, 1989; Raman, 1999; Sivanappan, 1999 b; and Singh *et al.,* 2002 etc.).

Saxena and Gupta (2004) represented the productivity, water use efficiency and enhancement due to drip irrigation on 44 crops. The data were compiled on the basis of arithmetic mean of observed for a given crop. Ten crops that resulted higher value in higher yield due to drip irrigation were gherkins, mosambi, carrot, beans, mango, turmeric, popcorn, baby corn, papaya and capsicum.

On the other hand, the crops of chilli, coconut, radish, ridge gourd, tomato, guava, cabbage, banana, potato and beet root showed higher water use efficiency. Prominent water saving was observed for the crop beet root, bitter gourd, sweet potato, papaya, radish, sweet lime, mosambi, pomegranate, turmeric and cotton crops.

2.2 LOW COST DRIP IRRIGATION SYSTEMS

IDE has been conducting research on development of low-cost, low-pressure drip irrigation system since 1990. Its primary objective is to develop and promote systems that are affordable for small and marginal farmers. The success of low-cost drip systems depends on components that are readily produced by local manufacturers and could distribute through the private sector without subsidy.

A cheap bamboo drip irrigation system was designed, constructed and tested in 1990 at the Central Luzon State University, Phillippines (Baqui, 1990). Its field performance and evaluation were compared with another low cost drop irrigation system (P.E. Polytube) and a commercial drip system.

The average field emission uniformity of bamboo drip system was observed 95 per cent. Application efficiency was as high as 96-98 per cent which is quite acceptable. Clogging of low cost emitter by rapid algae infestation was a major problem in bamboo drip irrigation system. However it was presumed that a suitable irrigation interval would provide enough time for drying of the emmitter so that algae infestation would be minimized. Based on the test results, the P.E. polytube drip system was recommended as better than the commercial drip system in terms of cost efficiency and durability. The bamboo drip system needs further investigation by using chemically treated bamboos.

Uzunov and Binkov (1994) carried out theoretical and practical investigations to assess economic parameters that describe the performance of trickle emitters. Versatile systems, and over 1000 layouts, were analyzed to optimize flow/pressure relationship, coefficient of variation of manufacturing, tolerance and crop coefficient. A new classification of trickle emitters is suggested which includes all parameters that influence the economically optimum size of these irrigation systems.

Polak *et al (*1997) installed a low cost drip irrigation system on one half acre of mulberry crop at the Andhra Pradesh State Sericulture Research farm near Hyderabad. They observed that mulberry plants irrigated by the low cost drip system were uneven growth rate than the plants irrigated by the standard drip system. The manual punch method was replaced by a liver operated bench machine that uses a 0.70 mm punch heated by a soldering machine. This provided high uniformity of drip holes. The low cost system required two man hour's day than the traditional system to move the drip lines and clean the emitter holes.

Cornish (1998) carried out further study on pressurized irrigation technology for smallholders in developing countries. The following conclusions were made about the factors which influence the pressurized irrigation technologies by smallholders.

1. The technology must provide the farmer sufficient financial return or a decrease in labour to justify the capital input.
2. Farmers must grow high-value crops for an assured market return to cover the cost of equipment.
3. Increasing national or regional water shortage is a factor motivating governments to promote the use of modern water saving irrigation technology.
4. Government policies must encourage manufacturers and dealers to develop and promote appropriate irrigation technology for smallholders.
5. Recommended systems must be relatively cheap and easy to install and operate with low maintenance.
6. Farmers must be provided effective technical assistance during initial stage of new set-up.
7. Individual, communal and joint state/farmer-owned scheme offer various advantages and disadvantages of micro-irrigation methods. The system depends on local criteria. Generalized policies should not be imposed from outside.

The paper reviewed the physical and technical characteristics that determine their suitability for use by smallholders. It also identified a range of pre-conditions relating to water availability, institutional support and economic opportunity that must be satisfied before smallholders will adopt even low technology pressurized irrigation systems. The review demonstrated that where physical, economic and institutional conditions are right some forms of pressurized "modern" irrigation technology permit smallholder irrigation of high value crops where surface irrigation would be inappropriate. However, the paper warns against the danger of wide-scale promotion of such technologies without considering the issues of institutional and technical support. Where pressurized systems are promoted to increase water use efficiency it is essential that they be well designed installed and operated for savings to be realized.

Yadav (1998) studied and evaluated the hydraulic of low cost drip irrigation system. She concluded experiment in the laboratory of IWM, SWC, CTAE, Udaipur. Cost of system was significantly reduced by using microtubes in place of other emitters. The results indicated that the length and diameter of laterals do not effect the average discharge through microtubes but head and length of microtubes significantly affect the discharge which increases with higher head and decreases with increases length of microtubes. 15"and 18" long microtubes should be used with 3.0 m head to get excellent uniformity for 20.0 m long lateral.

Mofoke *et.al*. (2004) designed, constructed and evaluated an affordable continuous-flow drip irrigation system by using medical infusion set as emitters (medi-emitter). They tested tomato crop in Bauchi State, Nigeria. The system could continuously deliver the peak daily crop water requirement throughout the day. The observed non-stop flow rate was 9 drops of water per minute. The hydraulic design was based on a step wise use of the energy equation. The system was constructed from cheap and locally available materials, incorporating a modified form of the medical infusion set as emitter. The system's revealed high application efficiencies in the order of 95, 96, 96, and 98% under continuous discharges of 9, 13, 17, and 21 drops/min respectively. The corresponding irrigation efficiency was 94.0, 90.1, 91.0, and 88 per cent. Measured distribution uniformity for the four treatments was 90.0, 91.4, 93, and 97 per cent while the adequacy of irrigation was 92.0, 93.1, 94.0, and 98 per cent for the four treatments. Such high values of measured performance parameters indicate an excellent exploit of the continuous-flow system. Emitter clogging which is a common menace with drip systems was fairly controlled by using two improvised low-cost primary and secondary filters, and a weekly addition of sodium hypochloride solution. The drip system has an initial cost of N 11,280 to N 48,480 (US $80 to 350) depending on materials used. The systems can irrigate 288 vegetable crop stands continuously for ten days without refill. They supplied water to the field through the medi-emitter in jets, with discharges of 14 - 15 l/hr.

Westarp *et al*. (2004) compared low-cost drip irrigation (LCDI), conventional drip irrigation (CDI), and hand watering (HW) in Nepal. Comparison was made on the effects of soil volumetric content and cauliflower yield of three irrigations methods (LCDI, CDI, and HW) operated under three different irrigations regimes in the Jhikhu Khola Watershed, Nepal. Irrigation regime R_1 supplied only half of the estimated crop water requirement, characterized by small volumes applied on alternate days. The other two irrigation regimes (regimes R_2 and R_3), supplied the full estimated crop water requirements, however differed in application timing. Small volumes were applied frequently (daily) under regime R_2, whereas in regime R_3, greater water volumes were applied less frequently (alternate days for the majority of experiment).These results suggested that LCDI and hand HW are both viable options to increase food production in water scarce, small-scale farming in Nepal.

Anonymous (2005) conducted study on design of low cost, low head drip irrigation system for Tribal Belt of Rajasthan. The results indicated that yield of vegetable crops significantly increased due to LCLH drip irrigation system as compared to the flood irrigation method.

In Chilli the BC ratio without subsidy was 2.10 as compared to 1.65 under flood irrigation. Statistical uniformity ranged from 89.90 to 95.61. Statistical uniformity was also higher if the operating head was above 3.0 m. Thus, it can be concluded that a head above 3.0 m can be recommended as operating head for achieving uniformity in the low head drip irrigation system.

Kahlown and Kemper (2007) evaluated the performance of trickle irrigation systems installed in Balochistan, Pakistan during 1982–2002, conducted field surveys, physical verifications and interviews with farmers. 30 systems were fully or partially operational and 76 were abandoned. Operating systems required clean and reliable water supply, availability of spare components and accessories for replacements, skilled manpower, and a high level of interest and participation by the owner. The dominant species irrigated with these trickle systems were apples, grapes, and mixed orchards. Installations of trickle systems on old mature orchards were not generally successful due to lack of adaptation of the new system to limited and scheduled irrigation supplies. Many of the irrigators were not instructed on how to adjust the trickle system to meet changing needs of the plants. Consequently, growth of some of the trees was stunted and a few of them died. Lack of technical skill to repair and maintain the system and non-availability of replacement parts were general causes of failure of installed trickle irrigation systems. Clogging of the emitters was the primary specific cause of failure. Emitters with a larger opening, was not clogged by most of the contaminants contained in the water available to these farmers and turbulent action screening systems to take out the other contaminants was proposed as solutions to this problem. Commercial shops, which sell the components, carry replacement parts and provide after-sales service was needed to keep trickle systems functioning in these isolated areas.

Karlberg *et al.* (2007) developed a drip-irrigation module and included in an ecosystem model and tested it on two independent datasets, spring and autumn with tomato crop. Simulated soil evaporation correlated well with measurements for spring (2.62 mm d^{-1} compared to 2.60 mm d^{-1}). Changes in soil water content were less well portrayed by the model (spring $r^2 = 0.27$; autumn $r^2 = 0.45$).

In a fresh-water drip-irrigated system, about 30% of the incoming water was transpired, 40% was lost as non-productive evaporative flows, and the remainder left the system as surface runoff or drainage. Simulations showed that saline water irrigation (6 dS m^{-1}) caused reduced transpiration, which led to higher drainage and soil evaporation as compared with fresh water. Two different drip-irrigation discharge rates (0.2 and 2.5 l/h) were compared; however the simulations indicated that the discharge rate had no impact on the partitioning of the incoming water with respect to the system. The model evaluates the specific management options.

2.3 MICROTUBE EMITTERS FOR PRECISION WATER CONTROL

IDE (1990) has developed many options for low cost precision water delivery for resource less farmers. The most economic configuration was perforated plastic tubes. They also reviewed and tested sophisticated on-line emitters. However, they found that use of short microtubes for the emitters is the best solution for addressing cost, flexibility in use, uniformity in water application, and ease of maintenance. IDE has selected microtubes instead of on-line emitters due to following reason:

Low Cost:

1. The lay-flat lateral KB drip tubes with microtube emitters are very cheap and hence affordable by smallholders without subsidy.
2. The lateral tubes can be manufactured locally by using simple low-cost extruders. These are compact and easily transportable.

Flexibility and High Uniformity of Application:

1. The spacing between on-line emitters is fixed at the factory where as microtube emitters are installed in the field in accordance with plant spacing, for example, the crop spacing may be different in various parts of the farmer's plot and they may even have some tree crops.
2. Emitters made of short lengths (20-cm) of microtube provide excellent uniformity in water distribution at low pressures (as good as any on-line emitters); and
3. It is not possible to achieve good hydraulic performance with a simple perforated tube (instead of emitters), while on-line emitters requires high precision manufacturing using very expensive and sophisticated extruders.

Ease of Operation and Maintenance:

1. Farmers can easily install, operate and monitor the microtubes system.
2. Pressure testing of the distribution system is simple and intuitive using a clear plastic tube; this is not possible with on-line emitters.
3. The water filtration required for microtube emitters is easier than that for on-line emitters.
4. When microtube emitters get clogged these can be easily cleaned or replaced. It is not possible with on-line emitters.

2.4 BASIC HYDRAULICS OF DRIP IRRIGATION SYSTEM

The estimation of pressure loss along a drip line was derived in from of simple differential equation by Wu and Gitlin (1973). Keller and Karmeli (1974) devised an equation that was of the power form.

$$q = kH^x \quad \text{....2.1}$$

Where,

q = emitter discharge, l/h

k = constant of proportionality

H = working pressure head at the emitter, m

x = emitter exponent

The Darcy-Weisbach equation was applied for calculating the head loss due to friction in the trickle irrigation system as the drip pipes were assumed to be hydraulically smooth by Watters and Keller (1978).

A polynomial expression for inlet discharge and inlet pressure head was developed and used to design the drip irrigation system by Kang and Nishiyama (1995).

$$q_L = C_0 + C_1 H + C_2 H^2 + C_3 H^3 + ... + C_n H^n \qquad ....2.2$$

Where,

q_L = inlet discharge of the lateral

C_0, C_1, C_2….C_n = coefficients, determined by the least squares method

H = inlet pressure head of the lateral

n = 3-7 depending on lateral parameters, type of emitter, and field slope

Singh (1999) listed and described various standardized specifications and details of laterals, emitting pipes, micro-tubes, emitters, micro-sprayers, media filters, ventury injectors etc. along with the design, installation, operation and field evaluation of micro-irrigation systems as per the Bureau of Indian Standards.

Kirnak *et al*. (2004) studied on in-line emitters manufactured by 4 different companies in Turkey. 9 drip irrigation lines, comprising 7 non-compensating and 2 compensating emitters, were tested at pressure of 50, 100, 150, 200 and 250 kPa. Non-compensating type emitters were not tested at 250 kPa. Compensating emitter exponents ranged from 0.02 to 0.05 while non-compensating emitters varied from 0.60 and 0.85. Test results showed that only 1 non-compensating emitter and both compensating emitter had flow rate variation of ± 10% of manufacturers reported values. The t-test between listed and measured average flow rates at listed nominal operating heads showed that there was no significant statistical difference at < 0.05 level. As per ASAE standards, the measured coefficients of manufacturing variation values for non-compensating emitters were not acceptable, although compensating emitters were in the excellent class.

2.4.1 Design of Lateral and its Hydraulics

Anthony and Pissotsch (1973) evaluated irrigation and uniformity with low pressure trickle system. According to them the pipe lines of the drip system should be laid on a downward slope so that the pressure loss due to friction could be compensated by the falling slope and net changes of energy throughout the line would be zero or negligible.

Wu and Gitlin (1973) reported that the pressure distribution along the lateral can be estimated by the line slope and energy drop calculated by using average discharge of four sections. The error was less than 2 per cent as compared with the pressure gradient line, calculated by using all sections between emitters. The calculation was based on uniform flow from all emitters and with a constant emitter spacing. It was observed that if the pressure distribution was determined along the lateral line for constant flow for each emitter then uniform irrigation can be achieved by using different sizes of emitters, different length of microtubes.

Howell and HilIer (1974b) developed the design procedure for determining the pressure losses and emitter flow rates for trickle irrigation laterals. Two methods were given by them, including one of the general types involving the computer programme while the second was a simplified procedure which could be applied when the reduction coefficients to compensate for diverging flow along the lateral are known. The following important aspects were highlighted:

1. 50 per cent of lateral pressure drop occurred in the first 20 per cent of lateral length.
2. Emitters inserted into the pipe caused significant pressure loss due to the flow path restrictions.
3. Hazen-William's roughness coefficient was found to be 130 for 12 mm polyethylene pipe.
4. The reduction coefficient (F) was depended on emitter spacing and lateral pressure.

Keller and Karmeli (1974) considered all the parameters in designing the trickle irrigation system. The hydraulic design for lateral and manifold was based on irrigation depth and interval, system capacity, emitter flow characteristics and uniformity. Once the hydraulic design has been achieved, the acceptability of design including manufacturing and other variation was determined. They have suggested the emission uniformity as the criterion which should be around 90 per cent for practical purpose.

Wu and Gitlin (1975) developed a dimensionless energy gradient line which can be used to calculate energy drop along the line if the total energy drop at the end of the line is known. They derived mathematical equation for the energy gradient line which can be applied to hydraulic analysis of microtubes.

Swamee and Jain (1976) successfully demonstrated the variability of Hazen William and Manning friction factors over the range of conditions encountered in irrigation and water distribution application. They suggested that the Hazen Williams coefficient 'C' and Manning coefficient ‘n’ clearly depend on fluid velocity and pipe diameter as well as on pipe wall roughness and should be adjusted to account for these factor.

Hughes and Jeppson (1978) compared two equations of Hazen Williams ‘C’ to Darcy Weisbach ‘f’ for 27 mm pipe. Clearly the C value range from 130 to 150 depending on Reynold number in terms of the friction factor. Many pipe manufacturers recommended a maximum velocity of 1.5 m/s in plastic pipe. At this velocity the value of C that compares best to the Blasius equation will depend upon the pipe diameter with C=130 for 14-15 mm pipe, C=140 for 18-19 mm pipe and C=150 for 25 to 27 mm pipe. Estimating ‘C’ results in a more conservative friction loss for design purposes.

Solomon and Keller (1978) evaluated the pressure distribution in a lateral line considering the following factors:

1. Design emitter characteristics
2. Variability in manufacturing and aging of emitters and
3. Frictional head loss through out the pipe distribution network

They found for a wide range of “X” and “H” values, where H is the head corresponding to average discharge and X is a constant of the flow equation $q = K\ \Delta H^x$. H occurs at a distances of 39 per cent of the total length of the lateral, the distance being measured from the upstream end. Further they observed that 77 per cent of the total head loss in the lateral occurs with in first 39 per cent of the lateral length as measured from the upstream end of the pipe and the rest i.e. 23 per cent on the remaining part of the pipe. With the help of these observations they developed equations for determining the static pressure head at any point on the drip lateral line provided the inlet pressure and the pressure at the most down stream point is known. The greatest advantage of this equation is that any point on the loss curve can be predicted by a single calculation with a high degree of accuracy.

Watters and Keller (1978) studied the emitter connection losses for different barb sizes and lateral diameters. They stated that the friction loss across an emitter vary with diameter of lateral. Equivalent lengths versus inside lateral diameter curves are plotted for different emitter barb sizes. From the curve it can be inferred that equivalent length of emitter ‘Le’ decreases as lateral diameter increases. The equation, suggested for the head loss calculation was as

$$H_f = F \times \frac{L}{100} \times \left(S_e + \frac{L_e}{S_e} \right) \times K \frac{Q^{1.75}}{D^{1.75}} \qquad \text{….2.3}$$

Where,

H_f = friction loss, m

L = length of hose run, m

F = reduction coefficient.

Se = spacing between emitter, m

Le = equivalent length of emitter, m

K = constant, 7.89 x 10^7

Q = flow rate, l/s

D = Inside diameter of hose, mm

Wu and Gitlin (1982) computed drip irrigation lateral line network design. A dimensionless parameter ΔH'/ΔH (The ratio of total energy gain to the friction drop at the end of single inlet lateral line) was used not only to classify the shape of the pressure profile of the single inlet system but also for designing the double inlet and flow out flow systems.

Wu *et al*. (1983) evaluated the design of drip irrigation lateral length on uniform slope. They found that when a lateral is designed for a uniform slope situation, a dimensionless design parameter ΔH'/ΔH (a drop ΔH at the end of line) can be used to determine the pressure profile and maximum pressure difference ΔH max along the line. They developed graphical solutions and mathematical equation for determining the maximum pressure difference H max.

Wu (1985) developed a uniplot for drip irrigation lateral and submain design. The technique was derived based on polyconcept by plotting the length and energy term dimensionless. The design was made by using line slope and an allowable pressure variation to form a reference area, then fitting the energy gradient into the reference area. If the energy gradient line could be fitted into the area, the design which had the maximum pressure variation less than the allowable pressure variation was accepted.

Pitts *et al.* (1986) developed a computer model to analyze drip irrigation system lateral line design by predicting uniformity of emitter discharge. The coefficient of manufacturing variation and the pressure discharge relationship for fourteen commercial emitters was determined to validate and utilize the model.

Anyoji and Wu (1987) developed design technique using statistical approach. This technique was based on coefficient of manufacturing variation of pressure head along a lateral considering the proportionality factor K and pressure head H in the emitter flow equation Q = KH^x as a two random variables in an equation for mean emitter flow was derived by using Taylor's theorem. The coefficient of variation K indicates manufacturer variation. The coefficient of variation of pressure head was determined statistically from the average variance of pressure head which was affected by friction and slope changes along lateral line. Once the design criterion of an emitter flow variation (expressed as a coefficient of variation) was set and the type of emitter selected, the required coefficient of variation of pressure head for a lateral line can be calculated and the design length can be determined.

Yitayew and Warrick (1987) presented a paper on an analytical solution to a line source trickle lateral hydraulic. In this process the effect of velocity head on the total energy drop was evaluated. The magnitude of total energy drop was found to be greater for turbulent flow compared to laminar flow irrespective of whether velocity head was included. The relative error in the head loss by neglecting velocity head was found higher for laminar flow than for turbulent flow.

Kamand (1988) presented his paper on hydraulic friction factors for pipe flow. Hydraulic friction loss in the pipelines directly affects pipe and pump sizing as well as the hydraulic balance of network. All friction head loss equations have an uncertainty in the estimation of pipe interior surface roughness when a single resistance coefficient based only on the pipe material was used; different equations gave significantly different estimates of frictional head losses depending on pipe size and water flow rate. In complex pipe network systems, minor differences in equations or coefficient may accumulate and result in vastly different predicted head losses or flow rate in individual pipe. This study presented mathematical relationship to relate the friction factor of three widely used pipe friction equations and to determine the magnitude of the differences in calculated head losses. Friction factor were developed to use with Hazen-Williams and Manning equations for PVC and cast iron pipes and gave similar head losses as those of Darcy Weisbach equation.

Yitayew and Warrick (1988) designed the trickle lateral hydraulics. Examples were provided with the basic concepts and procedures based on this and related analytical solution giving very simple and yet powerful design curves for different flow regimes were presented. Verification of the solutions was also made by comparing the results with experimental measurements. The simplicity of the solution coupled with the case of including variable discharge, makes the analytical solution attractive for diversified uses in trickle system design.

Bagarello *et al.* (1989) conducted an experiment on water resistance to flow in the lateral line of drip irrigation system. By experimental test they evaluated the water resistance to flow in the lateral line. Experiment was carried out by measuring the influence of these simplifying hypotheses on the accuracy of the evaluations. The influence of the simplifying hypothesis was found to be significant and an easy method for evaluating all the energy losses due to friction of water along the line, and the presence of emitters in the same line was proposed. This method was based on a derived roughness coefficient in Hazen Williams equation.

Vonbernuth (1989) successfully demonstrated the variability of Hazen William and Manning friction factor over the range of conditions encountered in irrigation and water distribution application. Hazen Williams 'C' and Manning 'n' clearly depend on fluid velocity and pipe diameter as well as pipe wall roughness and should be adjusted to account for these factor. The author has noted some pertinent facts with regard to pipe friction equations. These facts were as follows

1. The Hazen Williams equation does not adequately allow for viscosity changes and can lead to error in calculating friction loss.
2. The errors that can result have been documented and are worst for low Reynold number and small diameter pipe.
3. In spite of the disadvantages of the Hazen Williams equation, engineers continue to use it because it is simple and require readily available information about flow rate, length and diameter.
4. It is possible to determine correction factors for Hazen Williams equation that agree with the more widely accepted Colebrook White equation.

Bagarello and Pumo (1992) studied about lateral line hydraulics. A frictional head loss equation was selected in order to estimate the pressure losses in the lateral line of drip irrigation systems. Additionally the amount of minor losses (i.e. the pressure losses produced by the presence of the emitters along the line) was also evaluated. The paper deals with the hydraulic design of lateral lines with in line emitters. After a critical examination of some well known frictional head loss equations, the result of an experimental analysis was carried out in order to evaluate the amount of minor losses in two differential lateral lines. The study focused on the influence of geometrical characteristics of the lateral line on the amount of minor losses. Particular attention was paid to the influence of some usually neglected characteristics, such as the geometrical morphology of the connections between emitters and the pipe.

Wu (1992) studied about the energy gradient line approach for direct hydraulic calculation of drip irrigation design. Direct calculation was made for line approach. Error caused by energy gradient line approach was evaluated by computer simulation. A revised energy gradient line approach developed by using a mean discharge approximation can reduce the errors and match with the result from step by step calculation for all emitters in a drip system. The equation developed can be used for computerized design of drip irrigation system.

Bralts *et al*. (1993) analyzed that the large system (10000 emitters or more) become more and more important as the use of micro irrigation expands. The purpose of their research was to improve the design of large micro irrigation systems using finite element method. A second order partial differential equation describing flow on a micro irrigation system was developed to accomplish this objective which was solved using finite element numerical procedure. Several alternative methods were evaluated using linear and quadratic elements. The resulting procedure was found to be fast, accurate and efficient in the hydraulic analysis of large micro irrigation systems.

Wu and Yue (1993) developed an energy gradient line approach for drip lateral line design. This approach provides direct calculation of all emitters flow along the lateral line. Error from the approach was evaluated and a revised approach was developed. Simple equation was derived for calculating emitter flows and can be used to develop computer aided design for drip irrigation lateral line.

Povoa and Hills (1994) developed a model for relating hydraulic characteristics of a micro irrigation system to pump performance and emitter plugging. Data from field trial was used to verify the model. The model was then used to determine pressure sensitivity at several system locations for different scenario's of partial and full emitter plugging, and lateral perforations.

Ahmed (1995) presented a paper on significance of energy losses due to emitter connections in trickle irrigation lines. The study was made on the effect of on line emitters on the energy losses in trickle irrigation laterals. The study involved eight types of emitters with the various barb area installed on to five commonly used polyethylene pipes of different diameters. He found that energy losses due to emitter connection were the function of lateral pipe diameters. There was an increase in energy loss of more than 32 per cent compared with plain pipe for a lateral of 13 mm diameter.

Kang and Nishiyama (1995) developed a simplified method for designing microirrigation laterals using the lateral flow rate equation. All hydraulics analysis was performed using the back step and forward step methods. When required average emitter discharge rate, required uniformity of water application and one parameter either the lateral length or diameter are given, the unknown parameter, best submain position and the operating pressure head can be accurately designed using personal computer.

2.4.2 Hydraulics of Different Emitters

Karmeli (1977) discussed the pressure and flow rate requirement from emitter. The emitters were classified according to the main characteristics of flow regime, pressure dissipation, lateral connections, water distribution, cleaning and pressure compensation. The flow regime is characterized by Reynolds number which is determined by flow cross section and discharge. The range for various flow are given in relation to the characteristics of drippers. He also described the flow for orifice long path compensating single and in multi exit drippers.

Watters and Keller (1978) studied the emitter connection losses for different barb sizes. They stated that the friction loss across an emitter vary with diameter of lateral. They plotted curves for emitter for connection loss equivalent length versus different inside lateral diameter for different emitter barb sizes. From the curves, it was inferred that equivalent length of the emitter ‘Le’ decreases as barb size decreased.

Khatri *et al.* (1979) evaluated the hydraulics of microtube emitters. The experiment showed that Darcy Weisbach equation for hydraulically smooth pipe can be used to represent friction drop relation for micro tube of size ranging from 0.8 to 4 mm. They can be concluded that the smooth pipe equation can be used with reasonable accuracy for all sizes of drip irrigation tube in turbulent flow conditions.

Bucks and Nakayama (1981) presented the design equation that includes emitters characteristics (emitter exponent, emitter variability) as well as lateral line hydraulics (length, diameter, land slope).

Risse and Chesness (1989) predicted the wetted radius from the point source emitter. Soil texture, emitter flow rate and soil water depletion potential was the only input required. Field test in a peach orchard, on a sandy foam soil, at two emitter flow rate showed that predicted wetted radius value was within 11 per cent and 19 per cent of measured value.

Babel *et al.* (1990) studied the relationship among hydraulic parameters viz., pressure head, discharge and physical characteristics namely, diameter and length of micro tubing used as emitter connector and pressure regulator in drip irrigation system. It was concluded that general flow equation developed in pipe hydraulic are also applicable to micro tubing. Hagen, Poiseuilli’s and Blasius empirical equations for friction coefficient given for larger pipes size, was also unified for their adoptability for tubings. It was concluded that these equations can be used with Darcy Weishbach equation for calculation of frictional head loss in microtubing in laminar and turbulent flow conditions respectively.

Ahmed (1995) presented a paper on significance of energy losses due to emitters connections in trickle irrigation lines. The study involves eight types of emitters with various barb areas installed into five commonly used polyethylene pipes of different diameter. Results of investigation indicate that there were significant energy losses due to emitter connections. The value of these losses is the function of emitter barb protrusion. A simple procedure is suggested to incorporate emitter barb losses in the design of trickle irrigation laterals.

Sharma *et al*. (2005) conducted experiment at Precision Farming Development Center, Orissa University of Agriculture and Technology; Bhubaneswar on 7 emitters and tested for their pressure discharge relationship, manufacturing coefficients and emission uniformity coefficients. Results indicated that pressure- discharge relationship follows a power function. It was also concluded that flow in J-Lock and Turbo Seal (2 l/h) was in the laminar region, while others were in turbulent region. Manufacturing coefficient of all emitters were found to be satisfactory and out of all the emitters tested for emission uniformity, Turbo-Key emitters, at a pressure 1.5 kg/sq.m was highest (97.90%) followed by self- compensating emitters.

2.4.3 Relation between Pressure and Discharge

Anyoji and Wu (1987) developed a design technique using a statistical approach. This technique was based on coefficient of variation of pressure head along a lateral. Considering proportionality factor ‘K’ and the pressure head ‘H’ in the emitter flow equation $q = KH^x$ as a two random variables, an equation for mean emitter flow was derived by using Taylor’s theorem.

Madramootoo *et al*. (1988) conducted experiment on hydraulic performances of five different trickle irrigation emitters and concluded that emitter discharge exponent in the equation $Q=KH^x$ (as given by Keller and Karmeli, 1975) was used to characterize the hydraulic performance of each emitter. According to their results for an emitter having $x > 0.5$ is a non pressure compensating type, for $x = 0.11$ to 0.34 is classified as partially pressure compensating type and for $x=0$, the emitter is fully, pressure compensating type. The study showed that the co-efficient of manufacturing variation of pressure compensating emitters was effected by pressure.

They studied about the effect of pressure changes on the discharge characteristics of pressure compensating emitters. Flow rate of three pressure compensating orifice type, on line emitters was measured under laboratory condition, at five operating pressure ranging from 69 kPa to 138 kPa. These emitters were all operated on the same principle and contained an electromagnetic flap for regulating flow. The coefficient of manufacturing variation, Cv of each emitter was calculated at each operating pressure. The result was presented graphically. It was found that the flow rate was independent of pressure contrary to design expectations. Calculation of ‘Cv’ showed that the katif emitter performed better at high than at low pressures, whereas the reverse was true of LPC-2L emitter. The LPC-4L emitter was unsatisfactory with relatively high unit to unit variability at all test pressures.

Correia (1990) tested drip irrigation emitters of six Indian companies, evaluated for pressure discharge relationship and other relevant parameters. The exponent of the emitter equation varied from 0.16 to 0.69. Manufacturing variation ranged from 0.14 to 0.70 at the rated discharge of 4 lph with one exception of 0.078 at 2 lph. The deviation of discharge from mean at the specified pressure varied from + 51 % to -80%. The coefficient of variation value ranged from 0.016 to 0.375. A lack of technical literature availability on the specification of the system provided by the suppliers was observed. The high susceptibility of clogging of emitters due to manufacturing defects, the coefficient of uniformity was likely to be beyond the limit of acceptability for field use. The author suggested that the manufacturers should be required to provide technical details and specification, duly verified and approved by competent authorities for the benefits of the farmers.

Sahu and Rao (2005) conducted experiment on micro drip irrigation system (MDIS) to design, develop and evaluate it for growing vegetables in the farmer's field (village Nardha, district Durg). The manifold and its laterals were designed and operated as a single unified system, controlled by single valve. They reported that average discharge value through microtubes at different pressure heads was found to be as fitted equation

$$Y = 0.3814X^{0.1714} \qquad \text{....2.4}$$

It revealed that the discharge through microtubes of 1.2 mm diameter increased with increased head.

2.4.4 Pressure Loss, Hydraulic and Manufacturer's Variations

The term manufacturer's variation of emitter was first introduced by Keller and Karmeli (1974). Later Solomon (1985) had defined the manufacturing variation as the ratio of the standard deviation to mean emitter flow rate, measured at standard pressure and temperature, with no plugging.

Five types of orifice type of emitters were tested at five operating ranges of 69-138 kPa under laboratory conditions by Madramootoo *et al.* (1988) and calculated the discharge exponents for all the emitters. The discharge curve for all emitters fell within the ten per cent of manufacturer's rated range.

Ozekici and Sneed (1995) compared the manufacturer's rated discharge and the coefficient of manufacturing variation for testing of online emitters. They reported that under the operating pressure range up to 100 kPa only 11 of 17 emitters had a permissible 10 per cent manufacturing variation. They concluded a high value of manufacturing variation could result a low uniformity as well as more water losses.

Pressure variation in pipe lines was evaluated using a modified form of Bernoulli's equation by Reddy *et al.* (2000). They evaluated the frictional head loss using Darcy-Weisbach equation. Emitter wise losses were considered while analyzing trickle lateral hydraulics. They also reported that it is possible to save up to 29 per cent on the total annual cost over the criteria where the emission uniformity as the lone parameter in designing the system. The difference in pressure head may increase or decrease the allowable friction head loss.

2.5 IRRIGATION EFFICIENCIES

The work done by various research workers in the past to study the irrigation efficiencies under micro irrigation systems was critically reviewed as under

Myers and Bucks (1972) reported that low pressure trickle systems are preferred over high pressure due to lower manufacturing and operating costs along with minimum clogging problems. Good emitter discharge uniformity can be obtained in low pressure trickle irrigation by using simple emitters of different diameters to compensate for pressure changes. The theoretical performance of a system using five emitter sizes, in a 250 feet lateral was compared with a system that was identical except that single intermediate size emitters were used. Initial pressure was 2 psi, emitter was spaced 2 feet apart and emitter design discharge was +21.0 to - 7.4 per cent for the multiple size system. They have reported increase in discharge of emitter with pressure and that variation in emitter flow from design discharge was due to manufacturing imperfections, clogging and pressure variations occurring in pipe with spatially varied flow.

Bucks and Myers (1973) presented paper on application uniformity from simple emitters in drip irrigation system. Application uniformity from low pressure trickle irrigations systems can be greatly improved by varying emitter sizes to compensate for friction induced pressure changes in the lateral pipes. Procedures for design and construction of two multiple size systems, using stainless steel and microtube emitter was developed. Mean discharge deviation for emitters operated at constant pressure was 1.7 percent to 3.3 percent for stainless steel emitters and from 1.8 percent to 2.5 percent for microtube emitters.

Wu and Gitlin (1973) used the same statistical approach for obtaining irrigation uniformity suggested by Christiansen. They gave the relation as follows

$$Ed = \left(1 - \frac{S_q}{q_{avg}}\right) \text{ and} \qquad \text{….2.5}$$

$$Ea = \left(\frac{q_{\min}}{q_{avg}}\right) \times 100 \qquad \text{….2.6}$$

Where,

Ed = distribution efficiency, (%)

q_{avg} = mean flow rate, I/h

S_q = average absolute deviation of all emitters flow from the average emitter flow, lph.

Ea = application efficiency, (%)

q_{min} = minimum emitter flow rate, l/h

Howell and Hiller (1974a) studied the design of trickle irrigation lateral for uniformity and derived equations that can be utilized for calculating maximum lateral length for given value of uniformity coefficient. The solution depends upon emitter flow function, elevation change, pipe size, reduction coefficient for dividing flow, pipe roughness coefficient, average emitter flow rates and either the average emitter spacing or number of emitters per lateral. For a given uniformity the solution is a line or a log line with a slope that only depends upon the flow rate exponent in the pipe friction loss equation. They also presented design equation that allows the length of trickle irrigation lateral to be designed to meet specific uniformity criteria. The emitter flow function ($q = KH^X$) was utilized to determine the allowable pressure loss to meet the uniformity standard.

Keller and Karmeli (1974) suggested formulae for evaluation of emission uniformity "EU" which is a measure denoting the degree of uniformity of water application to the field. They put two relations for determining the "EU_f". The first one takes into consideration the ratio of minimum and average discharge rates within the system while the other one includes the ratio of both maximum and minimum emitter flow rate to the average flow rate. The second relation is denoted by symbol EUa. (absolute uniformity coefficient), to distinguish it from the first. They recommended that EU's of 94 percent or more are desirable and in no case the design EU be below 90 percent. The given relations are

$$EU_f = \left(\frac{q_n}{q_a}\right) \times 100 \qquad \text{….2.7}$$

$$\text{EUa} = 100 \times \left[\frac{Q\min}{Qavg} + \frac{Qavg}{Qx}\right] \times \frac{1}{2} \qquad \text{….2.8}$$

Where,

EU_f = Field emmission uniformity

EUa = Aabsolute emmission uniformity

q_n = The average of lowest 1/4 of the emitter flow rate (l/h)

q_a = The average of all emitt`er flow rates (l/h)

q_x = The average of the highest 1/8 of the emitter flow rate (l/h).

Keller and Karmeli (1974) calculated emission uniformity by the following formula.

$$Eu = 100\left(1 - 1.27\frac{V_m}{N_e^{0.5}}\right)\frac{q_{min}}{q_{avg}} \quad \text{....2.9}$$

Where,

Eu = design emission uniformity, (%)

V_m = manufacturing coefficient of variation

N_e = number of emitters per plant

q_{min} = minimum emitter flow rate, l/h

q_{avg} = average emitter flow rate, l/h

Bralts and Wu (1979) concluded that the coefficient of manufacturing variation should behave independently of pressure and remain constant for any given emitter. Nakayama *et al*. (1979) compared the emitter flow uniformity by estimating the average flow rates for a specified sub group of entire emitter population. A design coefficient of uniformity for emitters (UCD) was obtained by taking into consideration number of emitters per plant term, similar in form to the uniformity coefficient used in the sprinkler irrigation. For calculation of application efficiency, they developed the following formula

$$Ea = eQ_{min}\left(\frac{T}{V}\right)\times 100 \quad \text{....2.10}$$

Where,

Ea	=	Application efficiency per cent
e	=	total number of emitters
Q_{min}	=	Minimum discharge rates of emitters (l/h)
V	=	Total water applied, l
T	=	Total irrigation period, h

Nakayama *et al*. (1979) compared emitter flow rate uniformity by estimating the average flow rates for a specific sub group of the emitter population and formulated the following equation for calculation of coefficient of uniformity

$$UCD = 100\left(1 - 0.798\frac{V_m}{n^{0.5}}\right) \quad \text{....2.11}$$

Where,

UCD = design coefficient of uniformity for emitters

n = number of emitters per plant

V_m = manufacturing coefficient of variation

Bralts *et al*. (1981) studied the coefficient of variation used to assessing the magnitude of emitter flow variation along single chamber drip irrigation lateral lines. The relationship between hydraulic variations and manufacturing variation was found to be orthogonal. This independent relationship allows the statistical combination of their respective coefficient of variation. As a result the statistical uniformity coefficient was recommended for use in determining the drip irrigation lateral line design uniformity including manufacturing variation.

Bralts and Kesner (1983) estimated drip irrigation field uniformity. The coefficient of variation was used to assess the magnitude of emitter flow variation in drip irrigation submain units. Based upon the assumption that the emitter flow variation was normally distributed, a simplified statistical method for estimating the coefficient of variation was developed. The estimate of coefficient of variation was used to demonstrate a method of determining field uniformity for drip irrigation submain units. A graphical technique for estimating the statistical uniformity and the relative confidence limit of the proposed method was presented.

Clemmens (1987) found two causes of trickle irrigation nonuniformity. These causes were the emitter properties and variation in pressure at the emitters. A simple algebric equation for evaluating the combined effects had been previously proposed for the case when both emitter and hydraulic properties are normally distributed and independent. A simulation model was found to evaluate this assumption for a simple lateral. First it was found that the emitter and the hydraulic properties are independent for practical purpose. Second was found that the nature of the pressure distribution can have an impact on the assessment of uniformity. In terms of distribution uniformity (Du), assuming normal pressure distribution for a single horizontal lateral gave lower value of uniformity. A simple procedure was presented for developing an equivalent coefficient of hydraulic variation which gave more accurate estimate of the combined effect. Finally it was shown that the proposed equation only gave an estimate of actual uniformity. The variation of this estimated combined uniformity was greater when it was caused by emitter variation than when it was caused by hydraulic variation.

Warrick and Yitayew (1988) studied about a uniform distribution of water delivered through emitter in trickle irrigation system. Computation of flow distribution requires knowledge of variables such as pressure, flow rate, length of lateral, characteristics of the orifices and frictional loss in the system, several studies have been reported that establish these relationship. In each study, the primary solution was based on discharge that was uniform although ramifications of the manufacturer’s variability have been modeled based on derived hydraulic profile. In their paper they presented an alternative treatment that includes a spatially variable discharge functions.

Karaghoul and Minasian (1992) worked on emission uniformity (EU) of drip irrigation system. They found that EU of the system decreased with time as a result of emitter clogging, but emitters manufactured by injection moulding possessed higher EU values with relatively low reduction rate compared with extruded emitters. Consequently injected type emitters gave a higher crop yield than extruded type.

Ozekici and Sneed (1995) stated that the efficiency of trickle irrigation systems depends directly on the uniformity with which water was discharged from the emission devices throughout the system. Ideally all emitters in the system discharge equal amount of water. One major cause of flow rate difference between two identical emitters from the same manufacturer was manufacturing variation. This study compared manufacturers rated discharges and coefficient of manufacturing variation values with tested values for various on line emitters. Discharge rates from different types of trickle irrigation emitters are collected at five different pressure levels. Pressure compensating emitters were tested at 100, 150, 200, 250 and 300 kPa. Non pressure compensating emitters were tested at 75, 100, 125, 150 and 175 kPa. Emitter discharge rate and coefficient of manufacturing variation was compared with manufacturer's specifications. At the suggested operating pressure of 100 kPa, eleven of the seventeen emitters had flow rates within 10 per cent of those claimed by the manufacturers. This was particularly true for non pressure compensating emitters. Measured values of coefficient of manufacturing variation were higher than those specified by the manufacturers. They suggested that design should be based on reliable test data and not on manufacturers supplied data.

Wu (1997) studied assessment of hydraulic design of micro-irrigation systems. Commonly used emitter flow variations of 10-20% were equivalent to a uniformity coefficient of about 98-95%. He concluded that hydraulic design criterion can be relaxed to 30% of emitter flow variation, $_{qvar(H)}$, which can still achieved less than 20% in coefficient of variation, or over 80% of uniformity coefficient in spatial uniformity of micro-irrigation system.

Capra and Scicolone (1998) have mentioned that a sample of 16 emitters is sufficient to test the uniformity distribution. In drip systems, to be representative of the whole population of emitters, the sample of emitters must be however, chosen from different positions on the laterals with respect to the water inlet.

Saxena and Gupta (2006) have compared plant wise and emitters wise uniformity coefficients from some of the above reported techniques. They reported that a simplified measure of coefficient of emitter flow variation could be easy to compute from large data sets.

2.6 CROP WATER REQUIREMENT, IRRIGATION SCHEDULING, FERTIGATION AND QUALITY OF WATER

Bralts *et al*. (1981) studied that the coefficient of variation was used to measure the effects of emitter plugging on the uniformity of emitter flow along single and dual chamber drip irrigation laterals lines. The number of emitter per plant was shown to be important when calculating uniformity including emitter plugging. As a result, the statistical uniformity coefficient of emitter flow along a drip irrigation lateral line when plugging was considered.

Vermeiren and Jobling (1984) provided the factors suggested by various authors in order to account for the reduction in evapotranspiration. Depending on the corresponding percentage of ground cover, the estimated ETcrop must be multiplied by the appropriate correction factor (K_t) value. For design purposes the peak ETcrop is multiplied by the K_t value that corresponds to a ground cover of 70% to 100% depending on the crop and its expected ground cover at maturity. A GC of 70% - 80% should be expected for matured orchards. They defined the net irrigation requirements (IRn) as the depth or volume of irrigation water required for normal crop production over the whole cropped area excluding contribution from other sources. They use the following equation

$$IRn = ETcrop \times K_t - R + L_t \quad \text{....2.12}$$

Where,

ETcrop = crop water requirements

Kt = correction factor for limited wetting

R = water received by the plant from sources other than irrigation

Lt = amount of water required for the leaching of salts

The same authors define the gross irrigation requirements (IRg) as the depth or volume of the irrigation water required over the whole cropped area excluding contributions from other sources, plus water losses and/or operational wastes. They use the following equation

$$IRg = ETcrop \times Kt \times Ea - R + Lt \quad \text{....2.13}$$

Where,

ETcrop = crop water requirements

Kt = correction factor for limited wetting

R = water received by the plant from sources other than irrigation

Lt = amount of water required for the leaching of salts

Ea = irrigation efficiency

According to them the application efficiency is expressed by the following equation

$$Ea = Ks \times Eu \quad \text{....2.14}$$

Where,

Ks = the ratio of the average water stored in the root volume over the average water applied

E = coefficient reflecting the uniformity of application

Goyal and Rivera (1985) conducted study and reported that irrigation in vegetable crops was initiated when soil water tension, as indicated by the tensiometers, was 45 cbars and was terminated when the soil moisture tension dropped to 15 cbar. The seasonal water application for tomato was 24.0 ha-cm in wet season.

Nakayama and Bucks (1991) reviewed recent investigations carried out on emitter clogging and the ways reducing the problems. They inferred that emitter clogging was closely related to the water quality. They also pointed out that use of urban and/or industrial sewage would increase emitter plugging. The causes of clogging were attributed to physical, chemical, and biological factors.

FAO (1992) has developed a computer programme "CROPWAT" which facilitates the calculation of ETo using mean temperature, minimum and maximum relative humidity, wind velocity at 2 m height and sunshine hours. Additionally the altitude, the latitude and the longitude of the project site are required. It provides ETo and corresponding Kc for each decade (10-day period) or month.

CROPWAT is a computer program to calculate crop water requirements and irrigation requirements from climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping patterns. The program is meant as a practical tool to help both the Irrigation Engineer and Irrigation Agronomist to carry out standard calculations for design and management of irrigation schemes. It will further help in the development of recommendations for improved irrigation practices and the planning of irrigation schemes under varying water supply conditions.

Lamm *et al.* (1995) conducted three-year study (1989 to 1991) on a Keith silt loam soil (Aridic Argiustoll) in northwest Kansas to determine the water requirement of corn grown using a subsurface drip irrigation (SDI) system. Corn yields were highly linearly related to calculate crop water use produced 0.048 Mg/ha of grain for each millimeter of water used above a threshold of 328 mm, calculated water balance components indicated that careful management of SDI systems can reduce net irrigation needs by nearly 25%.

Allen *et al.* (1998) defined reference crop evapotranspiration (ETo) as the evapotranspiration from a reference surface, not short of water. This surface is a hypothetical grass reference crop with specific characteristics. It expresses the evaporative demand of the atmosphere independently of crop type, growth stage and management practices. The only factors affecting ETo are climatic parameters. It can be computed using weather data. They recommend FAO Penman-Monteith as the only method for the determination of ETo, since it closely approximates grass ETo at the locations evaluated, is physically based and incorporates both physiological and aerodynamic parameters. Also, procedures for estimating missing climatic parameters have been developed. They presented a generalized crop coefficient curve. Such curve, developed for any crop can provide the corresponding Kc for each decade (10-day period) or month. By providing the relevant Kc values for each decade, CROPWAT can calculate the crop water requirements for the whole growing season on a decade basis or any other basis depending on the inputted Kc values. The same programme can be used for the preparation of irrigation schedules when data on soil type and root zone depth are provided.

Singh and Singh (2000) conducted a field experiment to standardize the K requirement of broccoli @ 0, 25, and 50 kg/ha. Plant height was increased with the application of K rates. Potash improved the development of root and utilization of nitrogen. The highest net head weight and yield were obtained with application of 50 K/ha.

Kumar *et al.* (2001) studied the performance of different broccoli cultivars under different N,P and K combinations i.e. 60, 45 and 15 kg/ha; 90,60, and 30 kg/ha and 150, 90 and 60 kg/ha respectively. Crop yield/plant (392.04 gm/plant) and yield/ha (13.05 t/ha) were highest in cv. DPGB 12 compared to other cultivars. The maximum value for yield and quality character were obtained at highest, N, P and K levels (150, 90, 60 kg/ha respectively).

Patil and Singh (2001) conducted field experiment on comparative performance of drip method vis-à-vis hand watering and check basin irrigation in sandy loam soils at Almora centre for Sioux tomato. Fertilizer was applied @100:50:50(N: P: K kg/ha), while the irrigation was scheduled to replenish moisture @ 15, 30, 45 and 60% of pan evaporation (PE) in drip method at 3 days interval. The result showed that in term of fruit yield, the method was superior to hand watering or check basin method with least amount of water (4.6 cm) drip irrigation @ 15% PE recorded highest yield of tomato was 45.2 t/ha.

Singh *et al.* (2001) conducted field experiment in sandy loam soil and investigated the water and nutrient-use efficiency of sprouting broccoli. The treatments included application of the recommended fertilizer dose as soil application and irrigation through drip system as well as 3 level of fertigation 100, 80 and 60% of recommended fertilizer doses. Marketable yield was achieved by applying 60% of the recommended dose. Yield obtained indicated that substantial saving in the fertilizer applied, to the extent of 20-40% could be accomplished through fertigation. The water use efficiency (WUE) ranged from 18.7 - 6.52 kg/ha-mm.

Savva (2001) used methods in estimating crop-water requirement by FAO Penman-Montieth method, the pan evaporation using the Kp factor and the pan evaporation using the Et/Eo ratio have been described. He concluded that crop water requirement for localize systems, over-design is avoided and the costs are reduced by use of correction factor. The pan evaporation method using the Et/Eo ratios is not recommended for estimating crop water requirements since the Et/Eo ratio combines the crop relationship to the evaporation of the pan and the environment of the pan. Since under localized irrigation only portion of the soil surface is wetted, the evaporation component of evapotranspiration should be reduced to correspond to the wetted area. For this purpose a correction factor (Kt) is introduced which varies with the crop ground cover. Another popular method for estimating crop water requirement is the pan Evaporation method. It is based on the principal that in the absence of rainfall, the amount of water evaporated daily (mm/day) from open water surface is the integrated effect of radiation, wind velocity, temperature and humidity. However its environment affects the evaporation from the pan. Hence the use of a pan coefficient (Kp) is required in order to relate the pan evaporation to the reference crop evapotranspiration, before the application of the Kc coefficient, as expressed in the following equation

$$ET_0 = K_p \times E_{pan} \qquad \text{….2.15}$$

Where,

ET_o = reference evapotranspiration [mm/day]

K_p = pan coefficient

E_{pan} = pan evaporation [mm/day]

Brahma *et al.* (2002) conducted an experiment with 80:30:20, 100:60:40, 150:80:60 and 200:120:80 kg NPK/ha. Application of NPK at 200:120:80 kg/ha resulted in the highest head diameter (19.52 cm), secondary head number (7.09), head yield (13.41 t/ha), cull head yield (4.70 t/ha) and total yield (18.11t/ha) of the crop broccoli.

Sharma et al. (2002) evaluated the effects of N (60, 120 and 240 kg/ha) and P (60, 120, 180 kg/ha) on the growth and yield of broccoli cv. Green head on a loamy soil under irrigated conditions. They reported that 240 kg N/ha plus 60 kg P/ha recorded the highest seed yield per plant (51.67 gm), and seed yield per ha (1.91 t).

Agrawal *et al.* (2005) conducted experiment on effect of water salinity on tomato under drip irrigation during 2001-2002 at CTAE Farm, Udaipur with 4 treatments. Daily irrigation was scheduled. The field emission uniformity was obtained as 89.04, 88.37, 88.31 and 87.65 per cent for the treatments T1, T2, T3 and T4 respectively. In the T1 yield was found maximum (18.74 t/ha) while minimum in T4 (5.34 t/ha). The mean maximum fruit girth was found maximum in T1 (25.73 mm) followed by T2 (24.22 mm), T3 (21.52 mm) and T4 (14.81 mm). WUE was found to be maximum in T1 (675.56 kg/ha-cm) followed by T2 (598.41 kg/ha-cm), T3 (452.42 kg/ha-cm) and T4 (192.50 kg/ha-cm). The seasonal water requirement of tomato was 27.72 cm. Observation prevailed that as salinity of irrigation water increased tomato yield, fruit girth and fruit weight decreased. Water use efficiency was found to be maximum for drip with 1.5 dS/m and minimum for drip with 3.0 dS/m salinity of irrigation water.

Bhandarkar *et al*. (2005) estimated crop evapotranspiration (ETc) for field crops and vegetables from 20 year weather data collected from CIAE observatory, Bhopal. Crop coefficients were obtained from the literature for different crops. ET_0 was estimated by using FAO Penman-Montieth equation and CROPWAT software. The seasonal crop evapotranspiration for vegetables crops of potato, cabbage, tomato and pea were 338, 268, 380 and 305 mm respectively.

Karlberg *et al.* (2007) conducted experiment on tomato crops (spring and autumn) produced during two growing seasons, starting from September 2003 and ending in April 2004, at the Hatfield Experimental Farm in Pretoria, South Africa. Two low-cost drip irrigation systems with different emitter discharge rates (0.2 and 2.5 l/h) were used to irrigate tomatoes (Lycopersicon esculentum Mill. cv. "Daniella") with water of three different salinity levels (0, 3 and 6 dS/m). They reported that drip irrigation is widely regarded as the most promising irrigation system in combination with saline water. Simple drip irrigation kits that are affordable for smallholder farmers have successfully been implemented for irrigation of vegetable gardens in several countries in sub-Saharan Africa. The possibility of using low-cost drip irrigation with saline water to successfully irrigate a common garden crop, tomatoes, was tested. An average yield of 75 t/ha was recorded for all treatments and seasons, which can be compared with the average marketable yield for South Africa of approximately 31.4 t/ha. Even at the highest irrigation water salinity (6 dS/m), a yield above the average marketable yield was achieved, indicating that low-cost drip irrigation works well in combination with saline water.

2.7 ECONOMIC FEASIBILITY OF DRIP IRRIGATION SYSTEM

The economic feasibility of microirrigation systems has been studied by different researchers on different crops.

Sivanappan (1978) worked out economics of drip irrigation. The water use and yield obtained by drip method was compared to the surface irrigation. The drip irrigation gave an increase in yield and fetched about Rs. 10,000 per year for a small farm when available water is not sufficient to irrigate the entire area of the farm by surface method.

Sanders *et al*. (1987) made a study on economics of drip and plastic for peppers, tomato and muskmelon for gross benefit. Gross profit was increased for pepper and tomato during two dry and one wet season, but only during dry season for muskmelon. The marginal benefit cost index was negative for muskmelon in the wet season. In dry seasons the marginal cost index was greater for the combination of drip irrigation and plastic than for either treatment alone for all three crops.

Atre *et al*. (1989) revealed that benefits received by adopting drip irrigation method was brought to prevent worth value of 15, 18 and 20 per cent rate of interest. So also the additional costs incurred for drip irrigation method using discounted cash flow method and benefit cost ratio were 5.95, 5.01 and 4.62 respectively. Thus the benefit cost ratios at all the interest rates were more than 1.25, it is justifiable for adoption of drip irrigation

Jadhav *et al*. (1990) studied economic feasibility of the drip irrigation for tomato. The BC ratio of the drip system for tomato crop was found to be 5.25, where as it was 2.86 for flood method.

Bendal *et al*. (1995) conducted field study on the economics of drip irrigation on pomegranates. The cost of installation was found to be Rs 30, 934/ha. Total cash out flow and inflow per ha at the end of ten years was found to be Rs. 52,588 and Rs 2,50,565 respectively. Net cash inflow per hectare was found to be Rs. 1, 97,976 at the end of ten years and BC ratio was estimated as 2.12.

Manjunatha *et.al* (2001) carried out economic feasibility of microirrigation systems for various vegetable, viz. cabbage, potato, brinjal, chilli, cauliflower and tomato were worked out for Nainital tarai region of Uttar Pradesh, India. The cost of cultivation is maximum for surface irrigation and minimum for drip emitters and drip microtubes. The net seasonal income obtained per hectare area of cabbage cultivation was highest for drip microtubes (Rs 60,788) followed by drip emitter (Rs 58,780), microsprinkler (Rs 57,246) and lowest for surface irrigation (Rs 42,809). The gross benefit: cost ratio of 2.65, 3.24, 3.19 and 2.49 were achieved for drip emitter, drip microtube, microsprinklers and surface irrigation respectively. The net profit achieved per mm application of water used for tomato was maximum for drip microtube (Rs 731), followed by drip emitter (Rs 648) and minimum for surface methods of irrigation (Rs 305).

Patel and Rajput (2001) conducted experiment on minimization of cost of drip system for field crops. The procedure of determining the optimal spacing of laterals and drippers was discussed for irrigating okra crop in sandy loam soils. Optimal operation duration's of drip system with dripper discharges of 2, 4 and 6 l/h were found to be 720, 480 and 240 min. based on the horizontal and vertical advance of soil moisture. Drip system with 4 l/h dripper discharge, laterals spaced at 92.5 cm apart was found to be the most economical system for irrigating okra in sandy loam soils.

Sahu and Rao (2005) conducted experiment on micro drip irrigation system (MDIS) to design, develop and evaluate it for growing vegetables in the farmer's field (village Nardha, district Durg). The economics of MDIS was worked out. The system cost was Rs. 78,000/ha. They reported that MDIS produced 25-35 per cent higher crop yields and saved

45-48 per cent water, 45 per cent labour cost and 50 per cent fertilizer cost. The B/C ratio was higher in case of MDIS (5.34) as compared to basin irrigation (4.14). Thus in 1 season (1/3rd year) additional cost on MDIS can easily be recovered.

Thakur and Spehia (2005) conducted field experiment during 1998-2000 at Himachal Pradesh, Solan district to reduce the cost installation of drip irrigation system for tomato keeping 4 different lateral distances and varying plant to plant and row to row spacing. Highest yield (41.79 t/ha) of tomato fruit was obtained under the treatment with drip lateral spacing of 2.60 m with 4 rows of planting along each lateral and paired row planting with interpair spacing of 40 cm plant spacing of 20 x 41 cm within the rows. The cost of installation of drip irrigation system per hectare for tomato crop under drip lateral spacing of 1.8 m was Rs. 1,00,000.00 The total cost of cultivation was found to be Rs.67,214.07 and benefit cost (B/C) ratio was 3.81.

Polak and Yoder (2006) examined the experiences of suppliers of treadle pumps, low-cost drip irrigation and water storage systems. They reported that 550 million of the current 1.1 billion people earning less than $1-a-day earn a living from agriculture in developing countries. A revolution in water control is needed to develop and mass-disseminate new, affordable, small-plot irrigation technologies. A revolution in agriculture is required to enable smallholders to produce high-value, marketable, labor-intensive cash crops. A revolution in markets is needed to open access to markets for the crops they produce and the inputs they need to produce them. Finally, a revolution in design, based on the ruthless pursuit of affordability, is needed to harness shallow groundwater.

Khan *et al.* (2008) conducted experiment on large-area farms of the Murrumbidgee Irrigation Area (MIA) and Coleambally Irrigation Area (CIA) in the Murrumbidgee River catchment, New South Wales, Australia. They investigated a range of water savings options at irrigation system level and rank these options according to the potential savings of each option and the economic return in terms of water saved (ML - megalitres) for each dollar invested. Field-based on-farm water savings for scenarios analysed ranged from 0.1 ML/ ha up to 3.9 ML/ ha (10-390 mm). As capital was a limiting resource to farmers, options that have the lowest cost per ML saved may be more appealing than options that have a higher cost but may also have higher net benefits over time. The water savings that derived the highest net benefit per megalitre saved were conversion to drip and subsurface drip for the case study farms and laser leveling which had net benefits ranging from A$ 64 to A$ 344 /ML saved per year. All of the other options had net benefits ranging from A$ 4 to A$ 37 /ML saved per year. All of the options that had a low annualised cost also had a relatively low net benefit (less than A$ 24 /ML saved per year). Marginal costs of off-farm water savings increased with the volume of water saved. In the MIA up to 20 GL (1 gigalitre = 1 MCM million cubic metres) of potential water savings was possible at a marginal capital cost of around A$ 1500-2000 /ML. Marginal capital costs then raised rapidly, reaching A$ 4000 /ML at around 38 GL reflecting the lower volumes saved at higher costs.

Ranawat (2008) conducted field experiment at RCA, Udaipur reported that quality and high yield (11.1 t/ha) of broccoli was obtained with the application of 100 kg N, 80 kg P_2O_5 and 80 kg K_2O per ha. The net returns of Rs. 88601/ha with B/C ratio 3.99 was obtained.

2.8 CONCLUDING REMARKS

Numerous studies have been conducted on drip irrigation system to optimize hydraulic parameters of lateral and microtubes, productivity of different crops, performance, economy and suitability of system. The results indicate application of irrigation water operating head of more than 3 m is recommended for uniformity in (Anonymous, 2005; Bralts *et al*, 1993; Keller and Karmeli, 1974; Mofoke *et al.*, 2004; Wu and Gitlin; 1973; Savva, 2001; Sivanappan, 1978; Yadav, 1998).

The drip systems require intensive capital due to sophisticated technology. Therefore, it is beyond the capacity of the most farmers in India. Therefore if the drip system could be made affordable and within the reach of small and marginal farmers in India, it will definitely increase the productivity and income of the farmers and would also, conserve the scarce precious water in the country. Thus, therefore urgent need to maximum and efficient utilization of available resources, pressurized irrigation system has a greater importance.

IDE affordable micro irrigation technology supports small and marginal farmers of India. It has working head 0.5-3 m with 73-84 per cent distribution uniformity (Polak *et al*., 1997). Higher head in KB drip system with increasing height of source is difficult to maintain and costly also.

Therefore, there is a need to develop an efficient and suitable low pressure low cost (LPLC) drip irrigation system having working head more than 3 m with higher distribution uniformity, constructed with locally available materials that would be adoptable and affordable for small land holders.

Keeping the above in view, an attempt has been made to develop an efficient low pressure low cost (LPLC) drip irrigation system. In the light of the above considerations, a field experiment entitled “Low Pressure Low Cost (LPLC) Drip Irrigation System for Small Land Holders” has been under taken.

III- MATERIALS AND METHODS

A field experiment entitled "Low Pressure Low Cost (LPLC) Drip Irrigation System for Small Land Holders" was conducted during the year 2008-09 at the Horticulture Farm, Rajasthan College of Agriculture, Udaipur.

The detailed technique and materials used, during the investigation, are described as under

3.1 EXPERIMENTAL SITE AND CLIMATE

The field experiment was conducted at Horticulture Farm, Rajasthan College of Agriculture, Udaipur, which is situated at $24^0 35^/$ N latitude and $73^0 42^/$ E longitude with an elevation of 582.17 meters above mean sea level. The region falls under Rajasthan agro climatic zone IVa (Sub- Humid Southern Plain and Aravali Hills). The climate of here is typically semi-arid and sub-tropical, characterized by mild winter and summer. It has relatively high humidity from July to September. The average annual rainfall of this tract ranges from 650 to 750 mm.

Weather, a non-monetary input influences the growth, yield and quality of crops as well as biotic phase of soil during the growing season; hence, it is important to present climatic variables in this chapter. The mean monthly meteorological observations recorded during the crop period at the meteorological observatory of the farm are presented in Appendix Table A-3.1. Data revealed the maximum and minimum values of temperature, relative humidity, evaporation and rainfall range from 25.6^0C to 34.0^0C, 10^0C to 21.7^0C, 74.6 to 85.3 per cent, 31.7 to 60.5 per cent, 2.3 to 3.8 mm and 0 to 224 mm respectively.

3.1.1 Survey and Data Collection

After surveying, the level of the field was recorded through leveling instruments. The proposed research work was conducted for two vegetables (tomato and broccoli) with micro-tubes and medi-emitters as emitters. Soil parameters were determined. Climatological data were collected from hydro-meteorological observatory, RCA, Udaipur. Primary data were collected from model operation where as secondary data were collected from Government Departments, Institutions and NGOs.

3.2 PHYSIO-CHEMICAL PROPERTIES OF SOIL

The soil samples were collected randomly from the test field at depth range of 0-30 cm and 30-60 cm in order to assess physio-chemical properties. Laboratory and field experiments were conducted to determine the bulk density and infiltration characteristics of the soil.

3.2.1 Bulk Density

Bulk density is defined as the weight of the soil mass per unit volume. It was determined by core sample method. The bulk densities of soil samples are presented in Table 3.1.

Table 3.1 Bulk density for silty-clay soil

S.No.	Depth of soil layer (cm)	Dimensions of core cutter		Total volume of core cutter (cm^3)	Weight of oven dried soil (g)	Bulk density of the soil (g/cm^3)
		Height (cm)	Diameter (cm)			
1	0-30	12.3	10.0	966.04	1643.0	1.7
2	30-60	12.7	9.9	977.61	1753.0	1.8

The average bulk density was found to be 1.75 g/cm^3.

3.2.2 Infiltration Characteristics of the Soil

Infiltration is defined as the movement of water into subsurface area of the soil. The infiltration characteristics of the experimental site were determined by cylindrical infiltrometer. The observed data are presented in Table A-3.2.

The infiltration was assessed by the following equation (Michael, 1978).

$$y=at^{\alpha} \quad ....3.1$$

Where,

y = cumulative infiltration in elapsed time, cm

t = elapsed time, min

a and α are characteristic constants determined by average method as suggested by Davis (1943).

The equation relating infiltration to time is transformed as:

$$y = 3.14\ t^{0.55} \quad ....3.2$$

The values of accumulated infiltration (y) and the average infiltration rates are plotted as a function of elapsed time (t) in Figure 3.1. The physio-chemical properties of soil analysis as determined by National Bureau of Soil Science (NBSS), Udaipur, are presented in Table 3.2.

Table 3.2 Physio-chemical properties of soil

A – Physical properties of soil

S.No.	Descriptions	30 cm depth	60 cm depth
a	Soil type	Silty - clay	Silty - clay
b	Percentage of proportion	Sand - 6.05 % Silt - 57.19 % Clay - 36.76 %	Sand - 6.81 % Silt - 57.51 % Clay - 35.68 %
c	Field capacity (%)	22.78	22.78
d	Wilting point (%)	6.85	6.85
	B – Chemical properties of soil		
a	pH value	7.62 (mild base)	7.57 (mild base)
b	Ec (dS^{-m})	0.681	0.961
c	$CaCo_3$ (%) content	2.3	2.3

(Source NBSS, 2008)

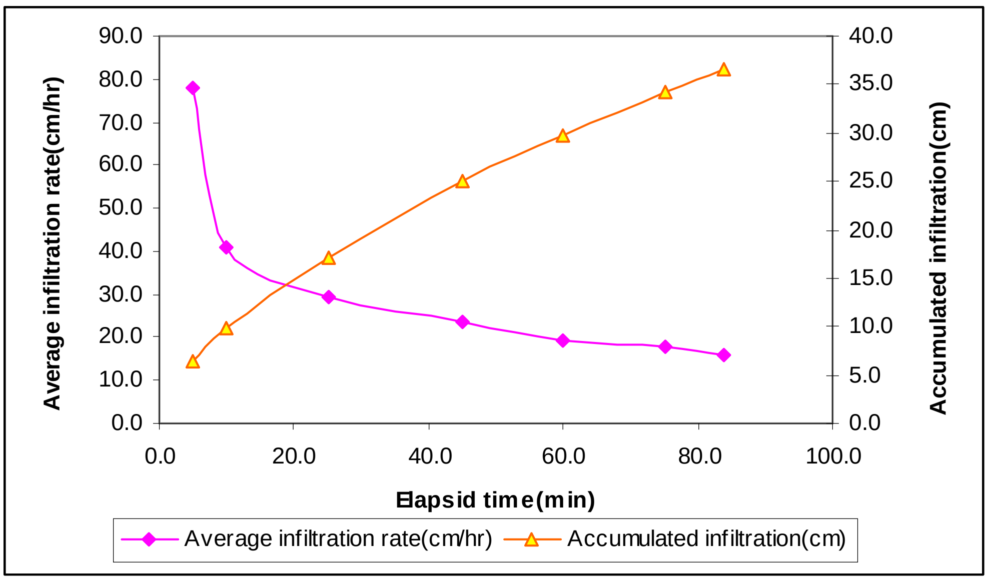


Fig. 3.1 Infiltration rates and accumulated infiltration versus elapsed time

3.3 THE EXPERIMENTAL SET-UP AND TREATMENTS

The experimental set-up comprising low cost KB pipes, KB pressure treadle pump with pressure drum as source, microtubes and medical infusion set as emitters, KB equipped submain and laterals with necessary accessories installed at horticulture farm, RCA, Udaipur. The experimental field of size 25 m x 25 m was sub divided into four equal sizes of sub plots 12.5 m x 12.5 m in order to reduce the pressure head requirement. The pressure drum (source) was installed in the centre of the field. Experiment were conducted in 2008-09 on tomato and broccoli crops by using microtubes and medi-emitters having I.D. of 0.9 mm and 3 mm respectively with level ground and 0.5 per cent up slope.

The moisture content was monitored (AIC tensiometer) on daily basis up to 4 months (growth period of vegetable crops on field). The study variables were as follows

Table 3.3 Study variables

Vegetables	Emitters	Slope
Tomato	Microtubes	Level ground
Tomato	Medi-emitters	0.5 per cent up slope
Broccoli	Medi-emitters	Level ground
Broccoli	Microtubes	0.5 per cent up slope

The field experiments were conducted on various independent parameters on different aspect for tomato and broccoli, such as vegetative growth parameters, hydraulic performances, crop water requirements, water use efficiency, and cost economics were evaluated. Treatments combinations were as under

T1: Broccoli grown on level ground with medi-emitters

T2: Tomato grown on 0.5 % up slope with medi-emitters

T3: Tomato grown on level ground with microtubes

T4: Broccoli grown on 0.5 % up slope with microtubes

System was operated under 6 m pressure head and discharge of emitters were evaluated. The application time was calculated on basis of Kc and pan evaporation (35 years weekly climate normal during growth period of vegetable crops, hydro-meteorological station, RCA, Udaipur). Crop coefficient (Kc) integrates the effect of characteristics that distinguish a typical field crop from the grass reference, which has constant appearance and a complete ground cover. Consequently, different crops will have different Kc coefficients. The changing characteristics of the crop over the growing season also affect the Kc coefficient. Discharge rate of emitters under 6 m head was observed 2.29, 2.11, 1.05 and 0.86 l/h for treatments T1, T2, T3 and T4 respectively.

Sprouting broccoli (*Brassica olreacea* L. var. italica) cv. Aishwarya (F_1 - Hybrid) and tomato (*Lycopersicon esculentum* Mill) cv. Dev variety were tested. The system incorporates medical infusion set as emitters, here after referred to as medi-emitter. The clogging of emitters was controlled by weekly addition of lime in storage tank.

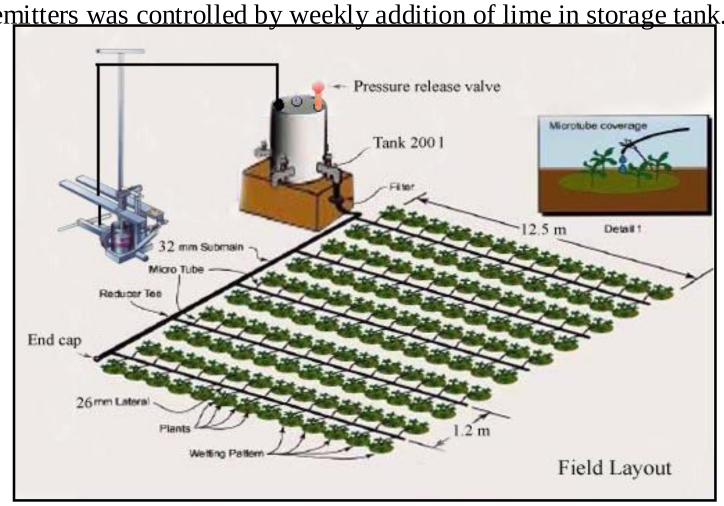


Fig. 3.2 Field layout of KB pressure treadle pump for one treatment

Plate No. 3.1 Overall view of experimental site

The experiment was laid out with four treatments and twenty-one replications (without treatment) for randomized block design (RBD). Each sub plot comprised of 21 rows with 566 plants. Five plants were selected randomly for observation. Paired rows planting pattern was adopted. Row to row and plant to plant spacing was 0.60 m and 0.45 m respectively. The set-up is shown in Fig. 3.2 and overall view of experimental site is shown in Plate No. 3.1.

3.4 DESIGN OF LOW PRESSURE LOW COST (LPLC) DRIP IRRIGATION SYSTEM

KB (Krishak Bandhu) drip irrigation system as manufactured by the IDE consisted of KB pressure treadle pump, low cost KB pipes (submain and laterals), microtubes (0.45 m) and accessories. KB drip with 200 l capacity as source pressure drum and medical infusion set (0.45 m) as emitters were used for LPLC modal design. MS drum was used as buffer pressure tank. It is easily available in market as oil tank. The capacity of pressure treadle pump varies from 3000.0 to 5000.0 l/h. It has delivery head of 13.0 m. One man can continuously operate treadle pump for 1.0 h. Tank feeding was done by treadle pump. System was design for tomato and broccoli crops having plant to plant spacing of 0.45 m and row to row spacing of 0.60 m under operating head 6 m. Paired rows planting pattern was adopted.

The system was designed on the basis of climatologically data, constructed with locally available materials and components available at IDEI, Ahmedabad. Pan evaporation method was used for estimating crop water requirement (Mane *et al.*, 2006).

Volume of water required

$$V = \frac{CA \times PE \times P_C \times K_C \times PWA}{E_U} \quad \text{…. 3.3}$$

Where,

V = Volume of water required (l/day/plant)

CA = Crop area (m^2)

PE = maximum pan evaporation (mm/day)

P_C = pan coefficient

K_C = crop coefficient

PWA = Percentage wetted area

E_U = emission uniformity, decimal.

Head loss was determined by William - Hazan empirical equation

$$\Delta H = 1.21 \times 10^{10} \times \left(\frac{Q}{C}\right)^{1.852} \times (D)^{-4.871} \times L \times F \quad \text{…. 3.4}$$

Where,

ΔH = head loss in lateral, m

Q = flow rate in the lateral, l/s

C = friction coefficient for continuous section of pipe and depends on pipe material

D = inside diameter of lateral, mm

F = outlet factor

L = length of lateral, m

Layout plan of experimental site and Schematic diagram of LPLC drip system are shown in Fig. 3.3 and Fig. 3.4 respectively.

3.4.1 Basic Components of LPLC Drip Irrigation System

LPLC drip irrigation system has the following components

1. KB pressure treadle pump

The KB pressure treadle pump lifts water from any water source to the surface. Water is discharged from the pump under pressure so it can pump water to an elevation above the pump. It was connected to drip system for irrigation. It can also be connected to a long delivery pipe to move water to whatever point required for irrigation.

2. Buffer water source

A 200 liter tank placed 0.5 m above ground level and fitted with pump was used as buffer water source.

3. Control valve

The control valve made of plastic was used to regulate the water flow into the system.

4. Filter

Filter is the heart of any drip irrigation systems. The screen filter is the most commonly used to filter water in drip irrigation system. But due to low cost, Drum filter (0.5 m^2c) was used in LPLC drip irrigation system.

5. Sub-main

Linear low density polyethylene (LLDPE) sub-main pipe supplied water to the laterals which were connected to the sub-main at regular interval of 1.2 m. 32 mm pipe (ID = 26 mm) was used for sub-main, which was only available at IDE, Ahmedabad.

6. Laterals

Lateral pipelines made of LLDPE were set along the crop rows with paired row, microtube and medi-emitters were installed along them to provide water to the plants. 26 mm pipe (ID = 20 mm) was used for laterals, which was only available at IDE, Ahmedabad.

7. Emitters (microtubes and medi-emitters)

These are the outlets for distributing water to the plants. The medi-emitters and microtubes having opening diameter of 3 mm and 0.9 mm were used respectively. Spacing of emitters was 0.45 m as per plant spacing.

8. Manometers

A simple transparent plastic pipe was used as manometer to measure pressure head at the two ends of submain and laterals in order to assess the pressure drop across the length.

9. Accessories

Tee, bend and pressure gauge (reading up to 10 m) were installed in the system.

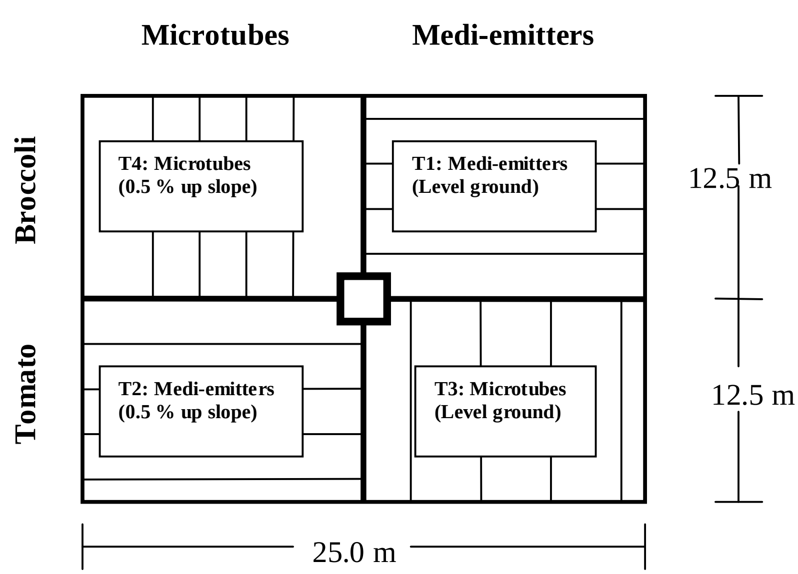


Fig. 3.3 Layout plan of experimental site

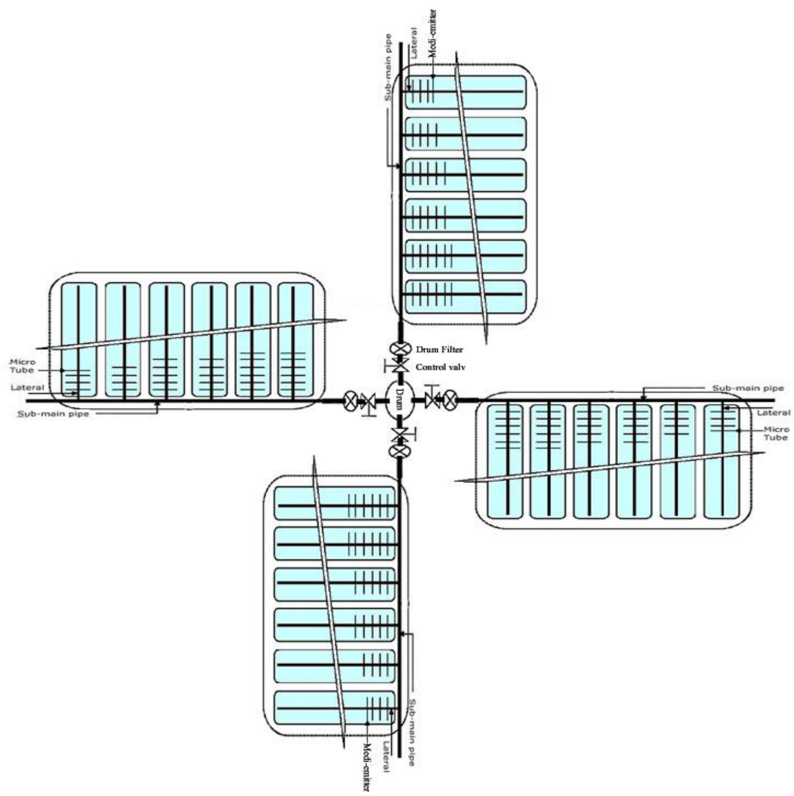


Fig. 3.4 Schematic diagram of LPLC drip system

3.4.2 Planting Geometry

Initially one lateral drip line for each row had been recommended for drip system which enhanced the installation cost. The cost could be reduced to half by keeping one lateral between two rows. Paired- row planting system was adopted with centrally located buffer tank as source of water.

3.4.3 Appropriation of KB Pressure Treadle Pump

KB pressure treadle pump can lift water from source up to 13 m. As the external electrical or mechanical power is not required the farmer can operate it as per requirement. As the body weight of the operator is effective in lifting water through this pump, it can be operated by all irrespective of age groups and sex. The out put of the pump may vary from person to person. KB pump is easily transportable due to low weight. As its total lift is 13 m, total head 17 m with a suction lift of maximum 6 m and has discharging output of 3000-5000 l/h depending upon the depth, the farmers can use this pump for drip, sprinkler and supplemental irrigation from available source of water (ground water, lakes, pond and storage tank).

KB pressure treadle pump was appropriated with non-return valve and bend arrangement in delivery pipe. The bend arrangement is fitted in the beginning of outlet pipe with end plug which helps in priming. After priming, the end plug should be tightened. Similarly, non-return valve proposed near the outlet of delivery pipe prevents water hammering and back flow of water in the system. This pump requires no external power. It has a low repair and maintenance cost. The least skill is needed to operate and maintain the pump. Its assembly parts are readily available in the local market. The appropriated KB pump is shown in Plate No. 3.2

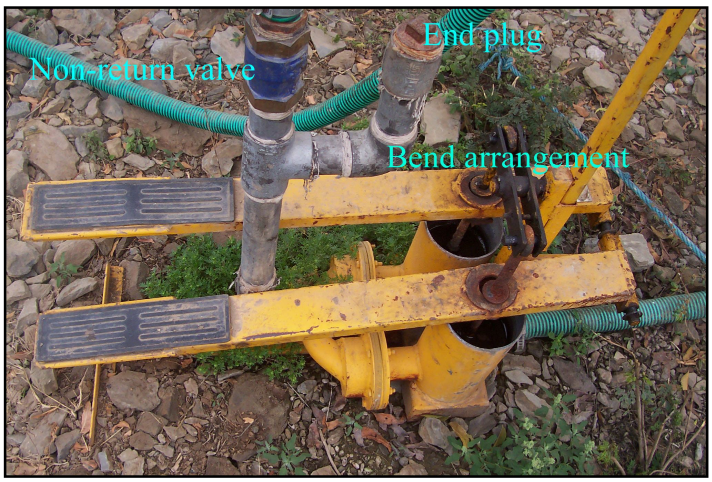


Plate No. 3.2 Appropriated KB pressure treadle pump

3.4.3.1 Details of components

Junction box with tee arrangement is the base frame of the KB pressure treadle pump. Its operating system consists of a pair of pedals with foot rest assembly, pivot pin, equaliser, equaliser pin, bucket washer, rubber valve disc. Equaliser support pedal, piston for efficient operation. The operator can stand comfortably on the pedal with the help of tee handle for applying force downward alternatively. It consists of 2 cylinders with delivery chamber. Piston is mounted with bucket washer. The cylinder assembly receives the suction water through the suction pipe during suction stroke and rubber valve discs deliver the water through the delivery pipe in exhaust stroke.

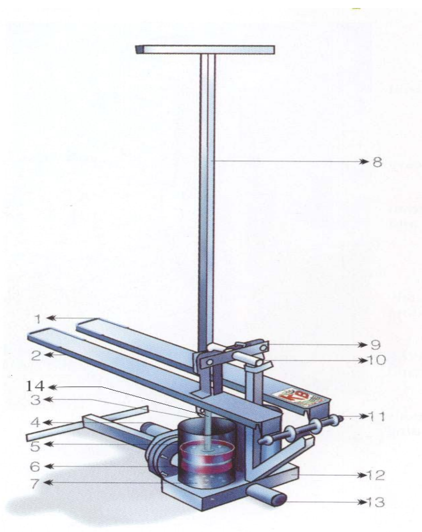
Specifications of pump are given in Table 3.4.

Table 3.4 Specifications of KB pressure treadle pump

No. of Cylinders	Cylinder Height	Diameter of Cylinder	Diameter of Suction pipe	Diameter of Delivery	Foot Rest	Tee Handle

				pipe	**Length**	**Height**
2	0.19 m	0.11 m	0.0375 m	0.032 m	0.77 m	1.07 m

The various assembled parts of KB pressure treadle pump are shown in Fig.3.5.



1. **Foot Rest**
2. **Pedal**
3. **Cylinder**
4. **Delivery Pipe**
5. **Delivery Chamber**
6. **Bucket Washer**
7. **Rubber Valve Disc**
8. **Tee Handle**
9. **Equaliser**
10. **Equaliser Pin**
11. **Pivot Pin**
12. **Junction Box**
13. **Suction Pipe Holder**
14. **Piston**

Fig. 3.5 KB pressure treadle pump

(Source: IDE, India, 2007)

3.4.3.2 Working of KB pressure treadle pump

Priming of the pump is done to remove the air pockets from the suction pipe before operation. During operation, the operator, stands on the pedals with the help of tee handle and press his/her left/right foot downward simultaneously. As one pedal is pressed down, the plunger assembly at the other end moves up. The suction of water occurred through rubber valve disc which acts as the suction valve. The sucked water inters into the delivery chamber. When the other pedal is lifted up, the plunger at the other end moves down and water inside the cylinder enters the delivery chamber. As the operations of the cylinder as well as plunger are carried out simultaneously, the output discharge is constant. The discharge variation, if any, depends on depths of pump operation, capacity of the operator, water table position, condition of the pump etc.

3.5 EXPERIMENTATION

The hydraulic and vegetative growth parameters of LPLC drip irrigation system can be classified as:

1. Estimation of the design parameters of LPLC drip irrigation system.
2. Measurement of average discharge through microtubes and medi-emitters at different pressure heads.
3. Establishment of relationship between average discharge output at various pressure heads.
4. Measurement of hydraulic characteristics like pressure and discharge variations for various pressure heads.
5. Study of statistical data and system uniformity of various design parameters in order to test the technical performance of the system.
6. Computation of moisture depletion, crop water requirements, biometric parameters and water use efficiency of the crops under research experiment.
7. Estimation of the benefit cost (B/C) ratio under different treatments.

3.5.1 Methodology

Following procedure was adopted for conducting experiments:

1. The system was brought to equilibrium condition by operating for 15 minutes. The discharge through emission devices were collected in the plastic mugs for 5 minutes. It was done for four laterals that divide submain into four equal parts. The collected discharge was measured with help of graduated cylinder from 4 laterals line at 4-8 m pressure head.

2. The discharge of the emitters was measured at the first point, 1/3 point, 2/3 point and last emitter on the corresponding laterals in the subplot. Sixteen data points thus obtained were used for hydrological analysis and study of uniformity of application.
3. Daily pan evaporation was incorporated from pan evaporation data for that week as the weekly pan evaporation data (35 years mean) was collected from RCA hydro-meteorological observatory.

   Crop coefficient (Kc) was considered as suggested by Allen *et al* (1998). Pan evaporation methods were used to calculate the crop water requirement. The irrigation scheduling was fixed.

   Two tensiometers were installed at the depth of 30 and 60 cm in the centre of each subplot for recording moisture depletion per day. Gravimetric methods were used to calibrate tensiometers.
4. Five plants selected at random in each subplot were tagged for recording the observations. Their biometric parameters were calculated.

   Benefit - Cost (B/C) ratio was calculated on the basis of production and cost as per market rate.

3.6 RELATIONSHIP BETWEEN DISCHARGE (Q) AND OPERATING PRESSURE HEAD (H)

A statistical regression technique was used to analyze the experimental data to obtain empirical equations for microtubes and medi-emitters. Since length of lateral (12.5 m) as well as that of microtubes and medi-emitters (0.45 m) was kept fixed in the experiment according to subplot size, both parameters are constant.

Thus following equations were developed for discharge

$$Q = k\,H^x \qquad \text{….3.5}$$

Where,

Q	=	average discharge through emitters, l/h
H	=	Head of operation in meters
x	=	emitter exponent
k	=	constant of proportionality.

3.7 PRESSURE AND DISCHARGE VARIATION IN SUBMAIN AND LATERAL LINES

Since the variations in discharge and pressure for drip irrigation depend on submain, lateral line hydraulics through emitters takes the form given by Wu (1975, 1997). The flow variation through emitters is given by

$$q_{\text{var}} = \frac{(q_{\max} - q_{\min})}{q_{\max}} \qquad \text{....3.6}$$

Where,

q_{var} = flow variation through emitter

$q_{\max}$ = maximum emitter flow

$q_{\min}$ = minimum emitter flow

The pressure variation is given by

$$h_{\text{var}} = \frac{(h_{\max} - h_{\min})}{h_{\max}} \qquad \text{....3.7}$$

Where,

h_{var} = emitter pressure variation

$h_{\max}$ = maximum pressure in line

$h_{\min}$ = minimum pressure in line

Above equations were used to measure variation in assembly.

3.8 UNIFORMITY COEFFICIENT

Wu and Gitlin (1973) used the statistical approach for obtaining irrigation uniformity as suggested by Christiansen. They gave the following relationship:

$$Ed = \left(1 - \frac{S_q}{q_{avg}}\right) \text{ and} \qquad \text{....3.8}$$

$$Ea = \left(\frac{q_{\min}}{q_{avg}}\right) \times 100 \qquad \text{....3.9}$$

Where,

Ed = distribution efficiency, (%)

q_{avg} = average flow rate, I/h

S_q = average absolute deviation of all emitters flow from the average emitter flow, lph.

Ea = application efficiency, (%)

q_{min} = minimum flow through emitter, l/h

Keller and Karmeli (1974) suggested the equation for the evaluation of emission uniformity "EU" measures the degree of uniformity of application of water in the field. These are denoted as EU_f (field emission uniformity) and EUa (absolute uniformity coefficient). The relations are given as:

$$EU_f = \left(\frac{q_n}{q_a}\right) \times 100 \qquad \text{....3.10}$$

$$\text{EUa} = 100 \times \left[\frac{Q\min}{Qavg} + \frac{Qavg}{Qx}\right] \times \frac{1}{2} \qquad \text{....3.11}$$

Where,

EU_f	=	Field emmission uniformity
EUa	=	Absolute emmission uniformity
q_n	=	The average of lowest 1/4 of the emitter flow rate (l/h)
q_a	=	The average of all emitters flow rate (l/h)
q_x	=	The average of the highest 1/8 of the emitters flow rate (l/h).

Keller and Karmeli (1974) suggested design emission uniformity by the following equation:

$$EU_d = 100\left(1 - 1.27\frac{V_m}{N_e^{0.5}}\right)\frac{q_{\min}}{q_{avg}} \qquad \text{....3.12}$$

Where,

EU_d = design emission uniformity, (%)

V_m = manufacturing coefficient of variation

N_e = number of emitters per plant

q_{min} = minimum flow rate through emitter, l/h

q_{avg} = average flow rate through emitter, l/h

There are four commonly used parameters for micro-irrigation evaluation Wu (1997)

1. Christiansen uniformity coefficient

$$CUC = \left[1 - \frac{\frac{1}{n}\sum_{i=1}^{n}\left|q_i - \bar{q}\right|}{\bar{q}}\right] \times 100\% \qquad \text{....3.13}$$

Where,

CUC = Christiansen uniformity coefficient

$\bar{q}$ = mean emitters flow discharge

2. Coefficient of variation

$$C_v = \frac{S}{\bar{q}} \qquad \text{....3.14}$$

Where,

C_v = Coefficient of variation of emitter flow

S = Standard deviation of the emitter flow

3. Statistical uniformity coefficient

$$UCS = 1 - C_v \quad \text{....3.15}$$

Where,

UCS = Statistical uniformity coefficient.

4. Emitter flow variation, q_{var} (Equation 3.6)

C_v, depict the system uniformity and CUC for the spatial uniformity and q_{var}, is used for hydraulic design only. Above mentioned formula were used for calculating uniformity.

3.9 CLASSIFICATION OF EMITTERS AND RANGES OF UNIFORMITY

The suggested pressure loss along a drip line was estimated by Wu and Gitlin (1973) while Keller and Karmeli (1974) devised an equation that was of the power form (Equation 3.4).

The emission exponent x measures the variation of emitters flow due to pressure change. A linear regression between ln (H) and ln (q) gives the values of x and k.

$$\ln(q) = x\ln(H) + \ln(k) \quad \text{....3.16}$$

Which is of the linear form

$$y = xz + b \quad \text{....3.17}$$

By substituting the values and rearranging

$$q = e^b H^x \quad \text{....3.18}$$

It is also possible to calculate x from the discharge rate out from two different operating pressure. The lower value of x, the less discharge will be affected by pressure variations.

For laminar flow, the value of x approaches to 1. For long flow path emitters the value of emitters ranges 0.5 to 1.0. For turbulent flow, value of x should be expected to 0.57.

Non-pressure compensating orifice and nozzle emitters are always fully turbulent, having x value as 0.5, while the fully pressure compensating orifice and nozzle are having value of x = 0.

Classification of manufacturer's recommended coefficient of variation, recommended ranges of design emission uniformity and comparison of uniformity are shown in Table 3.5, 3.6 and 3.7.

Table 3.5 Classification of manufacturer's recommended coefficient of variation (Cv) as per ASAE standards (1998)

Type of emitter	C_v range	Classification
Point source	<0.05	Excellent
	0.05 to 0.07	Average
	0.07 to 0.11	Marginal
	0.11 to 0.15	Poor
	>0.15	Unacceptable
Line source	<0.10	Good
	0.10 to 0.20	Average
	>0.20	Marginal to Unacceptable

Table 3.6 Recommended ranges of design emission uniformity (EU) as per ASAE standards (1998)

Emitter type	Spacing (m)	Topography	Slope, %	EU range, %
Point source on perennial crops	>4	Uniform	<2	90 to 95
		Slope or Undulating	>2	85 to 90
Point source on perennial or semi permanent crops	<4	Uniform	<2	85 to 90
		Slope or Undulating	>2	80 to 90
Line source on annual or perennial crops	All	Uniform	<2	80 to 90
		Slope or Undulating	>2	70 to 85

Table 3.7 Comparison of uniformity as per ASAE standards (1998)

Method acceptability	Statistical uniformity, Us	Emission uniformity, EU
Excellent	100-95	100-94
Good	90-85	87-81
Fair	80-75	75-68
Poor	70-65	62-56
Unacceptable	<60	<50

3.10 CROP RAISING

For conducting experiment two crops were raised i.e. tomato and broccoli.

3.10.1 Raising of the Nursery

Two nursery beds of size 2 m x 1 m x 0.15 m were raised by mixing fine vermicompost in the soil at the rate of 10 kg/m^2. The seeds were treated with Bavistin (2 gm/kg) to eliminate damping off and other soil borne diseases. Seeds of sprouting broccoli (*Brassica olreacea* L. var. italica) cv. Aishwarya (F_1 - Hybrid) and tomato (*Lycopersicon esculentum* Mill) cv. Dev variety were sown by 5-6 cm in lines in the nursery beds on 1st September, 2008. A thin layer of powdered leaf mould was spread over the seeds. Regular watering, hoeing, weeding and plant protection measures were adopted. The seedlings were ready for transplantation within one month. Monocrotophos was spread twice at the interval of 15 days from sowing in order to prevent the seedling from insect damage.

3.10.2 Field Preparation

The experimental field was ploughed with a tractor driven disc plough followed by disk harrow. Then planking and leveling were done to provide good tilth to the field. 84 beds of 0.60 m x 12.5 m (@ 0.60m, height 0.15m) were prepared for easy intercultural operation, root growth protection and crop logging as per requirements.

3.10.3 Fertilizer Application

Soluble fertilizer Samadhan (19:19:19) at 15 days interval was applied to crop through buffer tank at the rate of 200 kg/ha.

3.10.4 Transplanting

One month old seedlings having height of about 11-15 cm were transplanted at 45 cm x 60 cm spacing on 1st October, 2008 evening and irrigation was done thereafter.

3.10.5 Intercultural Operations

First hoeing and weeding was done after 20 days of transplantation and second after next 20 days in all the treatments to get rid of weeds.

3.10.6 Plant Protection Measures

The tomato and broccoli crop were protected from insects and pests by spraying monocrotophos was spread (0.02 per cent) at 15 days intervals after transplanting. Both the crops to protect them from black rot diseases, Aciphate (0.2 per cent) and monocrotophos (0.2 per cent) were spread at the interval of 15 days after transplanting for broccoli and tomato respectively.

3.10.7 Harvesting

The matured heads of broccoli were harvested with sickle from last week of December, 2008 and harvesting of secondary heads continued up to last week of January,

2009. Similar harvesting time was maintained for tomato for marketable yield. Both crops were labeled and the observations were recorded.

3.11 CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING IN DIFFERENT TREATMENTS

In all treatments T1 to T4, the crop was irrigated daily as per water requirement. The evaporation data were collected from hydro-meteorological observatory. Pan evaporation method was used to assess crop water requirement. System was operated at 6 m operating head. Average emitter discharge and field emission uniformity were evaluated and the application time was fixed for each treatment. Pan evaporation method (equation 3.3) was used for estimating crop water requirement (Mane *et al*., 2006). Irrigation time is the ratio of volume of water applied to the plant and discharge rate of emitters.

Computer programme "CROPWAT" provides ETo and corresponding Kc for each decade (10-day period) or month (FAO, 1992) so that it was not used for crop water requirements for daily irrigation scheduling.

3.12 SEASONAL CROP WATER REQUIREMENT

The total amount of water used in evapotranspiration by a cropped area during entire growing season of crop is called seasonal consumptive use (CU). The seasonal water requirement (WR) of the crop was computed by adding measured quantities of irrigation water applied, effective rainfall received during the season and the contribution of the soil moisture from the ground water table.

The seasonal crop water requirement was calculated by the following formula (Michael, 1978).

$$WR = IR + ER + S \qquad \text{....3.19}$$

Where,

WR = seasonal water requirement, cm

IR = total irrigation water applied, cm.

ER = effective rainfall received during the crop period, cm.

S = soil moisture contribution from ground water table, cm (considered as nil because GWT >10 m)

3.12.1 Soil Moisture Depletion

The soil moisture was recorded daily by tensiometer installed in the centre of subplot during crop growth period prior to irrigation so as to study the per cent depletion over field capacity. Two tensiometers manufactured by AIC Agro-instrument (p) ltd. were installed at the depth of 30 and 60 cm within soil profile of each subplot. Gravimetric methods were used to calibrate tensiometer. Soil samples were collected using screw auger.

After calibration, a general equation was developed for determining the soil moisture content from tensiometer reading. Tensiometer reading indicates tenacity of soil i.e. cbar (Centi bar) instead of direct reading of moisture content in the soil, hence calibration is necessary.

The equation is as follows:

$$\% \quad Moisture \quad Content \quad = \quad 39.57(cbar)^{-0.2398} \qquad \text{….3.20}$$

Fig. 3.6 shows the calibration curve of AIC tensiomete and data given in Table A-3.3.

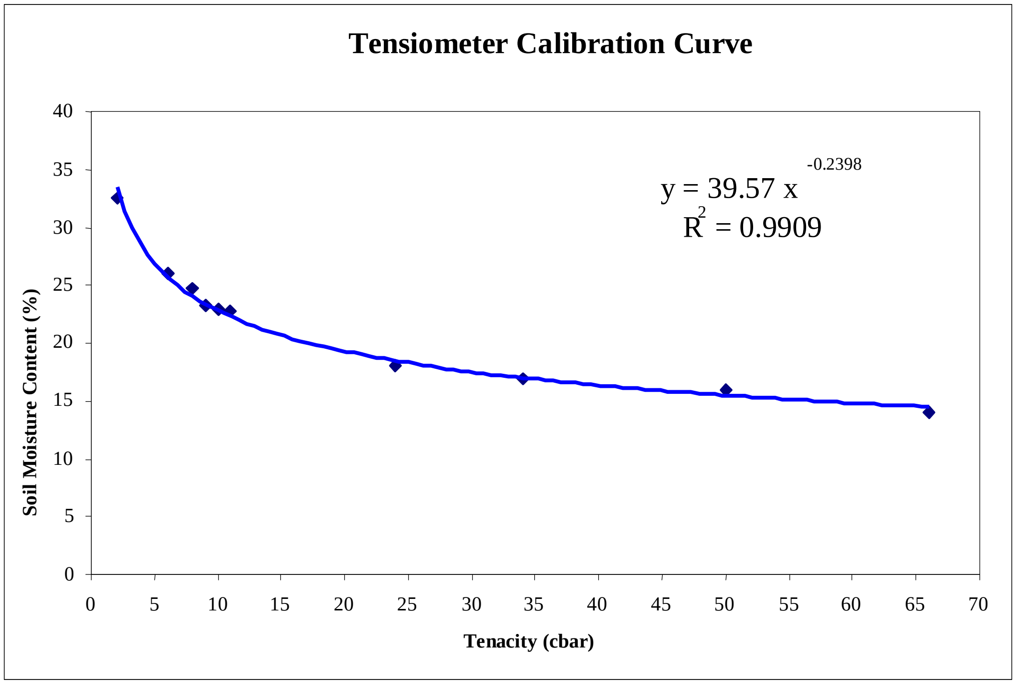


Fig. 3.6 Calibration curve of AIC tensiometer

3.13 VEGETATIVE GROWTH PARAMETERS

Following vegetative growth parameters were recorded from the randomly selected and tagged five plants in each treatment. These parameters were plant height, number of leaves, steam girth, leaf area, leaf area index, root growth and dry matter content.

3.13.1 Plant Height

The height of plant was recorded at the time of harvesting. It was measured from the ground level up to the base terminal of leaf bud on the main stem with the help of steel scale.

3.13.2 Number of Leaves

Number of leaves of all matured leaf lets was recorded for each test plant at the time of harvesting.

3.13.3 Stem Girth

Diameter of stem girth was measured with the help of Vernier caliper at 1 cm above the ground level. The stem girth of plant equals to $2\pi r$, where r is the radius of stem.

3.13.4 Leaf Area

The leaves of observational plants were traced on the graph paper then the area of each leaf was determined for each plant.

3.13.5 Leaf Area Index (LAI)

Leaf Area Index (LAI), a dimensionless quantity, is defined as the ratio of leaf area (upper side only) to the area of soil below it. It is expressed as leaf area(m^2) /ground area(m^2). The active LAI is the leaf area index that actively allows the surface heat and vapour transfer. It is generally the upper, sunlight portion of dense canopy (FAO, 1998).

The leaf area index (LAI) was determined at the time of harvesting as follows:

$$LAI = \frac{Total \quad leaf \quad area}{Ground \quad area} \qquad ....3.21$$

3.13.6 Root Growth

The maximum root growth of the test plants was determined for each treatment after harvesting of the yield from them. The soil surrounding the plant was dug and the plant along root was pulled out carefully. Then the maximum root length was measured using scale.

3.13.7 Dry Matter Content

The weight (residue) of freshly harvested tagged plants (excluding fruits) was recorded at the final harvest. After taking the fresh weight the plants were sun dried. The plant samples were transferred to electric oven till the moisture of samples got dried up completely. Finally the weight of these oven dried plant samples was recorded and percentage of dry matter content above ground (AG) biomass and root mass was calculated as follows:

$$Dry \quad matter \quad content, \quad (\%) = \left(\frac{Dry \quad weight \quad of \quad sample}{Fresh \quad weight \quad of \quad sample} \right) \times 100 \qquad ....3.22$$

3.14 CROP YIELD AND QUALITY OF TOMATO AND BROCCOLI

3.14.1 Crop Yield

The tomato and broccoli fruits were picked out in the form of picking when it was upon fully maturity. The fruits picked from five selected plants were weighed. The remaining general plants from the treatments were also picked and weight of plant fruits was taken. The total weight of sample plants and general plants gave picking wise total yield of plant per treatments.

3.14.2 Quality of Fruits

The quality parameters considered in the field investigation were mean girth, weight and height of fruits. 5 fruits of each treatment plant were selected to determine the quality parameters of fruit.

3.14.2.1 Mean girth of fruit

Mean girth of fruit was measured at the middle with the help of vernier caliper and multiplied by pi (π) to get its value.

3.14.2.2Weight of fruit

The weight of sample fruits was taken by the precise weighting balance having least count 0.05 g.

3.14.2.3 Height of fruit

Height of fruit was measured from the head to the tip of each sample fruit using measuring scale.

3.15 WATER USE EFFICIENCY

Water use efficiency of crop in all irrigation treatments was determined by ratio of the total marketable yield obtained per hectare to the depth of water applied throughout the crop period. It is expressed as t/ha-cm.

3.16 ECONOMIC STUDY

The economy of a particular crop was assessed through analysis of detailed cost and return. The cost includes total, variable, fixed and cost per hectare of the output produced. The net return includes income obtained from produce. Finally, the benefit-cost ratio analysis was performed to judge the economic feasibility of LPLC drip irrigation system. The economic analysis was conducted per hectare of cultivated area under test crop.

3.16.1 Income from Produce

The income obtained from per hectare produce of tomato and broccoli as obtained from various irrigation treatments was computed according to prevailing market price of the two commodities.

3.16.2 Cost of Production

The cost of production was computed for each treatment. It includes wages paid to hired human labor, the cost of machine, seeds, fertilizers, water operation charges, supervision charges and interest on working capital. As the store water was used to operate press treadle pump, the water storage charge is not included in the production cost.

3.16.3 Net Returns

The net return was evaluated by subtracting the cost of production from the income obtained throughs produce for each treatment.

3.16.4 Benefit Cost Ratio

Benefit cost (B/C) ratio was calculated by dividing the income obtained through crop produce by the cost of production in each treatment.

3.17 STATISTICAL ANALYSIS

Descriptive as well as analytical statistical approaches were used to analyze the data and information. Statistical procedure includes percentage; mean, standard deviation, coefficient of variation, simple linear and polynomial regression.

Significance of difference in the treatment effect was tested by 'T' test at 5 % level of significance by using SPSS complete softwere.

The coefficient of variation (C_v) occurs in the following form:

$$C_v = \frac{S}{\bar{q}} \qquad ....3.23$$

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad ....3.24$$

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n} \left|q_i - \bar{q}\right|^2 \qquad ....3.25$$

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} \left|q_i - \bar{q}\right|^2} \qquad ....3.26$$

Where,

C_v = Coefficient of variation of emitter flow

S = Standard deviation of the emitter flow

S^2 = Variance of the emitter flow

q_i = Emitters flow discharge

$\bar{q}$ = mean emitters flow discharge

n = Number of emission devices tested

Power regression equation was used for analysis.

$$q = k\,H^x \qquad ....3.27$$

where,

q = Dependent variables (Discharge)

H = Independent variables (Head)

x = emitter exponent

k = constant of proportionality

The ratio of the squares due to regression to the total sum of squares corrected for the mean measures the ability of the regression line to explain variations in the dependent variable. The ratio is commonly denoted by R^2 and may be written in a number of ways.

R^2 = Sum of the squares due to regression/sum of the squares corrected for mean.

R^2 = Coefficient of determination and ranges from zero to one.

3.18 SUSTAINABILITY

Pressure treadle pump (PTP) can be used for irrigation as well as drinking water purpose. As our natural resources especially precious water is exhausted day by days, it is necessary to sustain the existing resources with the use of PTP. Physical and chemical properties of irrigation and drinking water are presented in Table 3.8 and 3.9, respectively.

Table 3.8 Physical and chemical properties of irrigation water

Dissolved Solid, ppm	PH	EC, µmho/cm	SAR	Na^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^-	CO_3^-	HCO_3^-
				meq/l						
<230	<7	<750	2.5	2.35	2.2	1.2	0.8	2.2	0.34	2.5

(Source: Michael, 1978)

Table 3.9 Physical and chemical properties of drinking water

Turbidity, TU	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Nitrate
	mg/l						
1-5	0.05	1.00	0.01	0.05	0.05	0.002	10.00

(Source: Spellman, 1998)

IV- RESULTS AND DISCUSSION

The study was conducted to find the technical feasibility of Low pressure low cost (LPLC) drip irrigation system. The results of experiments entitled “Low Pressure Low Cost (LPLC) Drip Irrigation System for Small Land Holders” conducted during the year 2008-09 are being presented in this chapter.

4.1 DESIGN EVALUATION OF LPLC DRIP IRRIGATION TREATMENTS

The system was designed based on climatologically data and constructed with locally available materials and components available at IDEI, Ahmedabad. Subplot area was 156.25 m^2, soil type was Silty-Clay, area to be wetted as a percentage of total area was taken as 70 %, crop spacing was 45 cm x 60 cm. Water source was at the center of field, spacing of dripper along the lateral was 0.45 m, spacing of lateral was 1.2 m. Hazen William constant for Linear Low Density Polyethylene (LLDPE) pipes were taken as 140, internal diameter of lateral was 20 mm, internal diameter of submain was 26 mm with pan evaporation 4.7 mm/day in each treatment. Treatment combinations T1, T2, T3 and T4 were broccoli grown on level ground with medi-emitters, tomato grown on 0.5 % up slope with medi-emitters, tomato grown on level ground with microtubes and broccoli grown on 0.5 % up slope with microtubes, respectively. A perusal of data in Table 4.1 indicated that average discharge of emitter at level field was more than 0.5 % up slope (T1>T2 and T3>T4) in case of medi-emitters and microtubes, respectively.

Table 4.1 Design evaluation of LPLC drip irrigation system operating at 6 m head

S.No.	Data	Treatments			
		T1	T2	T3	T4
1	Topography of field	level	0.5% up slope	level	0.5% up slope
2	Distribution uniformity, EU_f	94.65%	89.70%	95.79%	89.08%
3	Crop type	Broccoli	Tomato	Tomato	Broccoli
4	Crop factor, Kc	1.05	1.15	1.15	1.05
5	Type of dripper	Medi-emitters	Medi-emitters	Microtubes	Microtubes
6	Average discharge of emitter, l/h	2.29	2.11	1.05	0.86
7	Irrigation time, h	0.3	0.38	0.71	0.85
8	Head loss in lateral, cm	0.5	0.43	0.12	0.08
9	Head loss in submain, cm	14.04	11.94	3.3	2.3
10	Total head loss from lateral and submain, cm	14.54	12.37	3.42	2.38
11	% head loss from operating head 6 m	2.42	2.06	0.57	0.40

NB: 26 mm (ID=20 mm) and 32 mm (ID = 26 mm)
KB pipes were only available at IDE, Ahmedabad.

4.1.1 Performance Evaluation of KB Pressure Treadle Pump

Experiments were conducted with 26 m long, 1.25” (0.032 m) diameter polythylene pipe fitted at outlet of KB pressure treadle pump. The head-discharge relationship was measured for different heads in the range of 1- 6 m. The pump was operated by both male and female workers in the age range of 19 to 50 years and from 38 to 45 years having the weight in the range of 38 to 75 and 42 to 62 kg, respectively. The total head created by the pump was also measured by pressure gauge, fitted in a 200 l buffer tank.

Head-discharge relationship was determined by rising pipe from 1–6 m and measuring discharges by collecting outflow in a container of 16 liter and time was recorded with the help of stop watch having least count of one second.

4.1.1.1 Head-discharge relationship

Discharge capacity differs from sex to sex, body-weight, the depth of water table and head to be lifted. The discharge variation of KB pressure treadle pump was recorded for the pressure head 1-6 m. Single male person having age 32 years and weight 55.5 kg performed the discharge measurement at different heads. Data Table A- 4.1 and Fig. 4.1 revealed that maximum discharge at 1 m head was 3566 l/h and minimum discharge at 6 m head was 3028 l/h. Head-discharge relationship observed linear trend. The Fig. 4.1 shows discharge decreases with increasing head similar to other pumps (Michael, 1978).

Fig. 4.2 shows the variation in the discharge with weight and age of the male operator at 5 m head. It was observed that discharge was maximum (4595 l/h) for the worker of 28 years age and weight 75 kg, consequently decreases (2650 l/h) for worker of 50 years age and weight 38 kg. This result shows that discharge rate is more prominent to body weight of person rather than age.

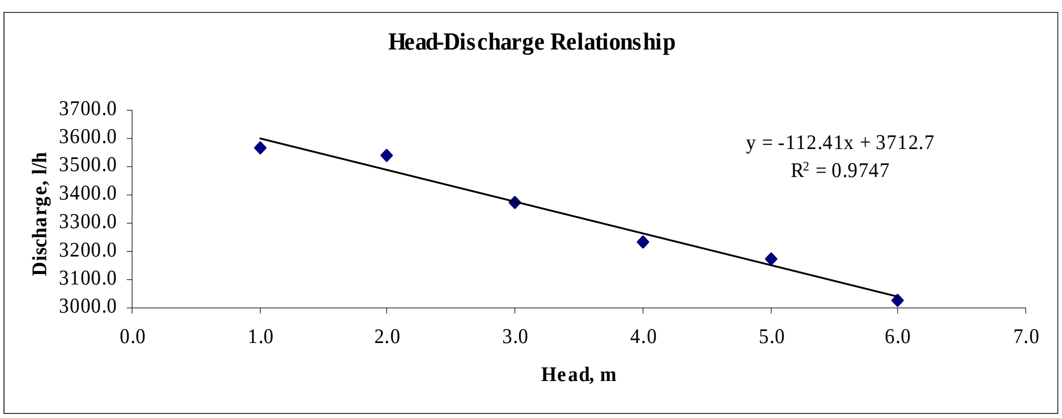


Fig. 4.1 Variation in discharge for different head (sex-male, weight-55.5 kg, age-32 year)

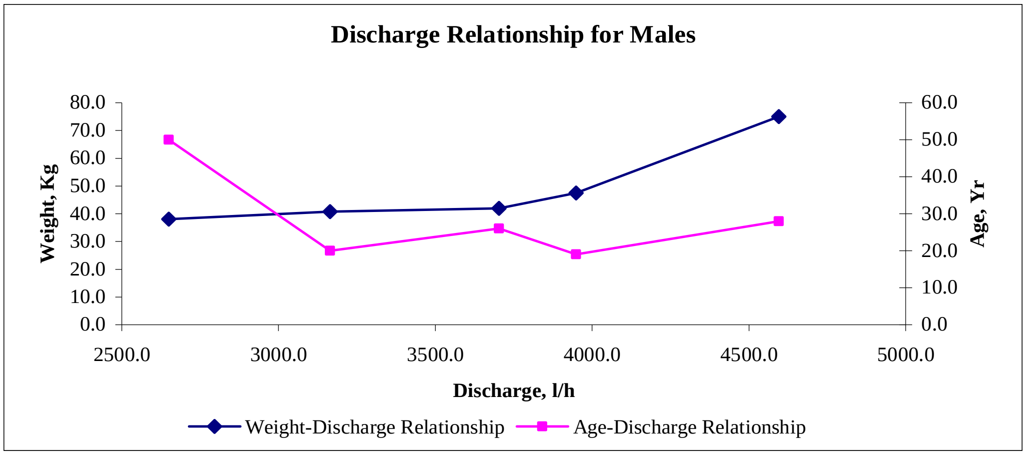


Fig. 4.2 Variation in discharge with weight and age for male operator for 5 m head

Similarly, it is clear from Fig. 4.3 that maximum rate of discharge (3250 l/h) was observed at 5 m for female having weight 61.2 kg, age 45 year and minimum (2757 l/h) for weight 41.9 kg and age of 35 years. Fig. 4.3 also shows that discharge increased with increasing weight and age.

Data (Table A-4.2 and Table A-4.3), Fig.(4.2 and 4.3), prevailed that male having weight of 47.5 kg was discharging 3948 l/h where as female having same weight was discharging only 2850 l/h.

Since the total lift of KB pump is 13 m, the farmers can use this pump for drip, sprinkler and supplemental irrigation from available source of water (ground water, pond and storage tank, etc). Performance of KB pressure treadle pump depends upon various factors viz age, sex, weight of person, head to be lifted, etc. Major factor was weight. Male can perform the KB pressure treadle pump operation more efficiently than female having same weight. Result revealed that discharge decreases with increasing head. Ergonomically designed KB pressure treadle pump was found to operate satisfactory, divisible and affordable by small land holders, where full body-weight of the operator is involved to operate the pump with easy operation.

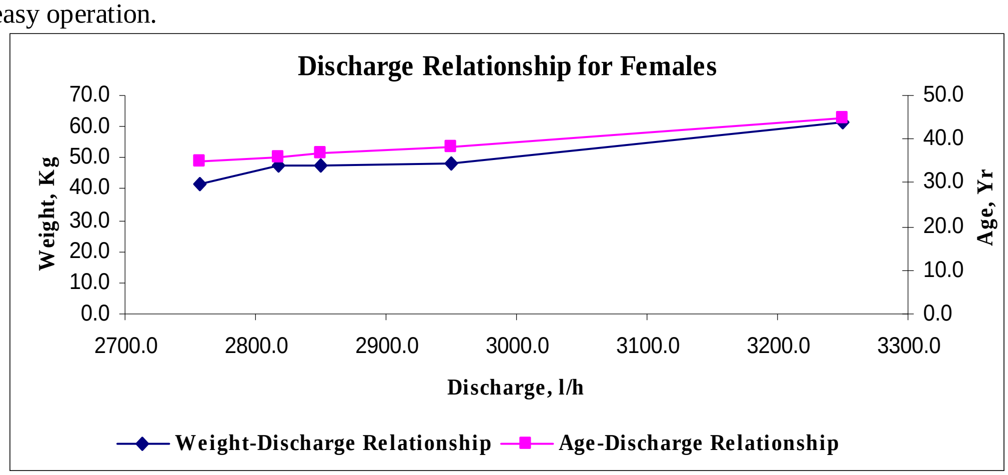


Fig. 4.3 Variation in discharge with weight and age for female operator for 5 m head

4.1.2 Average Discharge through Different Head of LPLC Drip Treatments

Average discharge under different heads was calculated for different treatments (T1 to T4). Four lateral lines among eleven lateral lines of the subplot were chosen for discharge measurement. Selected lateral lines again divided in four parts and middle location (emitters) of each part was used for discharge measurement. Each lateral line had both side emitters due to paired-row planting system. Both emitters at same locations were used for discharge measurement and averaged it for calculation. The sixteen data collected for particular head were used for different criteria evaluations as well as performance evaluation. Discharge from emitters was collected in plastic mug for five minute. Average discharges under 6 m head was 2.29, 2.11, 1.05 and 0.86 l/h for T1, T2, T3 and T4 treatments, respectively. Average discharges under different heads for different treatments are shown in Table A-4.4 to Table A-4.15.

A perusal of data in Table A-4.4 to A-4.15 indicated that average discharge rate of medi-emitters (3 mm) is more than microtubes (0.9 mm) under same head due to large internal diameter of medi-emitter. At the same time discharge variation among sixteen location is more as compared to microtubes. Pluging is the problems with medi-emitter. It was required weekly cleaning of emitters where as microtubes is less prone to pluging. Due to white colors and enlarge section of medi-emitters, algae formation was observed.

It was observed that as head increased by 1 m, average discharge increased by 37.91%, 13.15 %, 9.25 % and 6.22 % in case of T1, T2, T3 and T4 treatments respectively. Similar trends were reported by Magar *et al*. (1985) and Firake *et al*. (1992); they observed that 75 % increase in pressure head increased the discharge, through microtubes, by 60 %. Discharge variation was more in case of medi-emitters compared to microtubes due to large diameter.

4.1.3 Head-Discharge Relationship

A simple way to show head-discharge relationship for drip irrigation is based on lateral line hydraulics. The observation of average discharge as affected by operating head, length of lateral, length and type of microtubes and medi-emitters are presented on Table A-4.16 to A-4.19 and graphically in Fig. 4.4 for different treatments.

Fig. 4.4 shows that discharge increased with increasing head in all treatments but rate of increase depends upon size of emitters and slope of the fields. At 6 m head for medi-emitters, T1 (2.29 l/h) (level ground) had more discharge as compared to T2 (2.11 l/h) (0.5 % up slope). Similar trend was observed with microtubes i.e. T3 (1.05 l/h) (level ground) had greater discharge rate in comparison to T4 (0.86 l/h) (0.5 % up slope). The frictional loss depends upon velocity of flow, diameter of emitting devices and slope of the ground. Larger diameters have less velocity of flow in comparison to smaller diameters, hence, losses were minimum, at the same time upward slope reduces energy of flow.

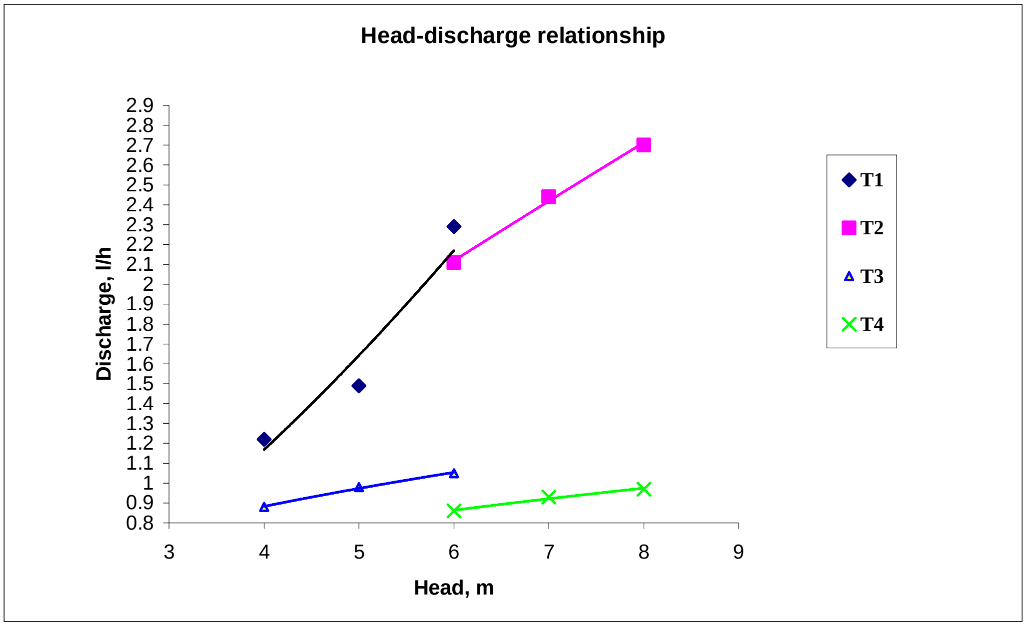


Fig. 4.4 Average discharge under different treatments with different head

Measured emitters' flow rates of non-compensating emitters varied under different pressure heads, as indicated by Wu and Gitlin (1973), Karmeli and Keller (1974), Bralts *et al.* (1981) and Ozekici and Sneed (1995). Gilead (1985) reported that low-head drip irrigation systems operate under pressure of 0.5-2 m compared to the 10-15 m water head needed for standard drip irrigation.

4.1.4 Emitter Exponent of LPLC Drip Treatments

Over a wide range of discharge of emitters, Wu and Gitlin (1973) gave an equation as follows

$$q = kH^{x} \qquad \text{.......4.1}$$

Where,

q = emitter discharge, l/h

k = constant of proportionality

H = working pressure head, m

x = emitter exponent, which characterizes the flow regime and it varies 0.1 to 1 depending on emission device.

The most common method of determining the value of k and x is to perform the linear regression on the logarithms of low and operating pressure i.e.

$$\ln(q) = x\ln(H) + \ln(k) \qquad \text{.......4.2}$$

Which is of the linear form similar to equation of straight line as

$$y = xz + b \qquad \text{.......4.3}$$

Where,

$y = \ln (q)$

$z = \ln (H)$

$b = \ln (k)$, i.e. $k = e^b$

A linear regression of ln (H) on ln (q) can produce the values for emitter exponent (x) and b.

A perusal of data in Table 4.2 and graphically in Fig. 4.4 showed that emitter exponent was 1.53, 0.86, 0.44 and 0.42 in treatments T1, T2, T3 and T4, respectively. The lower the value of x indicates that less discharge will be affected by pressure variations. For laminar flow, the value of x should be 1. For long flow path emitter the value of x ranges between 0.5 to 1.

For turbulent flow, value of x should be 0.5. Non-pressure compensating orifice and nozzle emitters are always fully turbulent, having x value as 0.5, while the fully pressure compensating orifice and nozzle are having value of x = 0.

From Table 4.2 (A-4.20) and graphically in Fig. 4.4 shows that in treatments (medi-emitters) T1 (level ground) is fully laminar flow ($x > 1.0$) where as T2 (0.5 % up slope) is mostly laminar flow ($x > 0.5$).Treatment (microtubes) T3 (level ground) and T4 (0.5 % up slope) is fully turbulent ($x < 0.5$). It is clear that flow through microtubes was turbulent due to smaller diameters where as flow through medi-emitters was laminar due to larger diameters.

From Fig. 4.5 it is clear that field emission uniformity decreased with increasing emitter exponent. The discharge exponent is an expression of specific emitter type and flow regime and may be used to characterize hydraulic performance of any given emitter (Karmeli, 1977; Bralts and Wu, 1979; Madramootoo *et al.*, 1988 and Correia, 1990) presented value of x for several emitter types, under different flow regimes and reported similar results.

Table 4.2 Development of fitted equation for different treatments

S.No.	Treatment	k	x	Fitted Equation	R^2
1	T1	0.1402	1.5288	$q = 0.1402H^{1.53}$	0.9310
2	T2	0.4544	0.8593	$q = 0.4544H^{0.86}$	0.9962
3	T3	0.4814	0.4373	$q = 0.4814H^{0.44}$	0.9954
4	T4	0.4064	0.4207	$q = 0.4064H^{0.42}$	0.9831

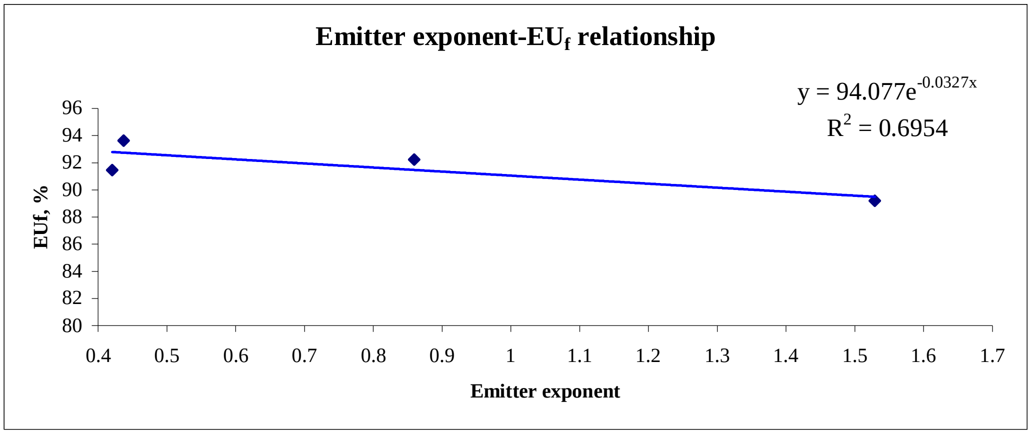


Fig. 4.5 Relation between emitter exponent and field emission uniformity

4.1.5 Discharge Variation

A simple way to show emitter discharge variation or pressure variation for drip irrigation is based on lateral line hydraulics. The observation of average discharge as affected by operating head, length of lateral, length and type of microtubes and medi-emitters are presented in Table A-4.21 and graphically in Fig. 4.6 for different treatments.

Fig. 4.6 shows that as the pressure heads are increased the discharge variation of the system decreased. In general, discharge variation was observed 10 % for head variation 20 %. Again variations among laterals depend upon operating heads. As operating head increased, discharge variations among the laterals decreased. Maximum variation was observed in last lateral and variations decreased gradually to first laterals.

For treatments T1 (level ground) at 6 m operating head, average Qvar was 16.6 % where as laterals discharge variations were 12.11, 12.92, 20.36 and 21.02 % respectively for selected 1st, 2nd, 3rd and 4th laterals. For treatments T2 (0.5 % slope) at 6 m operating head, average Qvar was 20.74 % where as laterals discharge variations were 12.27, 14.29, 21.47 and 34.94 % % respectively for selected 1st, 2nd, 3rd and 4th laterals. For treatments T3 (level ground) at 6 m operating head, average Qvar was 8.58 % where as laterals discharge variations were 6.37, 7.61, 8.52 and 11.83 % respectively for selected 1st, 2nd, 3rd and 4th laterals. For treatments T4 (0.5 % slope) at 6 m operating head, average Qvar was 17.02 % where as laterals discharge variations were 12.57, 14.20, 19.18 and 22.14 % respectively for selected 1st, 2nd, 3rd and 4th laterals. Discharge variation also depends upon slope of field and diameter of emitting device, as diameter and up slope of ground increases discharge variation also increases.

Wu and Yue (1993) reported that discharge variation along the lateral line can be determined by a linear combination of line slope and energy slope.

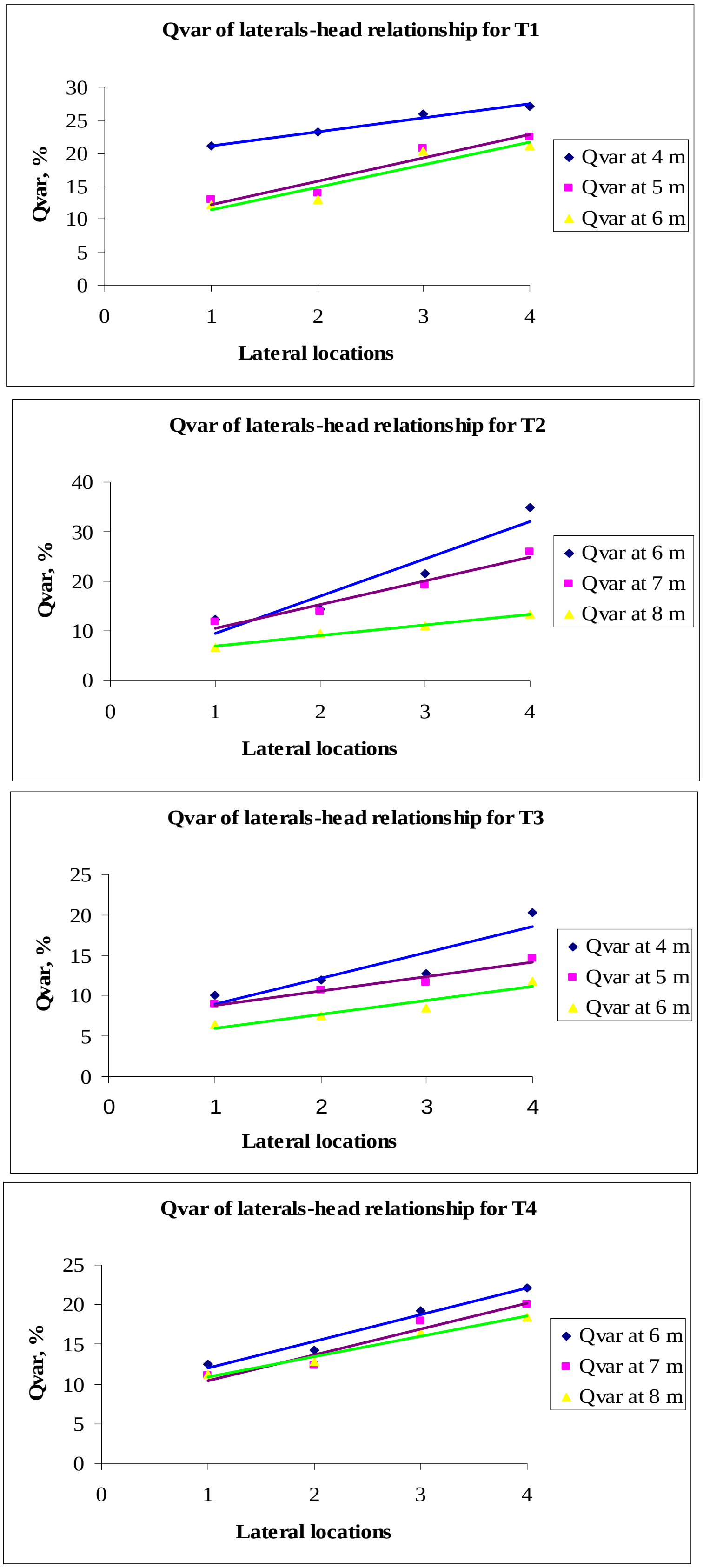


Fig. 4.6 Discharge variations of laterals under different head

4.1.6 Head Variation

The hydraulic variation of emitter flow is caused by the friction drop in the drip system and energy change due to field slopes. A simple direct calculation of all emitter flows was developed using energy gradient line approach (Wu and Gitlin, 1974). This approach was modified and verified by a step -by-step calculation (Wu, 1992).

From Table 4.3 and graphically in Fig. 4.7 it can be revealed that pressure variations decreased with increment in operating head in all treatments. It also depends upon the slope of the fields and diameter of the emitting devices. Head variation in submain under 6 m operating head for treatments T1, T2, T3 and T4 was 33.93, 42.00, 16.36 and 33.33 % respectively. Pressure head variation was minimum in case of treatments T3 (level ground with microtubes) where as maximum variations in T2 (0.5 % up slope with medi-emitters). It is clear that up slope and large diameter of emitting device have high head variations.

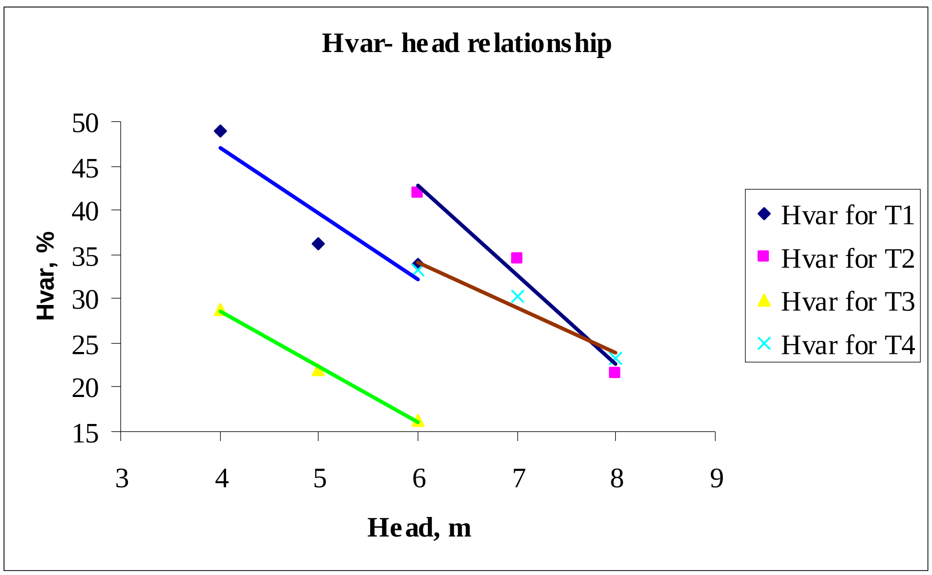


Fig. 4.7 Pressure variations of submain under different head

The maximum pressure head difference usually occurs between the pressure regulator at the inlet of each manifold and the farthest and/or highest emitter. Kermeli and Peri, 1972 also found the most economic division of the allowable head loss is approximately 55 per cent in the lateral and 45 per cent in the manifold.

4.1.7 Head Loss

Head loss depends upon length, diameter, number of outlets, and velocity of flow and surface roughness of pipe. Hazen William formula was used for head loss calculation. Details of design evaluation of the system are presented in Table 4.1. Head loss in submain for treatments T1, T2, T3 and T4 are 14.04, 11.94, 3.3 and 2.3 cm respectively. It was found that T1 (medi-emitters with level ground) had more head loss at operating head of 6 m compare to T2 (medi-emitters with 0.5 % up slope) due to high discharging rate of T1 (2.29 l/h) compared to T2 (2.11 l/h). Similarly T3 (microtubes with level ground) had more head loss at 6 m operating head compared to T4 (microtubes with 0.5 % up slope) due to high discharging rate of T3 (1.05 l/h) compared to T4 (0.86 l/h).It is evident from these data that under same conditions and same head, medi-emitters have high discharge rate compare to microtubes, consequently high head loss was occurred in submain and laterals.

Head loss in lateral for treatments T1, T2, T3 and T4 are 0.5, 0.43, 0.12 and 0.08 cm and total head loss was 14.54, 12.37, 3.42 and 2.38 respectively. Percentage head loss from operating head 6 m was 2.42, 2.06, 0.57 and 0.40 % for treatments T1, T2, T3 and T4 respectively.

4.1.8 Empirical Equations

A statistical regression technique was used to analyze the experimental data to obtain empirical equations for microtubes and medi-emitters. Since length of lateral (12.5 m) and length of microtubes and medi-emitters (0.45 m) was fixed in the experimentation according to subplot size, both parameters are constant. Thus equations of the type given below were developed for 12.5 m length of lateral with 0.45 m length of emitters.

$$q = k\,H^{x} \qquad \ldots.4.4$$

Where,

q	=	average discharge through microtube, l/h
H	=	Head of operation in meters

Where x is exponential constants and k is coefficient constant.

Empirical equations developed are presented in Table 4.2 for different treatments.

4.2 IRRIGATION EFFICIENCY

Hydraulic design affects both system uniformity and spatial uniformity of a micro-irrigation system. The hydraulic performance parameters used to evaluate drip systems. Differences in flow rates are reflected in discharge coefficient of variation. The hydraulic variation of emitter flow is caused by the friction drop in the micro-irrigation system and the energy change due to field slopes. Commonly used emitter flow variations of 10-20% are equivalent to a uniformity coefficient of about 98-95%. The hydraulic design criterion can be relaxed to 30% of emitter flow variation, which can still achieve less than 20% in coefficient of variation, or, over 80% of uniformity coefficient in spatial uniformity of micro-irrigation system (Wu, 1997).

The first three uniformity parameters, CUC, C_v and UCS are statistical uniformity terms, which were calculated by four lateral lines, dividing the lateral lines in four parts and from middle emitter of four locations. C_v is used to show the system uniformity and CUC for the spatial uniformity and q_{var}, is used for hydraulic design only. Performance parameters of LPLC drip irrigation systems are presented in Table 4.3 and calculation Table A-4.22 to A-4.33.

Table 4.3 Performance parameters of LPLC drip irrigation system

Treatments	Head m	q_{var} %	h_{var} %	EU_f %	EUa %	Ea %	Cv	UCS %	CUC %	EUd %
T1	4	24.29	48.84	83.13	80.98	70.78	0.1385	86.15	88.63	58.33
	5	17.51	36.17	89.78	84.33	76.38	0.1363	86.37	89.11	63.16
	6	16.60	33.93	94.65	84.74	81.08	0.1218	87.82	90.12	68.54
Average	5	19.47	39.65	89.19	83.35	76.08	0.1322	86.78	89.29	63.35
T2	6	20.74	42.00	89.70	82.42	76.73	0.1270	87.30	89.73	64.36
	7	17.73	34.48	93.29	82.94	77.33	0.1249	87.51	90.07	65.06
	8	10.11	21.67	93.68	88.07	79.94	0.1074	89.26	90.77	69.04
Average	7	16.19	32.72	92.22	84.48	78.00	0.1198	88.02	90.19	66.15
T3	4	13.76	28.89	91.35	87.73	80.89	0.1149	88.51	91.75	69.09
	5	11.48	22.00	93.77	88.29	82.05	0.0945	90.55	92.13	72.21
	6	8.58	16.36	95.79	90.32	85.08	0.0918	90.82	92.59	75.17
Average	5	11.27	22.42	93.64	88.78	82.67	0.1004	89.96	92.16	72.15
T4	6	17.02	33.33	89.08	82.30	70.99	0.1675	83.25	85.69	55.89
	7	15.32	30.36	90.63	86.89	80.13	0.1140	88.60	91.44	68.53
	8	11.88	23.33	94.68	87.61	82.04	0.0988	90.12	92.44	71.74
Average	7	14.74	29.01	91.46	85.60	77.72	0.1268	87.32	89.86	65.39

4.2.1 Emission Uniformity

Emission uniformity is a major parameter for evaluation of performance of microirrigation systems. The emission uniformity was determined before plantation so as to see whether the emitting devices are applying the water uniformly or otherwise.

The average and minimum discharge of emitting device (microtubes and medi-emitters) for the treatments was observed at 4-8 m head and their average emission uniformity values are given in Table 4.3 and graphically presented Fig. 4.8 and 4.9. It can be seen from Table 4.3 and Fig. 4.8 and 4.9 that the field emission uniformity and absolute uniformity values (%) at 6 m operating head for treatments T1 (94.65 and 84.74), T2 (89.70 and 82.42), T3 (95.79 and 90.32) and T4 (89.08 and 82.30) was observed. The reduction in the uniformity of emitting devices was may be due to the head losses in the systems. From the Table 4.4 it can be revealed that the minimum emission uniformity was observed in treatments T4 and maximum in T3. This may be due to more head loss due to 0.5 % up slope in treatments T4 while treatments T3 had level ground with microtubes.

Table 4.3 shows that the designed drip systems are operated excellently as the values of EU_f were nearly equal or higher than the design criteria of 90 per cent in each case (Keller and Karmali, 1974) where as EU_a rated as good (>80 to 90 %) in each treatment. Singh *et al.* (1989) obtained the maximum emission uniformity value of 88.5 % under operating pressure 0.5 to 1.5 kg/cm^2.

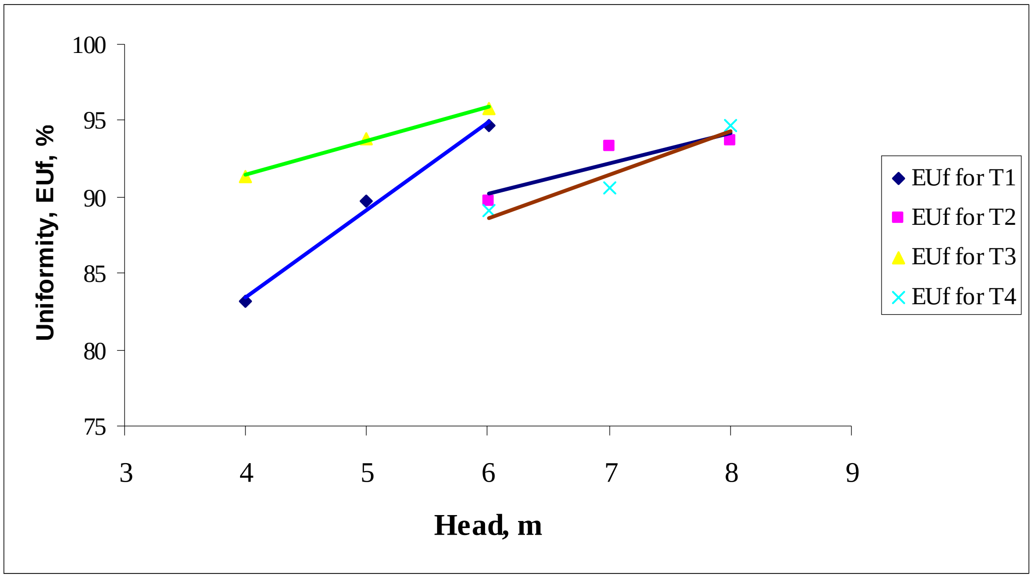


Fig. 4.8 Field emission uniformity (EUf) under different head

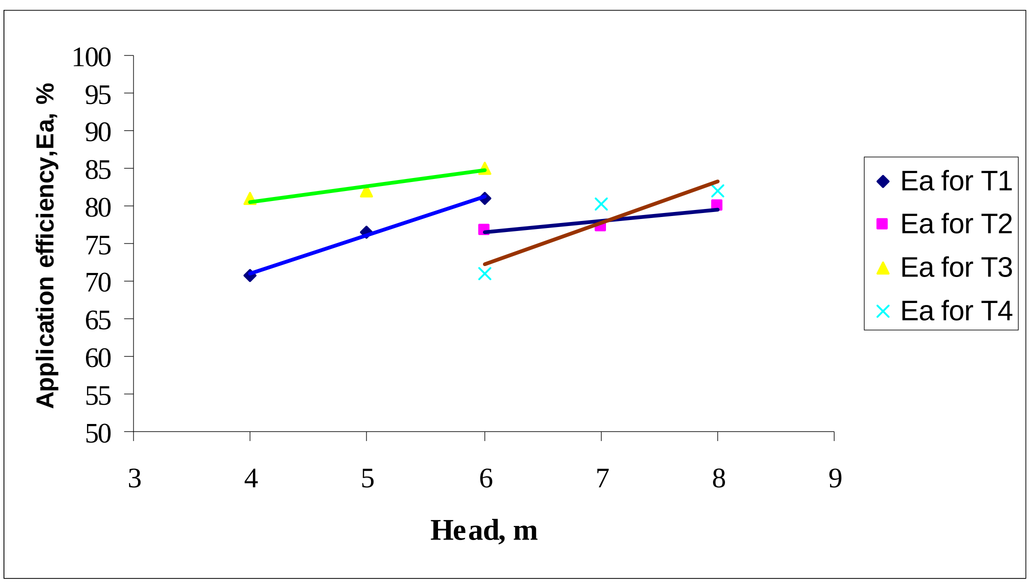


Fig. 4.9 Absolute emission uniformity (EUa) under different head

4.2.1.1 Design emission uniformity and application efficiency

Design emission uniformity is used for system design. The application efficiency is defined as the ratio of water required in the root zone to the total amount of water applied.

Perusal of data in Table 4.3 and graphically in Fig. 4.10 and 4.11 shows that the design emission uniformity and application efficiency values (%) at 6 m operating head for treatments T1 (68.54 and 81.08), T2 (64.35 and 76.73), T3 (95.79 and 85.08) and T4 (55.89 and 70.99) were observed. The reduction in the uniformity of emitting devices is due to the head losses in the systems. From the Table 4.3 it can be revealed that the minimum design emission uniformity was observed in treatments T4 and maximum in T3. This may be due to more head loss due to 0.5 % up slope in treatments T4 while treatments T3 had level ground with microtubes.

Based on ASAE standards criteria in Table 3.6, T1, T2 and T4 are not acceptable, since calculated EUd should exceed 85 % for level ground and 80 % for steep slope while T3 meet the criteria.

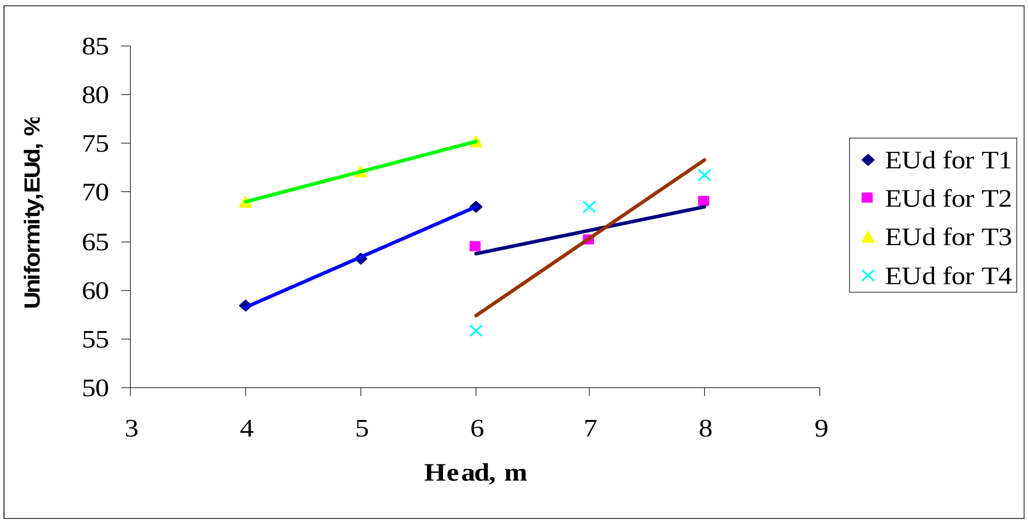


Fig. 4.10 Design uniformity (EUd) under different head

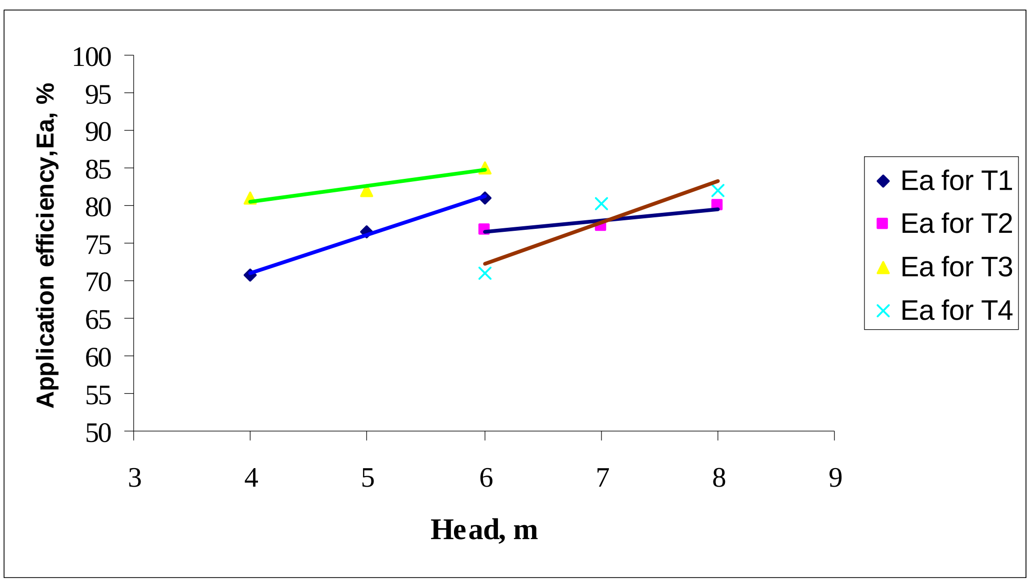


Fig. 4.11 Application efficiency (Ea) under different head

4.2.2 Statistical Uniformity

Uniformity expresses the nonuniformity in distribution of water from the emitting devices. The micro-irrigation system is designed on the basis of system uniformity and spatial uniformity. System uniformity is used for low density planting situation such as trees and for localized irrigation, and spatial uniformity is used for high density planting situation such as vegetables where the whole area is irrigated.

4.2.2.1 System uniformity (Cv)

Coefficient of variation (Cv) is highly correlated to other system uniformity. Cv is used to show the system uniformity. Uniformity is inverse of variation and is popularly used as the key criteria of application performance.

Perusal of data in Table 4.3 and graphically in Fig. 4.12 shows that the Cv (%) values at 6 m operating head for treatments T1 (0.1218), T2 (0.1270), T3 (0.0918) and T4 (0.1675) were observed. The reduction in the uniformity of emitting devices is due to the head losses in the systems. From the Table 4.3 it can be revealed that the minimum Cv was observed in treatments T3 and maximum in T4. This may be due to more head loss due to 0.5 % up slope in treatments T4 while treatments T3 had level ground with microtubes.

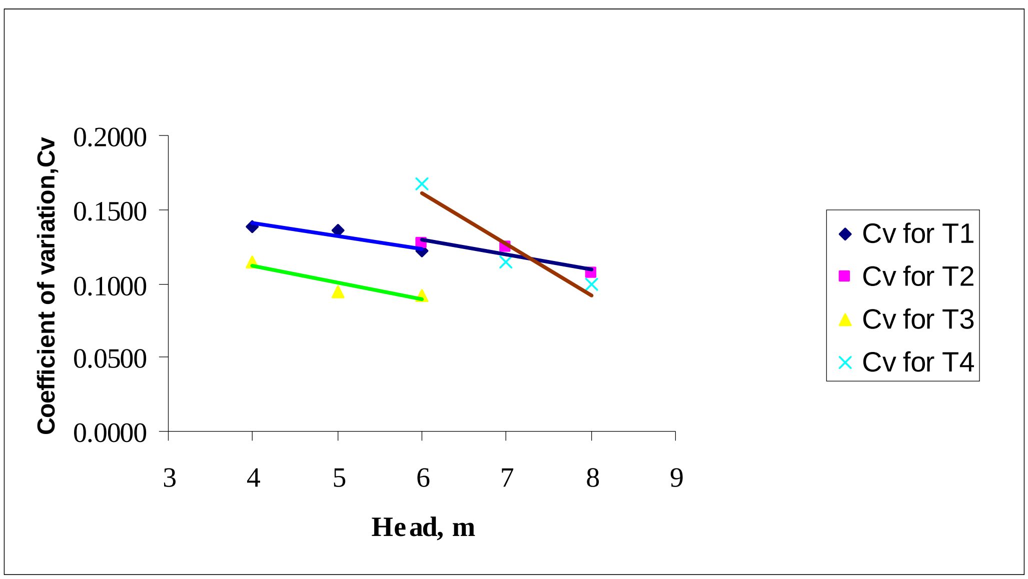


Fig. 4.12 Coefficient of variation (Cv) under different head

Based on ASAE standards criteria in Table 3.5, T1, T2 and T4 are classified as poor, since calculated Cv is >0.11 while T3 classified as marginal (0.07-0.11).

4.2.2.2 System uniformity (UCS)

An examination of data in Table 4.3 and graphically in Fig. 4.13 shows that the UCS (%) values at 6 m operating head for treatments T1 (87.82), T2 (87.30), T3 (90.82) and T4

(83.25) were observed. The reduction in the uniformity of emitting devices is due to the head losses in the systems. From the Table 4.3 it can be revealed that the maximum UCS was observed in treatments T3 and minimum in T4. This may be due to more head loss due to 0.5 % up slope in treatments T4 while treatments T3 had level ground with microtubes.

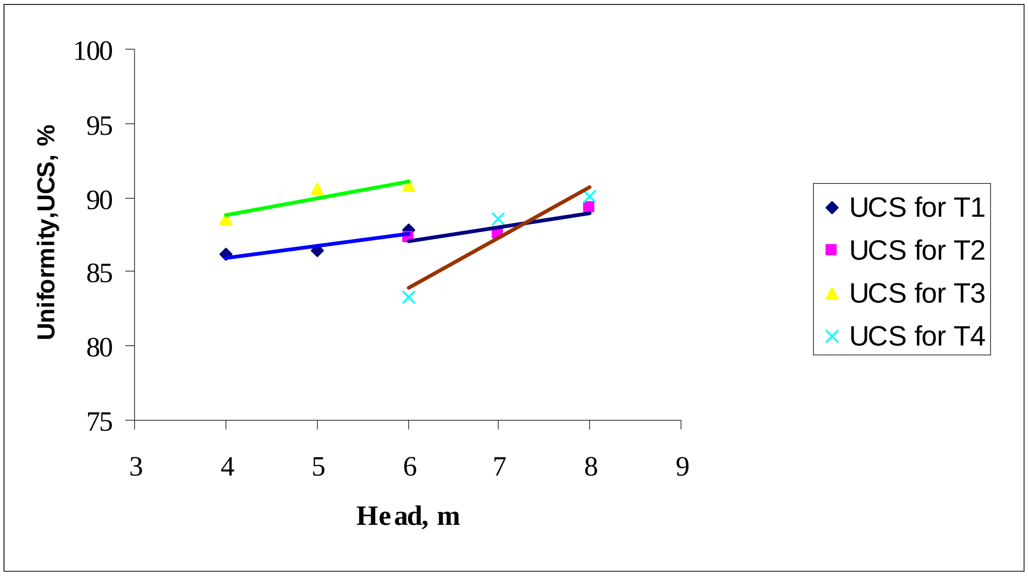


Fig. 4.13 System uniformity (UCS) under different head

Frausto (2001) reported that in all customized microtube system, drum kit and bucket system were having UCS values 89.1, 87.7 and 91.3 % respectively. Thus the results obtained are in agreement with work done on UCS by other scientists.

4.2.2.3 Spatial uniformity

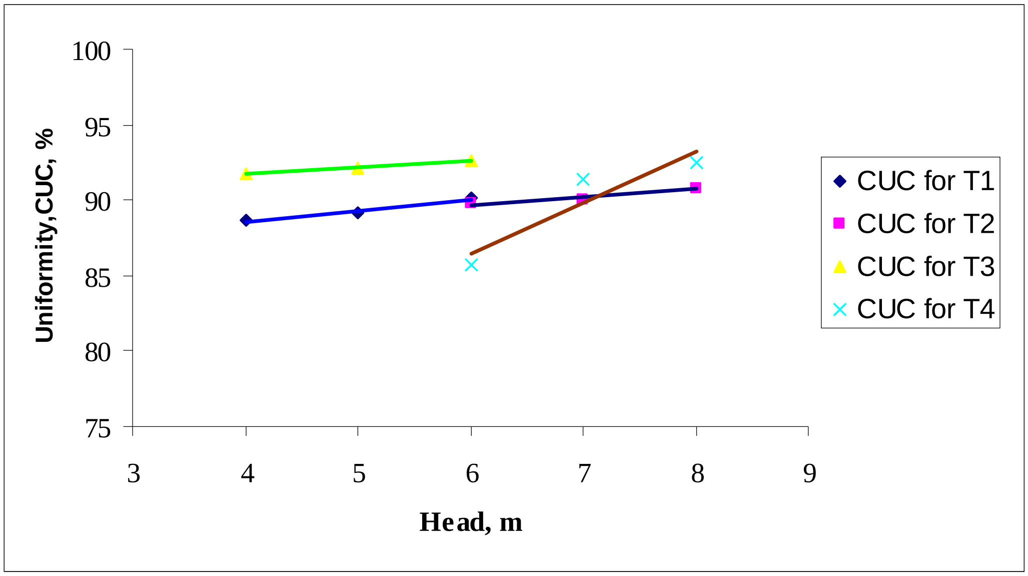


Fig. 4.14 Spatial uniformity (CUC) under different head

From the Table 4.3 and graphically in Fig. 4.14 shows that the CUC (%) values at 6 m operating head for treatments T1 (90.12), T2 (89.73), T3 (92.59) and T4 (85.69) were observed. The reduction in the uniformity of emitting devices is due to the head losses in the systems. From the Table 4.3 it can be revealed that the maximum CUC was observed in treatments T3 and minimum in T4. This may be due to more head loss due to 0.5 % up slope in treatments T4 while treatments T3 had level ground with microtubes.

Based on ASAE standards criteria in Table 3.7, T2 and T4 are classified as good, since calculated CUC (>85 %) while T1 and T3 classified as nearly excellent (>90 %). Mofoke *et al*. (2004) reported that in continuous-flow drip irrigation system, CUC value was 92.3 %. Thus the results obtained are in agreement with work done on CUC by other scientists.

4.3 IRRIGATION SCHEDULING AND CROP WATER REQUIREMENT

4.3.1 Irrigation Scheduling

The details about the dates of irrigation, quantity of irrigation water applied in each treatment, time of application and rainfall received during the crop period along with daily pan evaporation are given in Table A-4.35 to A-4.38. Data on Table A-4.34 shows weekly normal of pan evaporation since 1971-2006 and graphically shown in Fig. 4.15.

From Table A-4.35 to A-4.38 it can be seen that quantity of irrigation water applied depends upon crop coefficient (K_C), pan coefficient (K_P), daily pan evaporation, per cent wetted area, crop area and uniformity of system. Application time depends upon crop water requirement and discharge rate of emitters. Daily application time under 6 m operating head was in the range of 0.14 h (2.11l/h) to 0.85 h (0.86 l/h). Lower application time (0.14 h) applied during initial crop phase as well as low temperature with high discharge rate emitters (medi-emitters) when crop water requirement was less where as application time (0.85 h) was applied during crop development phase with high temperature and low discharge emitters (microtubes).

Data from Table A-4.35 to A-4.38 revealed that total depth of water applied through out the growing season were 174.25, 170.19, 159.44 and 184.04 mm in treatments T1,T2,T3 and T4 respectively. Out of 61 mm rainfall received during crop growing period only 26.60 mm was found to be effective. Effective rainfall was determined using dependable rain methodology developed by FAO, 1992. Estimating dependable rainfall, the combined effect of dependable rainfall (80 % probability of exceedance) and estimated losses due to runoff and percolation were considered. Following formula was used for calculation of effective rainfall

$$P_{eff} = 0.6\,p_{tot} - 10 \; for \quad p_{tot} \; < \; 70 \; mm \qquad ....4.5$$

Where,

p_{eff} = monthly effective rainfall, mm

P_{tot} = monthly total rainfall, mm

Calculated monthly effective rainfall proportionate in days based on proportion of rainfall received (2 days rainfall received in October).

A perusal of data in Table 4.4 indicated that as the ground water contribution was nil (GWT › 10 m) the seasonal water requirements were found to be 200.85, 196.79, 186.04 and 210.64 mm for treatments T1, T2, T3 and T4 respectively. The difference in seasonal crop water requirements (T1 and T4) and (T3 and T2) was due to nonuniform water application in subplots (level ground and 0.5 % up slope) due to slop variation and effect of emission device. From Table A-4.35 to A-4.38 it is clear that treatments T1 saved the water to the extent of 4.65 per cent over T4 and T3 to the extent 5.46 per cent over T2.

Goal and Rivera (1985) reported that irrigation in vegetable crops should be initiated when soil water tension increased to 45 cbars and terminated when the soil moisture tension dropped to 15 cbar. Magar *et al.* (1985) conducted studies during post-monsoon season and applied 29.9 cm of water in vegetables under traditional method where as 13.32 cm under drip irrigation. The seasonal water requirement of tomato reported by (Agrawal *et al*., 2005) was 27.74 cm for drip treatments for Udaipur region where as (Bhandarkar *et al*., 2005) reported 38.00 cm for Bhopal region.

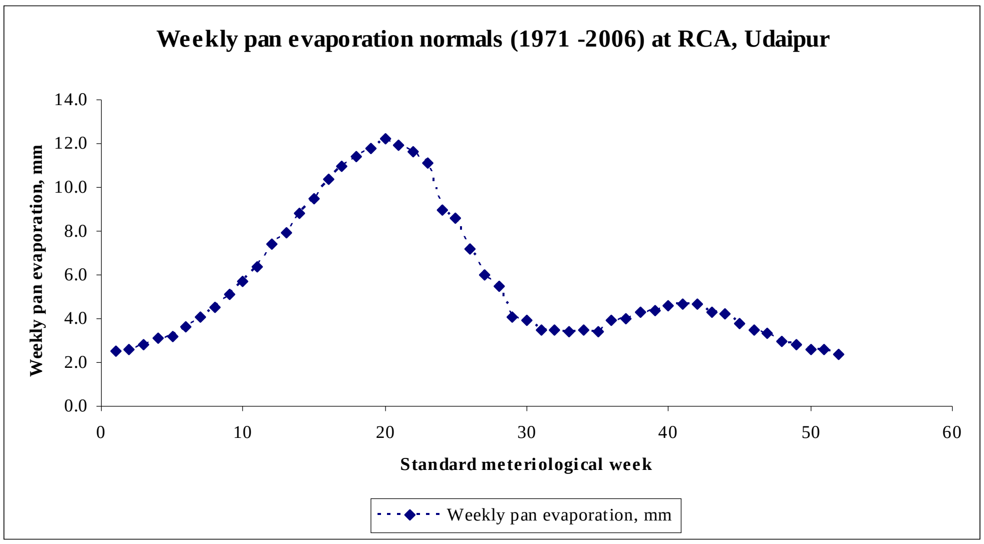


Fig. 4.15 Weekly pan evaporation normal based on standard meteorological week

4.3.2 Crop Water Requirements

In all treatments the seasonal consumptive use was calculated from the total net irrigation given and total effective rainfall received in the crop period. Consumptive use of September was calculated based on standard formula (Mane *et al*., 2006). A perusal of data in Table 4.4 and A-4.35 to A-4.38 indicated that as the ground water contribution was nil (GWT › 10 m) and seasonal consumptive use was found to be 200.85, 196.79, 186.04 and 210.64 mm for treatments T1, T2, T3 and T4 respectively. The difference in seasonal consumptive use (T1 and T4) and (T3 and T2) was due to non uniform water application in subplots (level ground and 0.5 % up slope).

Table 4.4 Seasonal water requirement and consumptive use

Treatments	Total rainfall received during crop period, mm	Seasonal water requirement, mm			Consumptive use (CU) mm
		Irrigation water applied, mm	Effective rainfall, mm	Total mm	
T1	61.00	174.25	26.00	200.85	200.85
T2	61.00	170.19	26.00	196.79	196.79
T3	61.00	159.44	26.00	186.04	186.04
T4	61.00	184.04	26.00	210.64	210.64

4.4 EFFECT OF DIFFERENT PARAMETERS AS INFLUENCED BY LPLC DRIP IRRIGATION SYSTEM

Vegetative growth parameters including four biometric parameters, above ground biomass (AG biomass), fruit mass (FM), crop residue (CR), and root mass (RM) were measured at the time of harvest. The fresh and dry weight of each aforementioned biometric parameters were also measured.

Plate No. 4.1 LPLC drip with microtubes

Plate No. 4.2 LPLC drip with medi-emitters

The performance of four treatments were assessed by vegetative growth parameters: crop residue (all leaves + steam but without fruit mass), fruit mass, aboveground biomass and root mass. However, farmers are most concerned with fruit mass produced as it reflects food production and /or cash income. Growth of tomato and broccoli as influenced by LPLC drip with medi-emitters and LPLC drip with micrtubes are shown in Plate No. 4.1 and 4.2. The details of vegetative growth parameters and biometric parameters are presented below in subheadings

4.4.1 Soil Moisture Depletion

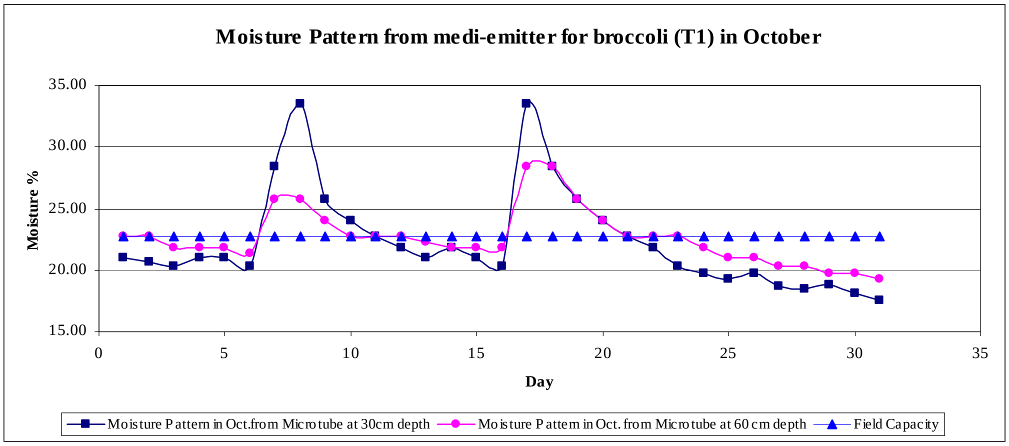
The daily soil moisture before irrigation was observed by AIC tensiometer installed in 30 and 60 cm depth of soil profile in each subplot and reading of tensiometer in all treatments are presented in Table A-4.39 to A-4.42. Soil moisture of September was not recorded because of plant was in nursery. Gravimetric method was used for calibration of tensiometer. Soil-water retention curve was prepared from different soil samples having different tensiometer reading. 10 cbar represents the field capacity of soil. Fitted equation is given below

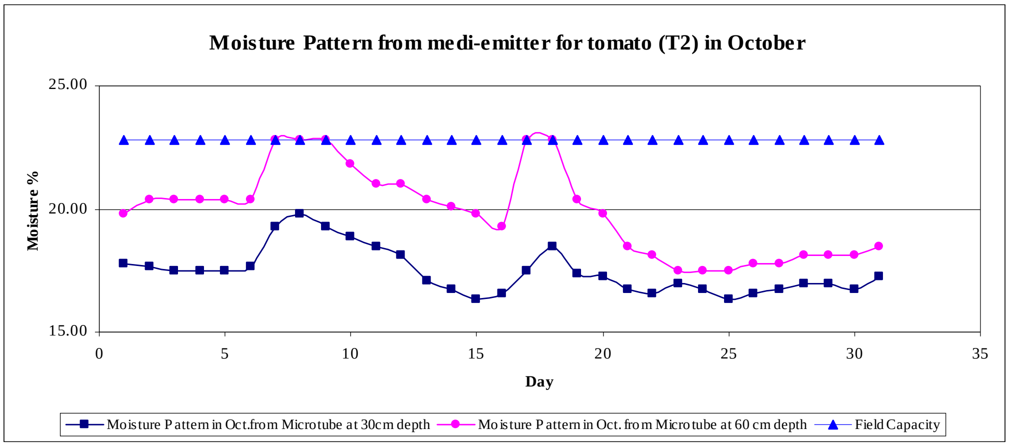
$$\% \quad Moisture \quad Content \quad = \quad 39.57(cbar)^{-0.2398} \qquad ....4.6$$

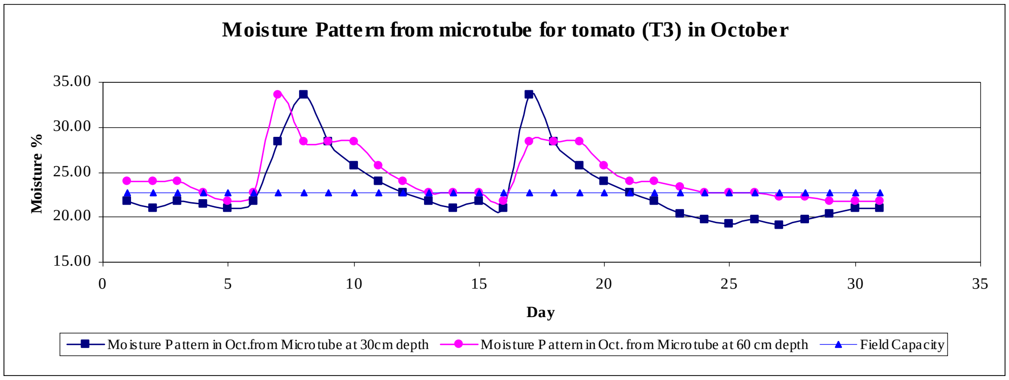
Soil water content at field capacity was 22.78%. Daily use drip irrigation maintained soil moisture near field capacity in 30 and 60 cm depth of soil profile.

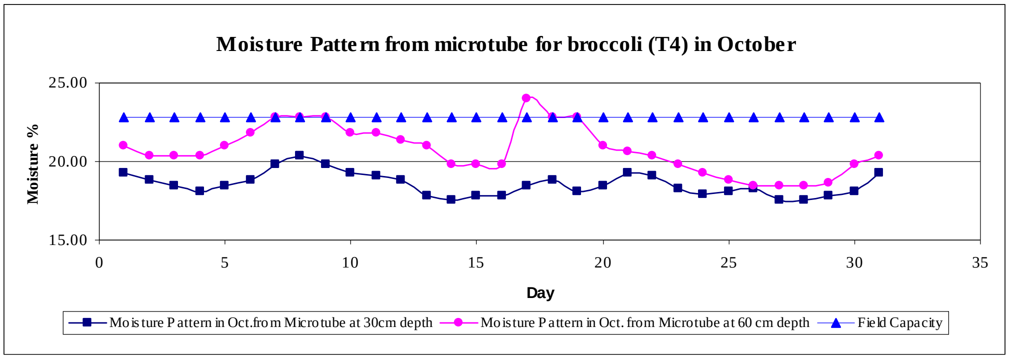
Periodically monitored soil moisture data are presented in Table A-4.43 to A-4.50 and shown graphically in Fig 4.16 to 4.19 for different treatments. It is evident from Table A-4.43 to A-4.50 and Fig 4.16 to 4.19 that the soil moisture was always closer to field capacity throughout the period and the irrigation was scheduled daily. The moisture content observed at 30 and 60 cm depth of soil profile is in the range of 16.44 to 28.38 and 18.12 to 33.51 per cent over the entire crop period respectively. In general 20 per cent soil moisture content was observed in both depths out of 22.78 per cent (FC). In case of medi-emitters, moisture content was low. This might be due to its high discharge rate and non uniformity (0.5 % up slope) which caused deep percolation and evaporation losses. In case of microtubes, moisture content was high. This is due to its low rate of application which minimises the deep percolation and evaporation losses. Soil moisture content in 60 cm depth was more than 30 cm depth of soil profile though out the crop growing period. This might be due to less evaporation from the inner depth of soil profile. It is also observed that moisture content during rainfall (7 and 17, October) was above the field capacity unless other wise it is near or below the field capacity through out the crop growing period at 30 and 60 cm depth of soil profile in all treatments.

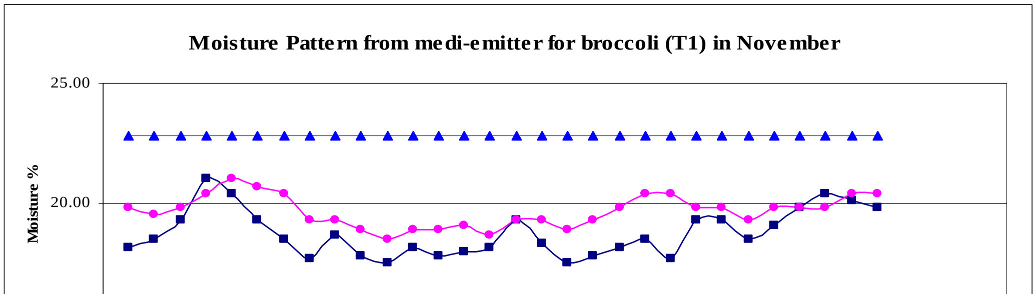
It can be seen from Table A-4.43 to A-4.50 that the soil moisture depletion over field capacity (FC) ranges from -47.10 to 33.51 % at 30 and 60 cm depth. The negative and positive sign indicate that soil moisture was above the field capacity especially when rainfall occurred and below the field capacity due to consumptive use of water by the plant during that day respectively. The recorded soil moisture depletion was more in case of T4 (0.5 % up slope) compare to T1 (level ground) in case of broccoli. Similar trend was observed for tomato where T2 (0.5 % up slope) had more soil moisture depletion compared to T3 (level ground). This trend was observed due to uniformity of application (T1> T4 and T3> T2). It was also observed that soil moisture fluctuation in 30 cm depth was more than 60 cm depth of soil and in both cases soil moisture depletion decreased after application of water. In 30 cm depth of soil profile regain or depletion of moisture content was faster where as in 60 cm depth of soil profile, it was slow and gradual.

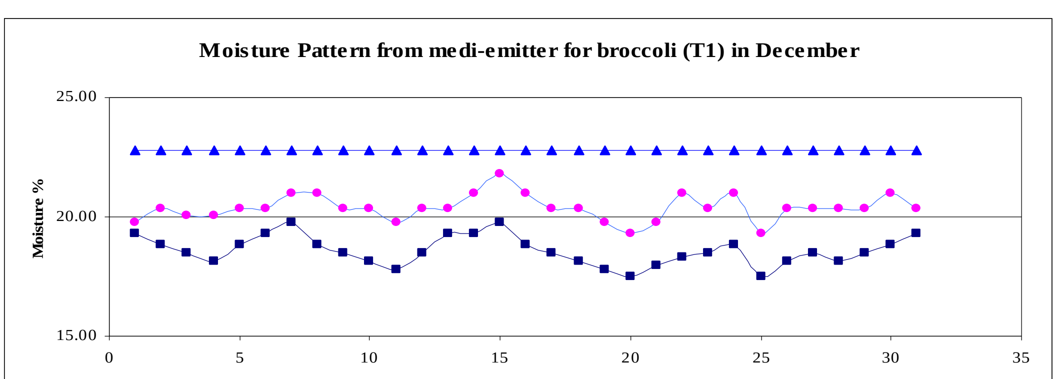

Moisture Pattern from medi-emitter for broccoli (T1) in October
35.00
30.00
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Oct.from Microtube at 30cm depth
Moisture Pattern in Oct. from Microtube at 60 cm depth
Field Capacity


Moisture Pattern from medi-emitter for tomato (T2) in October
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Oct.from Microtube at 30cm depth
Moisture Pattern in Oct. from Microtube at 60 cm depth
Field Capacity


Moisture Pattern from microtube for tomato (T3) in October
35.00
30.00
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Oct.from Microtube at 30cm depth
Moisture Pattern in Oct. from Microtube at 60 cm depth
Field Capacity


Moisture Pattern from microtube for broccoli (T4) in October
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Oct.from Microtube at 30cm depth
Moisture Pattern in Oct. from Microtube at 60 cm depth
Field Capacity


Moisture Pattern from medi-emitter for broccoli (T1) in November
25.00
20.00
Moisture %


Moisture Pattern from medi-emitter for broccoli (T1) in December
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35

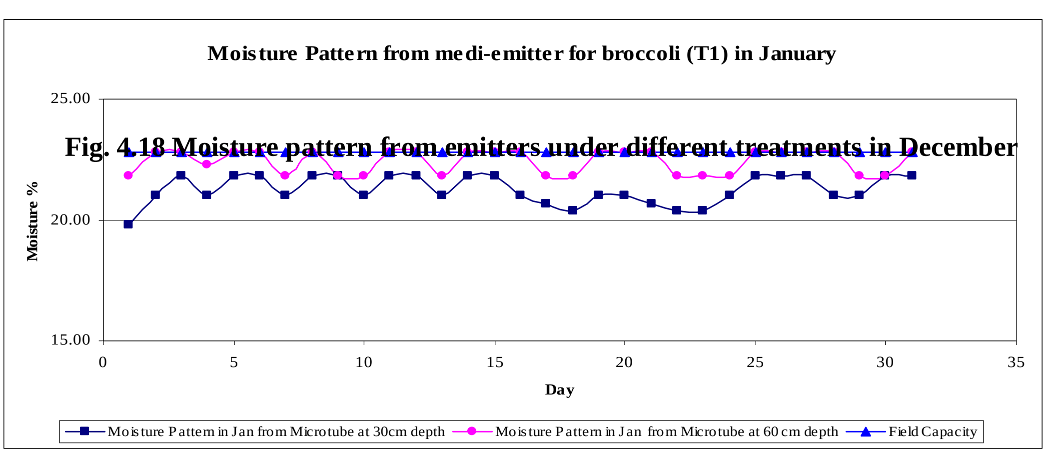
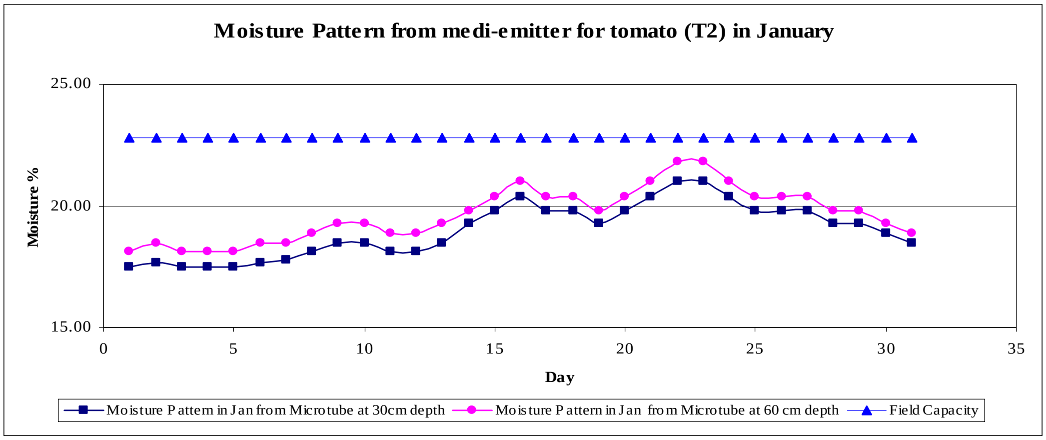
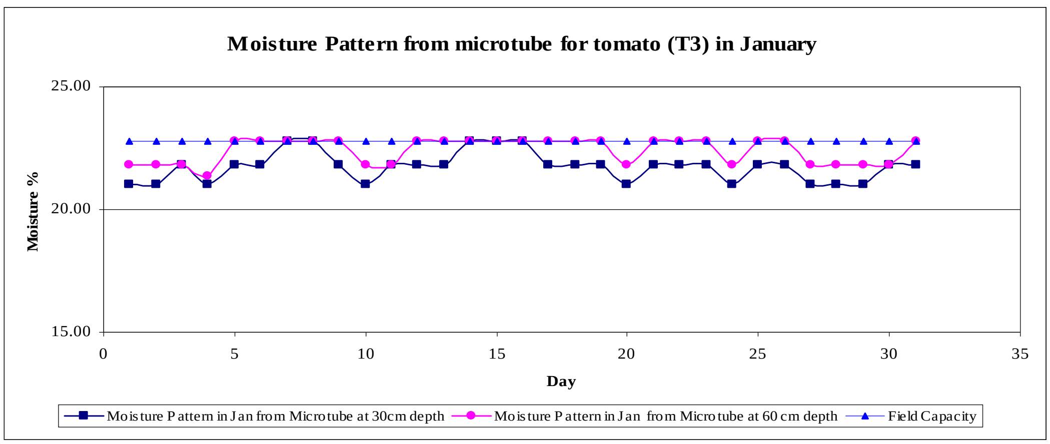


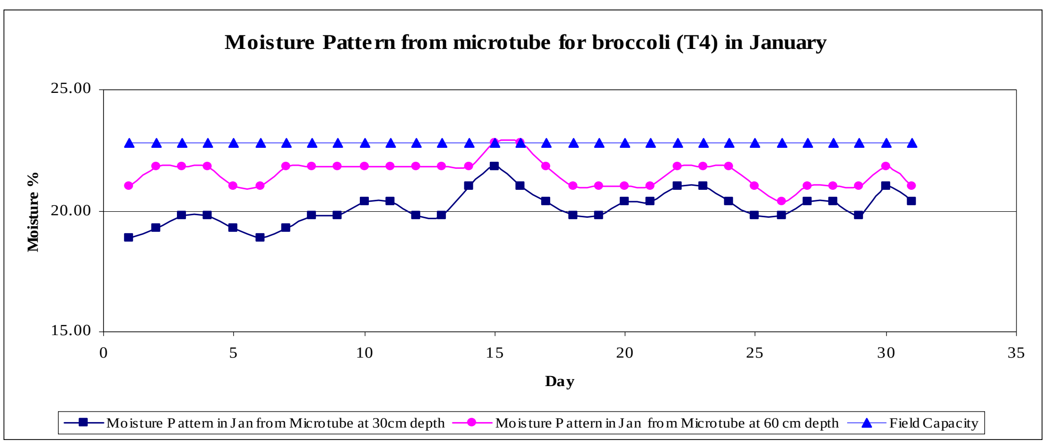
Fig. 4.18 Moisture pattern from emitters under different treatments in December



Moisture Pattern from medi-emitter for tomato (T2) in January
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Jan from Microtube at 30cm depth
Moisture Pattern in Jan from Microtube at 60 cm depth
Field Capacity



Moisture Pattern from microtube for tomato (T3) in January
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Jan from Microtube at 30cm depth
Moisture Pattern in Jan from Microtube at 60 cm depth
Field Capacity



Moisture Pattern from microtube for broccoli (T4) in January
25.00
20.00
15.00
Moisture %
0
5
10
15
20
25
30
35
Day
Moisture Pattern in Jan from Microtube at 30cm depth
Moisture Pattern in Jan from Microtube at 60 cm depth
Field Capacity

4.4.2 Plant Height

The height of broccoli and tomato was recorded at the time of harvesting in all the irrigation treatments. The data on height of broccoli and tomato for all treatments are presented in Table 4.5. The mean height of broccoli and tomato in treatment T1 (26.80 cm) followed by T4 (21.30 cm) and T3 (64.40 cm) followed by T2 (54.80 cm) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

All biometric parameters were recorded at the time of harvesting in all the treatments. Biometric parameters depend upon various factors, among all, uniform crop water requirements is the major one. The larger plant height in treatments T1 (94.65 %) and T3 (95.79 %) may be attributed to the fact that water was applied (field emission uniformity) through out the fields (level ground) uniformly compared to T2 (89.70 %) and T4 (89.08 %) (0.5 % up slope) due to which, soil moisture in the root zone maintained close to field capacity through out the field and hence the plant water usage was maintained at reasonable high level. This was the main causes for all below given biometric parameters in treatments T1 and T3 compared to T2 and T4.

Table 4.5 Final height of tomato and broccoli

Sample No.	Plant height, cm			
	T1	**T2**	**T3**	**T4**
1	22.00	40.00	55.00	19.00
2	25.00	52.00	50.00	19.50
3	28.00	57.00	70.00	20.00
4	29.00	60.00	72.00	21.00
5	30.00	65.00	75.00	27.00
T - test	S*	NS**	NS**	S*
Mean	26.80	54.80	64.40	21.30
SD ±	3.27	9.52	11.15	3.27
SEM	1.46	4.26	4.99	1.46
Sig. (2-tailed)	0.029	0.181	0.181	0.029

* Significant at 5 % level
** Not significant at 5 % level

The average of final plant height, plant girth, number of leaves, leaf area index of tomato after 135 days of transplanting were found maximum 63.0 cm, 4.22 cm, 583.33, 6429.87 cm^2 and 2.30 for treatment T1 whereas, these were minimum 55.73 cm, 2.94 cm, 544.33, 6072.81 cm^2 and 2.18 for treatment T4 respectively reported by Agrawal *et al.* (2005).

4.4.3 Numbers of Leaves

A perusal of data in Table 4.6 indicated that mean number of leaves of broccoli and tomato in treatment T1 (140.60) followed by T4 (57.80) and T3 (53.60) followed by T2

(30.40) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.6 Final number of leaves of tomato and broccoli

Sample No.	Number of leaves			
	T1	**T2**	**T3**	**T4**
1	95.00	18.00	33.00	41.00
2	119.00	20.00	40.00	45.00
3	140.00	26.00	43.00	48.00
4	171.00	41.00	68.00	50.00
5	178.00	47.00	84.00	105.00
T - test	S*	NS**	NS**	S*
Mean	140.60	30.40	53.60	57.80
SD ±	34.89	12.93	21.52	26.60
SEM	15.60	5.78	9.63	11.90
Sig. (2-tailed)	0.003	0.073	0.073	0.003

* Significant at 5 % level
** Not significant at 5 % level

4.4.4 Stem Girth

An examination of data in Table 4.7 showed that mean stem girth of broccoli and tomato in treatment T1 (11.31 cm) followed by T4 (6.94 cm) and T3 (4.59 cm) followed by T2 (3.02 cm) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in both case of broccoli and tomato at 5 % level.

Table 4.7 Final stem girth of tomato and broccoli

Sample No.	Stem girth, cm			
	T1	**T2**	**T3**	**T4**
1	9.11	2.20	2.51	5.97
2	10.68	2.51	4.40	6.13
3	10.99	3.14	5.03	6.28
4	12.57	3.46	5.34	7.85
5	13.19	3.77	5.65	8.48
T - test	S*	S*	S*	S*
Mean	11.31	3.02	4.59	6.94
SD ±	1.62	0.65	1.25	1.14
SEM	0.72	0.29	0.56	0.51
Sig. (2-tailed)	0.001	0.037	0.037	0.001

* Significant at 5 % level

4.4.5 Leaf Area

It is clear from data in Table 4.8 that mean leaf area of broccoli and tomato in treatment T1 (11053.73 cm^2) followed by T4 (3154.17 cm^2) and T3 (4264.04 cm^2) followed by T2 (1243.79 cm^2) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in both case of broccoli and tomato at 5 % level.

Table 4.8 Final leaf area of tomato and broccoli

Sample No.	Leaf area, cm^2			
	T1	**T2**	**T3**	**T4**
1	5655.15	440.82	2265.12	1260.85
2	8470.59	741.31	3188.86	1910.52
3	10610.86	1132.97	4125.33	2948.23
4	14074.95	1638.58	5231.82	4278.13
5	16457.12	2265.25	6509.08	5373.11
T - test	S*	S*	S*	S*
Mean	11053.73	1243.79	4264.04	3154.17
SD ±	4310.97	726.08	1669.41	1685.28
SEM	1927.92	324.71	746.58	753.68
Sig. (2-tailed)	0.005	0.006	0.006	0.005

* Significant at 5 % level

4.4.6 Ground Coverage

Data presented in Table 4.9 indicated that mean ground coverage of broccoli and tomato in treatment T1 (4358.96 cm^2) followed by T4 (2002.76 cm^2) and T3 (2002.76 cm^2) followed by T2 (746.13 cm^2) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in both case of broccoli and tomato at 5 % level.

Table 4.9 Final ground coverage of tomato and broccoli

Sample No.	Ground coverage, cm^2			
	T1	**T2**	**T3**	**T4**
1	2827.43	314.16	1256.64	1256.64
2	3848.45	490.87	1590.43	1590.43
3	4417.86	706.86	1963.49	1963.49
4	5026.55	962.11	2375.83	2375.83
5	5674.50	1256.64	2827.43	2827.43
T - test	S*	S*	S*	S*
Mean	4358.96	746.13	2002.76	2002.76
SD ±	1093.85	374.35	621.99	621.99
SEM	489.18	167.42	278.17	278.17
Sig. (2-tailed)	0.003	0.005	0.005	0.003

* Significant at 5 % level

4.4.7 Leaf Area Index (LAI)

From the Table 4.10 it can be revealed that mean leaf area index of broccoli and tomato in treatment T1 (2.46) followed by T4 (1.48) and T3 (2.08) followed by T2 (1.60) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in both case of broccoli and tomato at 5 % level.

Table 4.10 Final leaf area index of tomato and broccoli

Sample No.	Life area index (LAI)			
	T1	**T2**	**T3**	**T4**
1	2.00	1.40	1.80	1.00
2	2.20	1.51	2.01	1.20
3	2.40	1.60	2.10	1.50
4	2.80	1.70	2.20	1.80
5	2.90	1.80	2.30	1.90
T - test	S*	S*	S*	S*
Mean	2.46	1.60	2.08	1.48
SD ±	0.38	0.16	0.19	0.38
SEM	0.17	0.07	0.08	0.17
Sig. (2-tailed)	0.004	0.003	0.003	0.004

* Significant at 5 % level

4.4.8 Root Growth

A perusal of data in Table 4.11 shows that mean root length of broccoli and tomato in treatment T1 (29.00 cm) followed by T4 (22.10 cm) and T3 (32.20 cm) followed by T2 (30.60 cm) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.11 Final root length of tomato and broccoli

Sample No.	Root length, cm			
	T1	**T2**	**T3**	**T4**
1	23.00	20.00	24.00	19.00
2	25.00	25.00	30.00	19.50
3	30.00	32.00	32.00	20.00
4	32.00	35.00	35.00	22.00
5	35.00	41.00	40.00	30.00
T - test	S*	NS**	NS**	S*
Mean	29.00	30.60	32.20	22.10
SD ±	4.95	8.26	5.92	4.56
SEM	2.21	3.70	2.65	2.04
Sig. (2-tailed)	0.05	0.73	0.73	0.05

* Significant at 5 % level
** Not significant at 5 % level

4.4.9 Number of Fruit

The number of fruit of broccoli (including secondary heads) and tomato was recorded at the time of harvesting and are presented in Table 4.12. The mean number of fruit of broccoli and tomato in treatment T1 (10.20) followed by T4 (6.80) and T3 (27.80) followed by T2 (26.40) respectively. T- test (SPSS) was worked out for the observed value and found to be insignificant in both case of broccoli and tomato at 5 % level.

Table 4.12 Final number of fruit of tomato and broccoli

Sample No.	Number of fruit			
	T1	**T2**	**T3**	**T4**
1	7.00	15.00	16.00	4.00
2	8.00	18.00	20.00	5.00
3	11.00	27.00	28.00	6.00
4	12.00	34.00	35.00	8.00
5	13.00	38.00	40.00	11.00
T - test	NS**	NS**	NS**	NS**
Mean	10.20	26.40	27.80	6.80
SD ±	2.59	9.91	10.01	2.77
SEM	1.16	4.43	4.48	1.24
Sig. (2-tailed)	0.08	0.83	0.83	0.08

* Significant at 5 % level
** Not significant at 5 % level

4.4.10 Number of Branch/Secondary Head

An examination of data in Table 4.13 indicated that mean number of branch/secondary of broccoli and tomato in treatment T1 (9.20) followed by T4 (5.80) and T3 (15.40) followed by T2 (14.20) respectively. T- test (SPSS) was worked out for the observed value and found to be insignificant in both case of broccoli and tomato at 5 % level.

Table 4.13 Final number of branch/secondary head of tomato and broccoli

Sample No.	Number of branch/secondary			
	T1	**T2**	**T3**	**T4**
1	6.00	11.00	12.00	3.00
2	7.00	12.00	13.00	4.00
3	10.00	14.00	14.00	5.00
4	11.00	16.00	18.00	7.00
5	12.00	18.00	20.00	10.00
T - test	NS**	NS**	NS**	NS**
Mean	9.20	14.20	15.40	5.80
SD ±	2.59	2.86	3.44	2.77
SEM	1.16	1.28	1.54	1.24
Sig. (2-tailed)	0.08	0.57	0.57	0.08

* Significant at 5 % level
** Not significant at 5 % level

4.4.11 Wet Residue

4.4.11.1Wet crop residue

It is clear from data in Table 4.14 that mean wet residue of broccoli and tomato in treatment T1 (2.64 kg) followed by T4 (0.90 kg) and T3 (0.68 kg) followed by T2 (0.24 kg) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in both case of broccoli and tomato at 5 % level.

Table 4.14 Final wet crop residue of tomato and broccoli

Sample No.	Wet crop residue, kg			
	T1	**T2**	**T3**	**T4**
1	2.25	0.12	0.36	0.62
2	2.38	0.18	0.38	0.68
3	2.42	0.22	0.62	0.76
4	3.02	0.32	1.02	0.82
5	3.15	0.34	1.04	1.64
T - test	S*	S*	S*	S*
Mean	2.64	0.24	0.68	0.90
SD ±	0.41	0.09	0.33	0.42
SEM	0.18	0.04	0.15	0.19
Sig. (2-tailed)	0.00	0.02	0.02	0.00

* Significant at 5 % level

4.4.11.2 Wet above ground biomass

Data presented in Table 4.15 indicated that mean above ground biomass (wet) of broccoli and tomato in treatment T1 (3.65 kg) followed by T4 (1.50 kg) and T3 (2.87 kg) followed by T2 (2.17 kg) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.15 Final above ground biomass of tomato and broccoli

Sample No.	Above ground (AG) biomass, kg			
	T1	**T2**	**T3**	**T4**
1	3.00	1.07	1.37	0.99
2	3.23	1.31	1.72	1.14
3	3.50	2.03	2.72	1.31
4	4.17	2.87	4.00	1.53
5	4.37	3.57	4.56	2.54
T - test	S*	NS**	NS**	S*
Mean	3.65	2.17	2.87	1.50
SD ±	0.59	1.05	1.39	0.61
SEM	0.27	0.47	0.62	0.27
Sig. (2-tailed)	0.00	0.39	0.39	0.00

* Significant at 5 % level
** Not significant at 5 % level

4.4.11.3 Wet root residue

From the Table 4.16 it can be revealed that mean root residue (wet) of broccoli and tomato in treatment T1 (0.09 kg) followed by T4 (0.04 kg) and T3 (0.03 kg) followed by T2 (0.02 kg) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.16 Final root residue of tomato and broccoli

Sample No.	Root residue, kg			
	T1	**T2**	**T3**	**T4**
1	0.070	0.006	0.018	0.030
2	0.080	0.009	0.020	0.035
3	0.090	0.010	0.030	0.040
4	0.100	0.030	0.047	0.052
5	0.103	0.033	0.049	0.066
T - test	S*	NS**	NS**	S*
Mean	0.09	0.02	0.03	0.04
SD ±	0.01	0.01	0.01	0.01
SEM	0.006	0.005	0.006	0.006
Sig. (2-tailed)	0.001	0.12	0.12	0.001

* Significant at 5 % level

** Not significant at 5 % level

4.4.12 Dry Residue

4.4.12.1 Dry crop residue

A perusal of data in Table 4.17 indicated that mean crop residue (dry) of broccoli and tomato in treatment T1 (0.292 kg) followed by T4 (0.095 kg) and T3 (0.102 kg) followed by T2 (0.030 kg) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in both case of broccoli and tomato at 5 % level.

Table 4.17 Final dry residue of tomato and broccoli

Sample No.	Dry crop residue, kg			
	T1	**T2**	**T3**	**T4**
1	0.221	0.014	0.050	0.061
2	0.242	0.022	0.056	0.064
3	0.278	0.028	0.092	0.078
4	0.352	0.041	0.152	0.082
5	0.369	0.045	0.158	0.188
T - test	S*	S*	S*	S*
Mean	0.292	0.030	0.102	0.095
SD ±	0.066	0.012	0.051	0.053
SEM	0.029	0.006	0.002	0.024
Sig. (2-tailed)	0.001	0.017	0.017	0.001

* Significant at 5 % level

4.4.12.2 Dry root residue

It is clear from data in Table 4.18 that mean root residue (dry) of broccoli and tomato in treatment T1 (0.04 kg) followed by T4 (0.02 kg) and T3 (0.012 kg) followed by T2 (0.006 kg) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.18 Final dry root residue of tomato and broccoli

Sample No.	Dry root residue, kg			
	T1	**T2**	**T3**	**T4**
1	0.021	0.0018	0.0065	0.011
2	0.027	0.0028	0.0073	0.013
3	0.038	0.0032	0.0110	0.015
4	0.044	0.0104	0.0173	0.019
5	0.046	0.0116	0.0182	0.025
T - test	S*	NS**	NS**	S*
Mean	0.04	0.006	0.012	0.02
SD ±	0.01	0.005	0.005	0.006
SEM	0.005	0.002	0.002	0.003
Sig. (2-tailed)	0.009	0.094	0.094	0.009

* Significant at 5 % level

** Not significant at 5 % level

4.4.13 Dry Matter Content

4.4.13.1Crop residue

The dry matter content (crop residue) of broccoli and tomato was recorded at the time of harvesting and are presented in Table 4.19. The mean dry crop residue of broccoli and tomato in treatment T1 (10.97 %) followed by T4 (10.19 %) and T3 (14.71 %) followed by T2 (12.53 %) respectively. T- test (SPSS) was worked out for the observed value and found to be insignificant in case of broccoli where as significant in case of tomato at 5 % level.

Table 4.19 Final dry matter content (crop residue) % of tomato and broccoli

Sample No.	Dry matter content (crop residue) %			
	T1	**T2**	**T3**	**T4**
1	9.82	11.67	13.89	9.84
2	10.17	12.22	14.74	9.41
3	11.49	12.73	14.84	10.26
4	11.66	12.81	14.90	10.00
5	11.71	13.24	15.19	11.46
T - test	NS**	S*	S*	NS**
Mean	10.97	12.53	14.71	10.19
SD ±	0.90	0.60	0.49	0.77
SEM	0.40	0.27	0.22	0.35
Sig. (2-tailed)	0.18	0.00	0.00	0.18

* Significant at 5 % level

** Not significant at 5 % level

The mean moisture content of crop residue of broccoli and tomato in treatment T1 (2.35 kg) followed by T4 (0.81 kg) and T3 (0.58 kg) followed by T2 (0.21 kg) respectively.

4.4.13.2 Root residue

A perusal of data in Table 4.20 shows that mean dry root residue (root residue) of broccoli and tomato in treatment T1 (38.93 %) followed by T4 (37.15 %) and T3 (36.65 %) followed by T2 (32.59 %) respectively. T- test (SPSS) was worked out for the observed value and found to be insignificant in case of broccoli where as significant in case of tomato at 5 % level.

Table 4.20 Final dry matter content (root residue) % of tomato and broccoli

Sample No.	Dry matter content (root residue) %			
	T1	**T2**	**T3**	**T4**
1	30.00	30.00	36.11	36.67
2	33.75	31.11	36.50	37.14
3	42.22	32.00	36.67	37.50
4	44.00	34.67	36.81	36.54
5	44.66	35.15	37.14	37.88
T - test	NS**	S*	S*	NS**
Mean	38.93	32.59	36.65	37.15
SD ±	6.63	2.24	0.38	0.56
SEM	2.97	1.00	0.17	0.25
Sig. (2-tailed)	0.57	0.004	0.004	0.57

* Significant at 5 % level
** Not significant at 5 % level

The mean moisture content of root residue of broccoli and tomato in treatment T1 (0.05 kg) followed by T4 (0.02 kg) and T3 (0.018 kg) followed by T2 (0.014 kg) respectively.

4.4.14 Yield and Quality of Fruit

4.4.14.1 Girth of fruit

An examination of data in Table 4.21 indicated that mean girth of fruit of broccoli in treatment T1 (66.92 cm) followed by T4 (47.44 cm) and tomato in treatment T3 (17.59 cm) followed by T2 (16.65 cm), respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.21 Final girth of fruit of tomato and broccoli

Sample No.	Girth of fruit, cm			
	T1	**T2**	**T3**	**T4**
1	53.41	15.71	15.71	40.84
2	65.97	15.71	17.28	42.41
3	69.12	15.71	17.28	43.98
4	72.26	17.28	18.85	47.12
5	73.83	18.85	18.85	62.83
T - test	S*	NS**	NS**	S*
Mean	66.92	16.65	17.59	47.44
SD ±	8.13	1.40	1.31	8.91
SEM	3.64	0.63	0.59	3.98
Sig. (2-tailed)	0.007	0.305	0.305	0.007

* Significant at 5 % level
** Not significant at 5 % level

4.4.14.2 Quality of fruit

Data presented in Table 4.22 indicated that mean quality of fruit length of broccoli and tomato in treatment T1 (18.30 cm) followed by T4 (13.80 cm) and T3 (5.50 cm) followed by T2 (5.10 cm) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Table 4.22 Final length of fruit of tomato and broccoli

Sample No.	**Length of fruit, cm**			
	T1	**T2**	**T3**	**T4**
1	15.00	4.50	4.50	11.00
2	18.00	4.50	5.00	12.00
3	19.00	5.00	5.50	14.00
4	19.50	5.50	6.00	15.00
5	20.00	6.00	6.50	17.00
T - test	S*	NS**	NS**	S*
Mean	18.30	5.10	5.50	13.80
SD ±	1.99	0.65	0.79	2.39
SEM	0.89	0.29	0.35	1.07
Sig. (2-tailed)	0.012	0.408	0.408	0.012

* Significant at 5 % level
** Not significant at 5 % level

4.4.14.3 Yield of fruit

The yield of fruit of broccoli and tomato was recorded at the time of harvesting and are presented in Table 4.23 (weight per fruit), Table 4.24 (yield of fruit per plant) and Table 4.25 (yield subplot wise). The mean yield of fruit kg/plant of broccoli and tomato in treatment T1 (1.01 kg) followed by T4 (0.60 kg) and T3 (2.19 kg) followed by T2 (1.93 kg) respectively. T- test (SPSS) was worked out for the observed value and found to be significant in case of broccoli where as insignificant in case of tomato at 5 % level.

Data on Table 4.25 and Fig. 4.20 revealed that yield of fruit (per ha) of broccoli and tomato in treatment T1 (29.27 t/ha) followed by T4 (17.33 t/ha) and T3 (63.46 t/ha) followed by T2 (56.03 t/ha) respectively. Yield of broccoli and tomato under different treatments are shown in Fig.4.21. Quality of broccoli and tomato are shown in Plate No.4.3 and Plate No.4.4 respectively.

Similarly higher yield of tomato (67.3 t/ha) were reported for drip microtubes (Manjunatha *et al.*, 2001) where as 18.74 t/ha reported by (Agrawal *et al.*, 2005).

Kumar *et al*. (2001) studied the performance of different broccoli cultivars and yield/ha were highest 13.05 t/ha, Brahma *et al*., 2002 reported 18.11 t/ha where as Ranawat, 2008 reported 11.11 t/ha. The result is in close agreement with the findings of above researchers.

Table 4.23 Final weight per fruit of tomato and broccoli

Sample No.	**Weight/ fruit, kg**			
	T1	**T2**	**T3**	**T4**
1	0.450	0.063	0.063	0.220
2	0.500	0.063	0.067	0.260
3	0.580	0.067	0.075	0.300
4	0.600	0.075	0.085	0.360
5	0.620	0.085	0.088	0.400
T - test	S*	NS**	NS**	S*
Mean	0.550	0.071	0.076	0.310
SD ±	0.072	0.009	0.011	0.073
SEM	0.032	0.0042	0.0049	0.033
Sig. (2-tailed)	0.001	0.460	0.460	0.001

* Significant at 5 % level
** Not significant at 5 % level

Table 4.24 Final yield of tomato per plant and broccoli

Sample No.	**Yield of fruit/plant, kg**			
	T1	**T2**	**T3**	**T4**
1	0.75	0.95	1.01	0.37
2	0.85	1.13	1.34	0.46
3	1.08	1.81	2.10	0.55
4	1.15	2.55	2.98	0.71
5	1.22	3.23	3.52	0.90
T - test	S*	NS**	NS**	S*
Mean	1.01	1.93	2.19	0.60
SD ±	0.20	0.96	1.06	0.21
SEM	0.09	0.43	0.48	0.09
Sig. (2-tailed)	0.013	0.701	0.701	0.013

* Significant at 5 % level
** Not significant at 5 % level

Table 4.25 Sub plot wise yield of tomato and broccoli

Treatments	**Average yield per plant**		**Yield of tomato**		**Yield of broccoli**	
	Tomato,kg/p	**broccoli,kg/p**	**kg/plot**	**t/ha**	**kg/plot**	**t/ha**
T1		1.01			571.66	29.27
T2	1.93		1094.42	56.03		
T3	2.19		1239.54	63.46		
T4		0.60			338.47	17.33

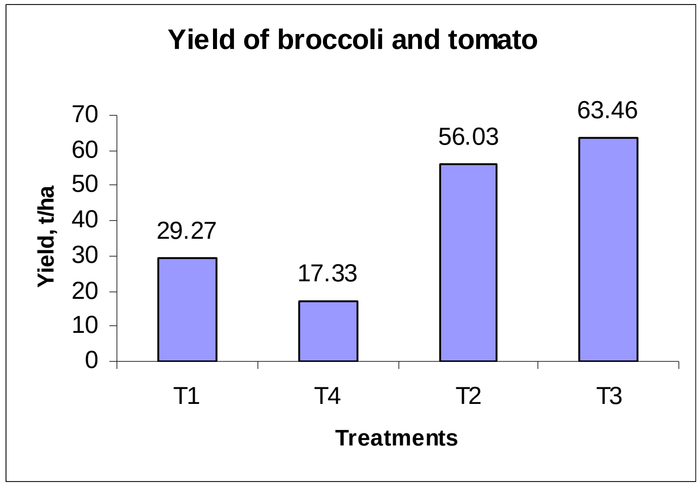


Fig. 4.20 Yield of broccoli and tomato under different treatments

Plate No. 4.3 Quality of broccoli

Plate No. 4.4 Quality of tomato

4.4.15 Water Use Efficiency

The Water use efficiency (WUE) is one of the best tools for the evaluating the performance of different irrigation treatments. WUE was calculated as the ratio of the crop yield (t/ha) to the total seasonal irrigation water applied (cm) during the field growing season.

The WUE for each treatment combination are presented in Table 4.26. The seasonal water requirement was found to be 20.08 cm, 19.68 cm, 18.61 cm and 21.06 cm respectively for treatments T1, T2, T3 and T4 and corresponding WUE are 1.46, 2.85, 3.41 and 0.82 t/ha-cm. The overall efficiency of water use in this experiment was found to be high due to saving of water. Only a small portion of the area was irrigated by controlled amount of water and deep percolation as well as the evaporation losses was minimum. High efficiency of water use is extremely important to farmers in water scarce areas. The WUE of tomato reported by Agrawal *et al.*, 2005 was 0.68 t/ha-cm for drip treatments. Singh *et al.* (2001) reported WUE range from 18.7 - 6.52 kg/ha-mm for sprouting broccoli.

Table 4.26 Seasonal water requirement, water use efficiency of tomato and broccoli

Treatments	Average yield, t/ha		Seasonal water requirement, cm		Water use efficiency, t/ha-cm	
	Tomato	Broccoli	Tomato	Broccoli	Tomato	Broccoli
T1		29.27		20.08		1.46
T2	56.03		19.68		2.85	
T3	63.46		18.61		3.41	
T4		17.33		21.06		0.82

4.5 ECONOMIC ANALYSIS

The economic viability of each irrigation treatments was calculated assuming each treatment was operated on a 156.25 m^2 (566 plants). The amount of fruit mass produce was based on the average yield derived randomly from 5 plants within the plot and prices based on market rate.

The Rajasthan State Government has approved rate per hectare for drip irrigation system ranges from Rs 19205.71 to Rs 163400.00 depending upon the crop. Subsidy provided to this micro-irrigation is 70 % (DOA, 2009). Cost is the major constraint in adoption of drip irrigation for small land holders. The economic analysis was done as per existing market situation and the data pertaining to each component, cost of production of broccoli and tomato, net return from different irrigation treatments are presented in Table A-4.51 to A-4.53 along with the economic analysis in term of benefit cost ratio. As the cost of materials is fluctuating very fast, the economic analysis may change with time and place. The price of the product may also vary from place to place and from time to time which will affect the economic analysis significantly. The generalized form of economic analysis data are given in

Table A-4.53 for different treatments. In analysis of economics of systems 70 per cent subsidy was also considered (DOA, 2009).

Since the payback period for all treatments is 1 season and B/C ratio is more than 1, even as high as 5.31(without subsidy) in case of microtubes, this may be considered to be a viable option for small landholders.

Manjunatha *et al* (2001) reported B/C ratio, 9.81 for drip microtubes in case of high yield tomato. The net return of Rs. 88601/ha with B/C ratio 3.99 from sprouting broccoli was reported by (Ranawat, 2008). Several researchers reported higher crop yield and more income from the produce besides saving of water through drip methods of irrigation (Atre *et al*., 1989; Jadhav *et al*., 1990; Singh *et al*., 1995; Sahu and Rao, 2005; Thakur and Spehia, 2005)

4.5.1 Cost of Production

Data presented in Table A- 4.53 indicated that maximum seasonal cost of component per hectare without and with subsidy (70 %) was in T1 (Rs. 168149 and Rs. 50445) and T2 (Rs.168149 and Rs. 50445) followed by T3 (Rs. 46249 and Rs.13875) and T4 (Rs. 46249 and Rs.13875) respectively. This is due to high rate of medi-emitters (T1 and T2) compare to microtubes (T3 and T4).

A perusal of data in Table A-4.53 indicated that maximum seasonal cost of cultivation per hectare was in T2 (Rs.54343) and T3 (Rs.54343) followed by T1 (Rs. 51784) and T4 (Rs. 51784). This is due to more seed rate of tomato (T2 and T3) compare to broccoli (T1 and T4).

An examination of data in Table A-4.53 showed that maximum seasonal cost of production without and with subsidy (70 %) per hectare was in T2 (Rs. 222492 and Rs.104787) followed by T1 (Rs.219933 and Rs.102229), T3 (Rs. 100592 and Rs.68217) and T4 (Rs. 98033 and Rs.65659) respectively. This is due to high rate of medi-emitters (T1 and T2) and seed rate of tomato (T2 and T3) compare to microtubes (T3 and T4) and seed rate of broccoli (T1 and T4).

4.5.2 Return from Produce and Net Income

It is clear from data in Table A-4.53 that return from produce was maximized in seasonal return from produce per hectare was in T3 (Rs.634600) followed by T1 (Rs.585380), T2 (Rs.560342) and T4 (Rs.346591) respectively. This is due to high yield of tomato (T2 and T3) compare to broccoli (T1 and T4). The market rate of broccoli (T1 and T4) was higher than tomato (T2 and T3). The uniformity of water application was also high in T3 and T1 (level ground) compare to T2 and T4 (0.5 % up slope) causing high yields.

Data presented in Table A-4.53 indicated that net seasonal income without and with subsidy (70 %) per hectare was in T3 (Rs.534008 and Rs.566383) followed by T1 (Rs.365447 and Rs.483151), T2 (Rs.337850 and Rs.455554) and T4 (Rs.248558 and Rs.280933) respectively.

4.5.3 Benefit Cost Ratio

From the Table A-4.53 it can be revealed that calculated value of benefit cost (BC) ratio in the treatments are observed in the range of 1.52 to 5.31. The lowest BC value (1.52) was observed in treatments T2 due to its highest initial investment and up slope of the subplot while treatment T3 was the best as far as BC ratio is concerned (5.31) due to its least initial investment with level ground among all other treatments. The benefit cost ratio range from 4.28 to 8.30 if subsidy.

Sahu and Rao (2005) reported that installation cost of micro-drip irrigation was Rs.78000/ha with B/C ratio 6.36 where as Thakur and Spehia, 2005 reported Rs. 100000/ha for lateral spacing of 1.8 m with cost of cultivation Rs.67214 having B/C ratio 3.81. The results obtained in this experiment are in agreement with other researchers.

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