FEASIBILITY STUDIES ON THE USE OF PRECISION POROUS PIPES FOR SUBSURFACE IRRIGATION

By

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THESIS

Submitted in partial fulfillment of the requirement for the degree

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DECLARATION

I hereby declare that, this project report entitled "**Feasibility Studies on the Use of Precision Porous Pipes for Subsurface Irrigation "** is a bonafide record of project work done by me during the course of project, and that the report has not previously formed, the basis for award of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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2004-18-01

CERTIFICATE

Certified that this project report entitled "**Feasibility Studies on the Use of Precision Porous Pipes for Subsurface Irrigation"** is a record of project work done independently by J. Eugine Spicer under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned, members of the advisory committee of Mr.J.Eugine Spicer, a candidate for the degree of Master of Technology in Agricultural Engineering majoring in Soil and Water Engineering agree that the thesis entitled "**Feasibility Studies on the Use of Precision Porous Pipes for Subsurface Irrigation"** may be submitted by Mr.J.Eugine Spicer in partial fulfillment of the requirement of the degree.

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SYMBOLS AND ABBREVIATIONS

Agrl	agricultural
ASAE	American Society of Agricultural Engineers
Anon.	anonymous
Bull.	bulletin
C	centigrade
CS	canopy spread of plants(cm)
Cv	coefficient of variation
cm	centimeter(s)
cm/hr	centimeter per hour
Co.	company
Contd.	continued
Cu .	coefficient of uniformity
D_1	depth of placement 10 cm
D_2	depth of placement 15 cm
D_3	depth of placement 20 cm
df	degrees of freedom
EMS	error mean square
Engg.	engineering
et al	and other people
Eu	emission uniformity
Ew	water use efficiency
etc	et cetra
FAO	Food and Agriculture Organization
Fig.	figure
gm	gram(s)
Ha	hectare

Hp	horse Power
HT	height of plants(cm)
hr	hour
IDE	Irrigation and Drainage Engineering
I.S	Indian Standard
Kpa	kilo Pascal
kg	kilogram
KAU	Kerala Agricultural University
KCAET	Kelappaji College of Agricultural Engineering & Technology
LDPE	low density polyethylene
LWRCE	Land and Water Resources and Conservation Engineering
m	meter
m^2	square meter
max.	maximum
min.	minimum
min	minute
ml.	milliliter
mm	millimeter
m^3	cubic meter
MSS	mean sum of squares
pp	pages
P1	plant 1
P2	plant 2
P3	plant 3
proc.	proceedings
PVC	poly vinyl chloride
res.	research
resour.	resources

R/F	rainfall
R	replication
r1	paired row
r2	double paired row
S_1	sand envelope
S_2	without sand envelope
Sec	second(s)
SS	sum of squares
Sl .no.	serial number
Scl.	selection
Sr.	senior
T	treatment
Tech	technical
TK	thickness of stem(mm)
Univ.	University
Vol.	volume
Viz.	namely
Vs	versus
&	and
>	greater than
<	less than
’	minute
/	per
%	percent
”	second
@	at the rate of
Ø	diameter
√	square root

CHAPTER 1
INTRODUCTION

Irrigation is the supplementation of rainfall with water from another source in order to grow crops. Irrigation has been recognized as an important factor for increasing agricultural production. In our country where crops can be grown throughout the year but rain falls only during monsoon periods, supplemental irrigation is a necessity to grow any crop except in few locations. Increasing and rationalising water use are the two key challenges in achieving food security and sustainable development of agriculture. Ninety per cent of the water consumed is for the production of crops in agricultural sector in our country. Besides, the industrial and urban growth has given rise to more rapid expansion in non-agricultural demand for water. This leads to shortage of water and hence efficient and economical utilization of water for irrigation is very important. In many areas of the world, water is already in limited supply and it is becoming increasingly less available in places where it was once available in plenty. As the supply of water decreases and the demand increases, it is imperative to minimize the water wastage.

Water resources of India are limited. The average annual rainfall of India is 1194 mm. The total geographical area of India is 329 million ha. The total cropped area of India is 185 million ha and the net sown area is 142 million ha. The gross irrigated area is 38.59 million ha and the net irrigated area is 31.59 million ha. In Kerala the gross irrigated area is 0.62 million ha and the net irrigated area is 0.44 million ha. This could be attributed mainly to the spread of irrigation. Cropping pattern of an area is determined by many factors including the type of soil, climate, water availability, food grain requirement, market supply and net rate of financial gains.

There are different methods of irrigation adopted in the world today. It is mainly classified as surface and subsurface irrigation. Porous pipe irrigation comes under subsurface irrigation. This type of irrigation is not very popular in India. Porous pipe is made from recycled rubber and polyethylene and it allows both air and water to pass through pores provided in the walls of the pipe even at low pressure. These micro openings of pore size 1.5 microns are in-built pores, and are not mechanically made holes. Hence there is no chance for the intrusion of roots or soil particles into the pores of the pipe. This allows for smaller and less expensive pumping system, smaller supply lines and lesser energy demand.

Porous pipe subsurface irrigation can be defined as application of water below the soil surface at the root zone of the plants through tiny openings provided on the walls of the pipe at a rate that allows the soil to absorb the water at its natural rate. The porous pipes can be placed on or into soils, sands and composts where the water it discharges moves from it by capillary action. Regular watering helps to maintain moisture levels in the root zone. Because porous pipe works at low pressure and low volume, it allows the wetting of large areas with small water sources. If it is to discharge evenly, there are certain limitations on how far a length of porous pipe can be extended after its connection to the main pipe.

Another advantage with porous pipes is its maintenance. Conventional irrigation systems are exposed to animals, equipments and activities. Porous pipes has no moving parts and it is buried which protects it from most damaging factors. Maintenance of porous pipes is minimal with no sprinkler heads, emitters and no surface pipe to damage by machines. All normal activities can take place on the surface while the roots are being watered. Water is not spread or dripped on surface where evaporation occurs, leaving stains and residues.

It is easy for a farmer or labourer with limited education and experience to understand the basics of watering with porous pipes. Regular inspection of soil moisture can indicate the need for irrigation. Farmers who monitor evapotranspiration rate can programme their irrigation system to maintain a proper level of moisture in the root zone. Porous pipe is a product that meets the irrigation needs of almost any farmer. It is easy to modify or expand the system to adjust to the changes that a farmer experience from season to season and year to year.

In dramatic contrast with surface watering, there is minimal loss of moisture to evaporation and runoff, and there is no wind effect. It is easy to save 30 to 50 percent of surface irrigation water using porous pipe subsurface irrigation system. Water can be directly applied to the roots of plants, encouraging deeper and more extensive root development and resulting in healthier, more productive plants. Diseases and insects that incubate in surface applied moisture are often completely eliminated.

There are additional benefits from watering with subsurface irrigation system using porous pipe. A more accurate and continuous moisture level can be made available to plants. This eliminates the shock effect of the wet and dry cycle that is common with conventional irrigation. The root zone can be kept at the desired moisture level without cutting off the oxygen supply. Without such stress the plants can devote all its effort in producing foliage, flowers and fruit.

Subsurface irrigation does not contribute to compaction like surface watering and so the soil needs less tillage. Adding moisture below the surface inhibits the development of hard pan and sealing of soil strata. This elimination of compaction is also a main benefit in turf areas used for sports and recreation as well as forage areas for livestock. Normal activities in soil such as earthworms and microbial life are encouraged by this moist but not wet environment.

Porous pipe can be used in a variety of ways to meet virtually any irrigation needs. It is not affected by freezing temperature and its flexibility prevents it from being damaged by expansion and contraction of soil. The porous pipe can only be responsible for applying water along its length. The material that is packed around the pipe is responsible for moving the water away from the pipe. Mulches over the soil will also aid lateral movement of moisture.

All trickle watering systems can be affected by the salts that are present in irrigation water, and porous pipe systems are also not immune. However porous pipe can be protected from suspended salts by the filters fitted to the system. The remaining salts that stay in solution are not a problem until successive wet and dry cycles eventually encourage the salts to deposit on the outside of the porous pipe. Instead of blocking many trickle pipes, this can slowly reduce the discharge rate of porous pipe. If the problem reduces the discharge rate to an intolerable degree, the advantage of porous pipe is that it can be treated to clear the problem. A higher pressure to remove the salts, together with a gentle stretching of the pipes is recommended.

Because porous pipe lasts for a long time than a lot of other irrigation devices, the capital investment is paid back quickly in subsequent years.   It can be installed on the soil surface after planting just prior to mulching. Where mulches are not intended, the porous pipe can be laid below the soil surface by way of drawing narrow drills in the soil before planting. The exposed pipe in the bottom of the drill can then be covered at planting time, thus allowing the positioning of the pipes to be traced during planting.

Porous pipes emit water all along the length of the tubing. There are literally thousands of places per meter where water weeps out of the tubing. This design has shown resistance to plugging by roots. The disadvantage is that it's flow path is very small. This increases the likelihood of plugging by fine particles. It typically has the largest coefficient of manufacturing variability, which can be a major detriment because it prevents high distribution uniformity and high efficiency.

Porous pipe is made from rubber and, in theory, if it is exposed to ultra-violet light from the sun, it will perish over a period of time. There is no limitation to the size of area that can be watered directly with porous pipe. The limitation on size depends on the strength of the water source and how the polytube distribution pipe work is sized and installed.

Even though porous pipe subsurface irrigation has so many advantages, it is not popular in India. There is only very little information available on the discharge, availability and operating characteristics of the porous pipe.

In this study an attempt is made to study the hydraulic performance of commercially available precision porous pipe.

The specific objectives of the study are

- To study the discharge characteristics of the precision porous pipe.
- To study the moisture distribution characteristics of the precision porous pipe.
- To find out the distribution efficiency of the precision porous pipe.

- To find out the optimum depth at which the precision porous pipe are to be installed for lateritic soil.

- To find out the suitable operating pressure for the precision porous pipe.

- To make a comparative study with surface drip irrigation regarding yield of the crop and moisture distribution.

CHAPTER 2
REVIEW OF LITERATURE

When a reliable and suitable supply of water becomes available for agriculture, it can result in vast improvements in agricultural production and economic returns to the grower. Irrigation technology provides a number of equipments and instruments to facilitate timely application of the design depth of irrigation. It is a known fact that surface flooding of water results in excessive runoff, deep percolation and evaporation losses. Micro irrigation systems such as the drip irrigation are at present considered to result in enormous savings of water since deep percolation and runoff losses are completely eliminated. However these systems also suffer from excessive losses due to surface evaporation. In this context providing a subsurface irrigation system with porous pipes at appropriate depth within the effective root zone would eliminate all possible losses of water.

As water is becoming a limited resource, its efficient utilization is very essential. Good scientific water management involves adoption of right method of irrigation to the crop at the right time and required quantity. Subsurface irrigation using porous pipe can be considered as an efficient irrigation method which is economically usable, technically feasible and socially acceptable.

2.1. HISTORICAL DEVELOPMENT OF SUBSURFACE IRRIGATION

In 1920, Charles Lee in California was granted a US patent for an irrigation tile that had orifices on raised ridge inside the pipe. Since irrigation tiles were intended to create a water table, as in subsurface irrigation, and to moisten the soil around the tile, this was probably one of the earliest subsurface drip or porous pipe irrigation.

Subsurface drip was a part of drip irrigation developed in the USA in the year 1959 especially in California. Laterals were constructed using polyethylene or PVC pipe with holes or slits drilled, punched or cut into the pipe or discrete emitter inserted into the pipe (Whitney, 1970). Typically these systems were operated at low pressures with varying water quality and filtration.

By 1970s, equipments for installing subsurface drip systems were developed. At the same time, surface drip irrigation systems, including fertilizer injection equipment were being developed in Israel (Goldberg and Shmueli, 1970). As commercial drip emitters and tubing became more reliable, surface applications grew to a greater rate than subsurface applications, because of problems with emitter plugging and root intrusion.

In the early 1980s, interest in subsurface drip increased possibly because of improved nutrient management and lower system cost that resulted from multiple years of use. Interest in subsurface drip irrigation increased greatly after 1985, the period when most reports of replicated research studies have been published.

2.2. DISCHARGE CHARACTERISTICS OF SUBSURFACE IRRIGATION SYSTEM

Warrick *et al*. (1996) examined the effect of limiting flow from subsurface emitters on irrigation uniformity by using soil data from a field in the Arava Valley, Israel. They observed that soil variability can affect the flow rate of water from subsurface trickle emitters. An analysis was developed showing the relationship between discharge versus the design discharge as a function of emitter characteristics and soil hydraulic properties. It was observed that when the design flow volume increases or the hydraulic conductivity of soil decreases, the pressure head of the soil next to the emitter increases, which reduces the flow-rate ,other factors remaining equal.

Camp *et al*. (1998) evaluated surface and subsurface drip systems after 8 years use, reporting more reduction in uniformity of discharge for subsurface systems than for surface systems, primarily because of emitter plugging caused by soil entry into main or sub-main during system modification.

Koumanov *et al*. (1997) observed that the irrigation evaluations of subsurface drip systems are extremely difficult. It is not feasible to excavate emitters for discharge measurements. So as an alternate arrangement, small totaling flow meters were installed permanently on selected drip laterals to monitor flow rate along the entire lateral length. The constant flow rate at a constant operating pressure indicates that no significant clogging or leaking is found in the lateral line.

Lomax *et al*.(1998) tested the porous tubing to characterize the emission rate as a function of supply pressure, particulate content of the water and start up pressure. Emission rate declined to a steady value using unfiltered water after about 10 days with a constant pressure. From the three constant pressure experiments, it was reasonable to say that a higher pressure provided a higher steady rate.

Discharge rates declined with time to reach stable values suggesting that both physical blockage and a change in the pipe characteristics occurred during the initial curing process. Filtration at 5 to 50 µm did not affect the emission pattern, but extended curing time produced higher stable discharge values (Teeluk *et al.*,1998)

2.2.1. Subsurface System Uniformity Coefficients

A major concern with subsurface irrigation system is evaluation of performance and uniformity. Several methods have been proposed for assessing the uniformity of application in drip irrigation system. The term emission uniformity has generally been used to describe the emitter flow variation for a trickle irrigation unit.

2.2.1.1. *Coefficient of Uniformity*

The coefficient of uniformity for a sprinkler irrigation system was proposed by Christiansen (1942). This is the most widely accepted uniformity evaluation technique.

Another method for determining the uniformity coefficient is by relating it with relative variation in discharge. (Wu and Gatin, 1975)

Simple uniformity or efficiency measures, such as Christiansen's uniformity coefficient, which do not appropriately weigh the values for the distribution of infiltrated depths, may not be good measures of irrigation effectiveness. The need for appropriately weighting the distribution has lead to the use of effective terms such as the low quarter distribution uniformity (Kruse, 1978)

Merman *et al*. (1996) tried three types of irrigation in green houses- overhead, drip and sub irrigation. From their study, they revealed that fixed overhead systems are characterized by low irrigation uniformity and efficiency. Drip systems were high in irrigation uniformity and moderate in irrigation efficiency, and although high in initial cost, subsurface systems were high in irrigation uniformity and efficiency.

Irrespective of filtration and applied pressures, discharge uniformity tests showed that even with filtration, the values of coefficients of variation (C_V) for the successive pieces of porous pipes ranged from 20 to 35 %, indicating an intrinsic variability of the product. It was concluded that the product does not possess a uniform porosity as a function of length and there is no improvement in the permeability of the material with time. (Teeluk *et al.* 1998)

2.2.1.2. Low *Quarter Distribution Uniformity*

For a normal distribution, low quarter distribution uniformity, DUlq was expressed in terms of the coefficient of variation, Cv which is the standard deviation divided by the mean of the emitter flow. (Hart and Reynolds, 1965)

2.2.1.3. *Emission Uniformity*

Basic emission uniformity is the ratio between the minimum discharge and the average discharge expressed in percentage**.**

Keller and Karmeli (1974) assumed emitter properties as normally distributed and proposed an expression for emission uniformity**.**

2.3. MOISTURE DISTRIBUTION PATTERN

Whitney *et al*. (1966) conducted the study of filter distribution from pressurised subsurface irrigation in laboratory conditions in which pressure and orifice size were the controlled variables and arrived at certain equations to plot the time of application against the distance travelled by the water front.

Said Mostoghim (1982) conducted laboratory experiments to study the effect of drip discharge rate on the distribution of soil moisture in silty loam and the results indicated that drip discharge rates resulted in an increase in vertical component and decrease in horizontal component of wetted zone.

The amount of water emitted by the porous irrigation tubing may be presented in either tubular or graphical form. (Pair *et al*., 1983). They describe the pressure – emission response of porous tubing designed to uniformly weep through its micro pores. The hydraulic characteristics observed were complex responses to particulate content and supply pressure.

Khepar *et al*.(1983) reported that the moisture distribution in drip irrigation systems depends on rates of application, amount of water applied and the initial moisture content. As the rate of application increased, the vertical component of the wetting zone increased in light textured soils.

Hanson *et al*. (1985) conducted experiment on row crops to investigate wetting patterns under drip irrigation under a variety of conditions. The conditions revealed the wetting pattern in a very fine textured soil, under different irrigation frequencies and at different installation depths of drip tape. Patterns were also developed for conditions of mild and severe deficit irrigation.

Kataria and Michael (1990) observed that under drip irrigation in tomato, the surface soil layer up to 10 cm depth had the maximum soil moisture content and it decreased with increasing depth. This coincided with the regions having the maximum number of effective roots, resulting in better environment for higher yields.

Prasher (1995) investigated the performance of a subsurface irrigation system in a clay soil under field conditions from 1989 to 1991 and found that subsurface irrigation could be practiced successfully in some clay soils of Quebec. The soil moisture content was found to follow the same behaviour as the water table elevation. It was also found that under the same applied hydraulic head, the drain spacing did not affect the soil moisture distribution. Subsurface irrigated plots were found to make better use of rain water since they did not permit the forming of well – defined macro pores allowing the rainfall to move below the root zone without wetting it.

Bush *et al.* (1996) investigated the movement of water from a certain experimental plastic pipe. A model was constructed to represent the cross section profile, transverse to the buried plastic pipe. The model showed the moisture movement in upward, downward and horizontal directions.

Muirhead *et al*. (1996) reported that the subsurface water distribution pattern for a given soil depends on the rate and duration of water application and depth of pipe installation.

The flow phenomenon under surface and subsurface drip irrigation was studied by Visalakshi *et al.* (2004) by observing the wetting pattern of the soil surface and soil profile under the system. Generally an inverse relationship was observed between discharge rates and area wetted. The lower the discharge rates, the wider were the areas wetted and vice versa. The subsurface application resulted in an increase in soil moisture retention of 3-4 % at the point of application compared to that of surface application. The pattern of moisture distribution was almost the same under both the locations of drip emitters. Mathematical models were also developed relating the horizontal and vertical water front advance and the rate of discharge.

2.4. DISTRIBUTION EFFICIENCY

Goldberg *et al*. (1969) observed that the distribution of water varies and infiltration and storage of water in the root zone are local and change over small distances from the source.

Gajare (1982) observed that as the distance from the dripper increased, the moisture content generally decreased with increase in time. It was also observed that the middle layer of 15 to 30 cm of soil depths generally contain more moisture than the top or bottom layers.

Goel *et al.* (1993) reported that the lateral movement of water and its distribution in the soil depends upon many parameters such as soil type, rate of infiltration, rate of emitter discharge, quantity of water applied, antecedent moisture content, depth to water table and certain climatic factors.

A study conducted at the Center for Irrigation Technology (1995) revealed that the uniformity coefficient for the porous pipe was 87% and distribution uniformity was 74%.

Suseela *et al.* (2005) reported that porous pipes provided with sand envelope gave better distribution efficiency and higher discharge rates than that without sand envelope.

2.5.LATERAL DEPTH AND SPACING

Phene *et al*. (1983) reported that the yield, quality and evapotranspiration of tomatoes are not affected by the depth of placement of trickle laterals when irrigated volumes and frequencies were the same.

Schwankl *et al.* (1990) investigated three lateral depths, three tomato seed depths and three irrigation amounts on a clay loam in California and they arrived at the best combination to get higher yield.

Lamn *et al.* (1995) evaluated subsurface irrigation at 1.5, 2.28 and 3 m spacing for corn in North Kansas and these spacing had the highest yield and water use efficiency.

Manges *et al.* (1995) predicted equations to estimate plant population to maximize grain yield for subsurface drip line spacing which varied from 0.76 to 3 meters. The equations could be used to evaluate the economics of alternate tubing spacing for corn.

A study of subsurface irrigation with porous tubes under different lateral spacing was conducted on a wheat crop in Riyadh region of Saudi Arabia (Mohammad, 1998). A lateral spacing of 1m resulted in water savings of 10% over the sprinkler irrigation system.

Nagarajan. (2002) studied the effects of porous pipe irrigation on the crop Bhendi and tested the performance by placing the porous pipe at three depths. He found out the optimum depth of placement of porous pipe for maximum yield of the crop. It was also found in the study that drip irrigation gave a higher water use efficiency and yield than the porous pipe irrigation treatments and the control treatment.

2.6. OPERATING PRESSURE OF POROUS PIPES

Porous tubing did not provide a mathematically predictable emission response to applied pressure. Relatively steady emission was obtained after an initiation pressure greater than 20 kpa using unfiltered water. Unfiltered water prevented the establishment of a steady response.

Smajstrla (1994) conducted a long term study on the hydraulic performance of line source porous pipe micro irrigation laterals installed in turf grass plots in Florida, USA. Commercially available porous pipe products manufactured by Aquapore pipe and Precision porous pipe were evaluated. Lateral flow rate were erratic and declined rapidly when flow was controlled using manifold pressure only. Flow rate declined slower, yet were still unacceptable when flow control valves were installed on individual laterals and operated at 1.7 kg/cm^2. Only when flow control valves were operated at a pressure of 3.74 kg/cm^2 to 4 kg/cm^2 were lateral flow controlled at acceptable rates over a period of several months.

Sohrabi *et al.* (1997) conducted experiments to study the effect of different pressures and pipe lengths on moisture and salt distribution with the combination of three pressures and three pipe lengths. The study was conducted in a Vineyard in Karaj, Iran. The statistical analysis of the data obtained from these experiments showed that the movement of water through the soil is a function of pressure, i.e. the positive pressure increased the moisture gradient from the water source.

Mohammad (1998) conducted research to study the factors leading to the uniform distribution of water from a subsurface irrigation system using porous tubes. The factors included the depth at which the tubes are installed, operating pressure, depth of impermeable layer and a gravel envelope surrounding the tubes. A laboratory soil tank was filled with sand and fitted with porous tubes. The tank and the tubes represented a section of soil profile. The depth of impermeable layer significantly affected the water table rise in the soil profile. The gravel envelope did not show any advantages over tubes without an envelope in sandy soils. It was observed that the porous tubes did not work efficiently either under low pressure of 80 KPa or very high pressure of 150 KPa.

Teeluk *et al.* (1998) conducted study to determine the effects of filtration and operating pressure on discharge rates of the porous pipes made from recycled car tyres. The time variation of the flow was also tested.

2.7. COMPARISION OF SUBSURFACE IRRIGATION SYSTEM WITH OTHER IRRIGATION SYSTEMS

Many studies have been conducted to compare the subsurface irrigation with other irrigation systems. From the studies it was found that subsurface irrigation systems have a number of advantages over other irrigation systems.

2.7.1. Evaporation Losses

Koumanov *et al.* (1997), conducted studies of different irrigation methods. He compared drip irrigation, subsurface irrigation and micro sprinkler irrigation system. He observed that evaporation under micro sprinkler irrigation particularly in a young orchard where the tree canopy is not fully developed , is greater compared to the drip and subsurface irrigation systems, due to the larger wetted area and spray losses during sprinkler irrigation.

2.7.2. Yield of the crop

Three new systems were tested in June 1970, by Zetzsche, J.B. and Newman to evaluate different types of irrigation systems. One system had perforated pipe, the other had micro pore plastic pipe and the third was trickle irrigation system with three emitters per tree with pipes laid on the surface. Cotton lint production increased from 9.87 kg per ha-cm to 14.23 kg per ha-cm water with subsurface irrigation.

Hanson *et al.* (1985) conducted studies on crop yield of cotton for 3 years with two irrigation methods, viz surface irrigation and subsurface irrigation. In each year the plants on subsurface irrigated plots grew faster and the bolls developed earlier. The cotton yields were greater each year for the subsurface irrigated plots. The average yield increase over the 3 years was 148.2 kg of lint cotton/ha/year. The percentage of yield in subsurface and surface irrigated plots were 86 and 75.

Phene *et al.* (1983) reported a comparative study of surface and subsurface drip on tomato. Yield data indicated that tomatoes irrigated by subsurface system produced more harvestable tomatoes than tomatoes irrigated by the surface systems when the same amount of irrigation water was applied.

Murugaboopathi *et al*. (1991) conducted the study of budding growth of cotton under different irrigation methods. The ability of the subsurface irrigation system to maintain a good soil condition was analysed through chemical changes of the soil and were compared with the changes resulting from the application of other types of irrigation and soil systems.

When compared to surface drip, subsurface drip had greater yield for sweet corn in Israel and California (Bar-Yosef *et al.,* 1989); and for tomato in California (Phene *et al*., 1987).

Cotton yields were greater with subsurface drip than with furrow irrigation on silty soil but not for sandy soil (Phene *et al.,* 1992) and were equal in another study .

The efficiency of the subsoil irrigation using micro porous pipe lines and of conventional drip irrigation lines was investigated in an apple orchard near Bulgaria

(Gospodinova *et al*., 1994). The trees were densely planted at 3.5 x 1.3m spacing. Using a three day cycle, drip irrigation induced higher vegetative growth rates, but lower average yields than the subsoil micro irrigation.

Dhotre *et al. (*2005) studied the Hydraulics of porous pipe irrigation system for Sugarcane and recorded that the drip irrigation treatment recorded the highest yield followed by the subsurface irrigation treatments.

2.7.3. Water Use Efficiency

Fox *et al*. (1956) pointed out that certain conditions must exist for sub irrigation to be practical, because sub irrigation involves actual management of the water table. Either an impermeable layer or a permanent water table should exist at a rather shallow depth to prevent excessive seepage losses. Further the topography should be nearly flat and the soil should have a high hydraulic conductivity so that reasonable drain spacing can be used to provide both sub irrigation and drainage.

Previous research in western Kansas has shown that, using subsurface drip irrigation, water savings of up to 25% are possible with little or no reduction in yield (Lamm *et al*., 1995).

In the humid southeast USA, Camp *et al*. (1998) showed that subsurface drip irrigation required less irrigation water than surface drip irrigation.

Nayanakantha *et al.* (2003) studied two types of irrigation methods namely; manual watering and a micro-irrigation system in which the porous pipes buried 10cm below the ground level were tested in a rubber nursery at the Rubber Research Institute of Sri Lanka for two consecutive years. Both poly bagged and ground rootstocks of rubber seedlings were used for the experiment. The system was operated for one hour everyday and the volume consumed by the system was about half of the requirement of that for manual watering.

Dhotre R.S *et al.* (2005) reported that the porous pipe irrigation system saves 52.33 % of water over furrow irrigation and 17.65 % over drip irrigation system.

2.7.4. Energy Requirement

Fox *et al*. (1956) reported that sub irrigation has a very low labour requirement than other irrigation systems. Where sub irrigation is adaptable and the system is properly designed and operated, it is probably the most efficient method from the labour stand point.

Strickland *et al.* (1981) found that sub irrigation of Corn required about 70% less energy than center pivot systems near Orangeburg. The water supply was from a deep well for each system.

A study of subsurface irrigation with porous tubes under different lateral spacing was conducted on a wheat crop in Riyadh region of Saudi Arabia (Mohammad, 1998). The results showed that the technique can save 80% of the energy compared to centre pivot systems.

CHAPTER 3

MATERIALS AND METHODS

3.1. LOCATION AND CLIMATE

The laboratory study was conducted in the Soil and Water Engineering Lab at KCAET, Tavanur, in Malappuram district. The field performance was evaluated at Instructional Farm, KCAET, Tavanur. The place is situated at 10^0 52' 30" North Latitude and 76^0 East longitude.

This area falls between the border line of Northern Zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon.

The table 3.1 shows the average rainfall at different months of the year in the instructional farm, KCAET, Tavanur.

Table 3.1. Average Annual Rainfall in the Experimental Site

Sl.No.	Month	Rainfall(mm)
1	January	9.38
2	February	3.96
3	March	18.15
4	April	66.52
5	May	105.49
6	June	435.86
7	July	481.98
8	August	342.61
9	September	165.89
10	October	173.71
11	November	93.38
12	December	27.44
Total		1924.4

The mean climatic parameters recorded during the study period were as follows:

Mean maximum temperature	: 32.5 ^{0} C
Mean minimum temperature	: 22 ^{0} C
Average relative humidity	: 83 %
Average annual rainfall	: 1924 mm
Mean evaporation	: 7 mm / day
Mean solar radiation	: 85 W/ m ^{2} / day

The climatic parameters recorded during the course of the study is given in Appendix I

3.2. EVALUATION OF PHYSICAL PROPERTIES OF SOIL

The soil properties like texture, bulk density and infiltration capacity are the dominant factors which determine the moisture holding capacity and moisture movement through the soil. Texture is an important soil characteristic since it affects the infiltration rate, water storage in the soil, ease of tilling the soil, the amount of aeration and the soil fertility. Knowledge of the bulk density is of particular importance in the determination of moisture content and other chemical and physical properties of the soil. It can be used to estimate the differences in compaction of the soil.

The soil samples were randomly collected from different points in the field at three different depths i.e. 0-10, 10-20, and 20-30 cm. The soil samples collected from the same depths were mixed thoroughly, air-dried, clods were broken and then the resulting mix was used for sieve analysis.

3.2.1. Determination of Particle Size

Particle size analysis or mechanical analysis provides the basic information for revealing the uniformity or gradation of a material within established size ranges and is used for textural classifications. The sizes of grains and their proportions are of major importance and they are determined as per IS 2720 (Part 4) - 1985.

The IS standard sieves of sizes, 4.75mm,2.36mm,2.00mm,1.18mm,1.00mm 600µ,425µ, 300µ, 212µ, 150µ, 75µ and 45µ were used. Sieving was performed by arranging the various sieves one over the other in the order of their mesh openings. The largest aperture sieve was kept at the top and the smallest one at the bottom. A cover and a receiver pan were kept at the top and bottom of the assembly respectively. Three soil samples of about 1500 gm were taken and oven dried. The weights of the oven dried soils were determined before they were subjected to sieving. The fractions of soil retained on each sieve were weighed using an electronic balance of 0.01 gm accuracy.

3.2.2. Bulk density

The core cutter method was adopted to determine bulk density. Soil samples were collected by using the core sampler. The weight (W_1) and volume (V_1) of the core cutter were found out. The soil sample collected in core cutter was oven dried and the weight of the soil sample was found out i.e. ($W_3=W_2-W_1$). Bulk density was then calculated by using the relation,

$$\text{Bulk density (gm/cc)} = \frac{W_3}{V_1}$$

3.2.3. Infiltration rate

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

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

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

where

y = accumulated infiltration (cm)

t = elapsed time(hr)

a,b, α = constant

Plate 3.1 Infiltration Measurement

3.3. DISCHARGE STUDIES OF PRECISION POROUS PIPE

3.3.1. Determination of Water quality

The assessment of the quality of water that was used for irrigation purposes was done to find out the impurities or harmful substances in the water. Two prerequisites of good quality water are that it must be safe for the crops and it should not damage the soils. Irrigation water drawn from different sources, surfaces or underground contains salts, silts and other materials. The quality of water desirable for irrigation is given in table 3.2.

Table 3.2.Desirable water quality for irrigation as per recommendations of FAO (1985)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
EC	dS/m	<0.7	0.7-3.0	>3.0
Total dissolved solids	mg/l	<450	450-2000	>2000
Infiltration				
SAR = 0-3 and EC =		>0.7	0.7-0.2	<0.2
3-6		>1.2	1.2-0.3	<0.3
6-12		>1.9	1.9-0.5	<0.5
12-20		>2.9	2.9-1.3	<1.3
20-40		>5.0	5.0-2.9	<2.9
Specific ion toxicity				
Sodium (Na) (7.4-480)				
Surface irrigation	SAR	<3	3-9	>9
Sprinkler irrigation	meq/l	<3	>3	
Chloride (Cl)(3.1-88)				
Surface irrigation	meq/l	<4	4-10	>10
Sprinkler irrigation	meq/l	<3	>3	
Boron (B) (< 0.1-0.5)	mg/l	<0.7	<0.7-3.0	>3.0
Nitrogen (NO_3-N) (0.4-4.9)	mg/l	<5	5-30	>30
Bicarbonates(HCO_3)	meq/l	<1.5	1.5-8.5	>8.5
pH (5-10)	Normal range 6.5-8			

3.3.2. Components of experimental setup in the laboratory

Storage tank

A 500 L Hycount tank was used for feeding water to the system.

Pumping unit

A centrifugal pump of the following specification was used for the study

Discharge	: 2.1 lps
Head	: 18.5 m
HP	: 0.5
Speed	: 2800 rpm

Control unit

A 32 mm diameter gate valve was provided at delivery line to control the discharge. The various operating pressures were obtained by adjusting the bypass control valve.

Screen filter

It consists of a perforated cylinder placed in a plastic container for removing the foreign materials. Generally 100 – 200 mesh stainless steel screens were used. The filter used for the present study had a capacity of 10 m^3/hr. It must be cleaned and inspected periodically for satisfactory operation of the system.

Mainline & Sub main line

Rigid PVC pipes of 40 mm diameter with pressure rating of 4 Kg/cm^2 were used as the main and sub main pipes.

Laterals

The laterals used for the study was porous pipes of 22 mm outer diameter. The length of lateral was limited to 4 m under lab condition.

Flushing unit

The sub main unit was provided with a flushing valve to flush out all the foreign materials. Periodic flushing once or twice in a week was done.

Plate 3.2. Laboratory experimental setting

Pressure gauge

They were located before and after the filter for indicating the pressure in the system with pressure range of 0-6 kg/cm^2. The operating pressure was read from these pressure gauges.

3.3.3. Evaluation of Pressure and Discharge relationship

The pressure discharge relationship was studied for testing the hydraulic characteristics of the porous pipe at room temperature of 25°C. The sizes of the PVC pipes used for the study as main and sub main pipes were 40 mm Ø. Random pieces of porous pipe of 4 m length were taken from the middle of the roll and used for the study under laboratory conditions. The laterals were arranged inside PVC pipes of 40 mm Ø. The main pipe was connected to a 0.5 HP centrifugal pump and the source of water was the sump. The water discharged was collected through PVC pipes with the help of plastic basins kept at each end of the laterals. The pressure was gradually increased starting from 0.2 to 1 kg/cm^2 at increments of 0.2 kg/cm^2. The corresponding discharge was measured for different time intervals from 5 to 60 minutes for each pressure. The set up is shown in Plate 3.2.

3.3.4. Determination of coefficient of manufacturing variation (Cv)

The determination of coefficient of manufacturing variation was done in the lab using six segments of porous pipes of length 4 m each taken randomly from the roll of porous pipe. For a given pressure, the discharges were collected from all the segments. A cylindrical tank was set up with a centrifugal pump with suction hose inside the tank and the delivery hose connected to the main pipe. Between the pump and the delivery pipe a pressure gauge was fitted to measure the delivery pressure and a by-pass arrangement to divert the excess water into the tank again. The size of the main pipe used was 40mm PVC pipe. From the main, PVC sub mains of 40 mm size were connected and on the sub mains, the lateral pipes were fixed by drilling the pipe with 20 mm drill bit. Six such drills were made for connecting six segments of 20 mm porous pipes. The porous pipes were fixed to the sub mains by means of grommets and washers. All these porous pipe segments were arranged inside PVC pipes. A small slope was given so that the water gets collected at one end of the PVC pipe. The arrangement is shown in plate 3.2.

The coefficient of manufacturing variation was determined using the equation proposed by Larry G.J. (1998).

$$C_v = \frac{[\, q_1^2+q_2^2+\ldots\ldots.. q_n^2 - nq^2 \,]^{1/2}}{q\,[n-1]^{1/2}}$$

Where,

C_V	= coefficient of manufacturing variation(%)
q_1, q_2, q_3 &qn	= discharges from different segments(l)
q	= average discharge for the total segments(l)
n	= number of segments

3.3.5. Determination of Emission Uniformity

The coefficient of uniformity is a measure of the hydrodynamic behavior of the system. It is an indicator of how equal the application rates resulting from the delivery devices are. A low coefficient of uniformity indicates that the application rates from the delivery devices are very different, while a high coefficient of uniformity indicates that the application rates from the delivery devices are very similar in value. The coefficient of uniformity by itself is not a measure of how well the system is distributing water within the root zone.

For determining uniformity of the system, the discharge rates at different segments were recorded. A porous pipe of length 10 m was cut from the roll at random. It was divided into ten segments of 1 m length. At 0.3 kg/cm^2 pressure, the discharge of water was calculated at each segment by using catch cans.

The coefficient of uniformity was determined for the porous pipe irrigation system using the equation proposed by Larry G.J. (1998)

$$E_u = 1.0 - \frac{1.27\,C_v}{\sqrt{N_e}} \quad \frac{Q_{min}}{Q_{avg}} \; 100$$

where,

E_u = emission uniformity(%)

N_e = number of point source segments

C_v = manufacturers coefficient of variation(%)

Q_{min} = the minimum discharge rate(lph)

Q_{avg} = the average rate(lph)

3.4. FIELD STUDY

3.4.1. Nursery preparation

Amaranthus seedlings of variety Kannara Local, KAU, were selected for the study. A nursery was raised for producing sufficient seedlings for transplanting in the field. The nursery was prepared on a raised bed. A section of the nursery is shown in plate 3.3.

Plate 3.3. Seedlings in Nursery

3.4.2. Experimental setup

Completely randomized design with 15 treatments and 3 replications for the crop was adopted for the study.

Two types of cropping were done in each sub mains. One was ***paired row cropping*** which has a single row of plants on each side of the porous pipe lateral. The other was ***double paired row cropping*** which has two rows of planting on either side of the porous pipe lateral. Three replications were done in all the treatments.

3.4.3. Crop and variety

In the experimental field, the crop raised for the study was *Amaranthus sp.*, variety kannara local. It is the most popular leafy vegetable of Kerala. The total duration of the crop was 90 days. The details of the treatments are given in table 3.2.

Table 3. 3.Treatment Details

Treatment	**Name**	**Area(m^2)**	**Description**
T_1	$S_1D_1r_1$	2.4	Porous pipe irrigation, with sand envelope ,at 10 cm depth, paired row
T_2	$S_1D_1r_2$	4.8	Porous pipe irrigation, with sand envelope ,at 10 cm depth, double paired row
T_3	$S_1D_2r_1$	2.4	Porous pipe irrigation, with sand envelope ,at 15 cm depth, paired row
T_4	$S_1D_2r_2$	4.8	Porous pipe irrigation, with sand envelope ,at 15 cm depth, double paired row
T_5	$S_1D_3r_1$	2.4	Porous pipe irrigation, with sand envelope ,at 20 cm depth, paired row

T_6	$S_1D_3r_2$	4.8	Porous pipe irrigation, with sand envelope ,at 20 cm depth, double paired row
T_7	$S_2D_1r_1$	2.4	Porous pipe irrigation, without sand envelope ,at 10 cm depth, paired row
T_8	$S_2D_1r_2$	4.8	Porous pipe irrigation, without sand envelope ,at 10 cm depth, double paired row
T_9	$S_2D_2r_1$	2.4	Porous pipe irrigation, without sand envelope ,at 15 cm depth, paired row
T_{10}	$S_2D_2r_2$	4.8	Porous pipe irrigation, without sand envelope ,at 15 cm depth, double paired row
T_{11}	$S_2D_3r_1$	2.4	Porous pipe irrigation, without sand envelope ,at 20 cm depth, paired row
T_{12}	$S_2D_3r_2$	4.8	Porous pipe irrigation, without sand envelope ,at 20 cm depth, double paired row
T_{13}	dr_1	2.4	Drip Irrigation paired row
T_{14}	dr_2	4.8	Drip Irrigation double paired row
T_{15}	C	3.2	Surface Irrigation

3.4.4. Field layout

The field layout plan for the study is given in Fig.3.1.

A hycount water tank of capacity 500 liters was used as the source for the irrigation systems which were fed by a large overhead tank by gravity. The water level inside the hycount water tank was controlled by a ball valve and float arrangement. An inlet screen filter was provided to screen any dirt coming from the hydrant. The outlet side of the water tank was connected to a screen filter to remove the impurities coming from the tank to the field. A water meter was fixed on the main pipe after the outlet screen filter.

The size of the main and sub main pipes were 40mm. The size of the porous pipe laterals were 20 mm. The drip irrigation laterals had a size of 16 mm and the drip emitters had a discharge of 4 lph and the emitters were installed 60 cm apart.

The porous pipe treatments involved a planting area of 43.2 m^2, with 12 treatments each double paired row treatment having an area of 4.8 m^2 and each paired row having an area of 2.4 m^2. The drip irrigated area comprised of an area of 7.2 m^2 with two treatments and the control plot had an area of 3.2 m^2. The total planting area was 53.6 $m^{2.}$

3.4.5.Land Preparation

The method of preparing the land for laying porous pipes is shown in plate 3.4 The porous pipes were provided at the depths of 10, 15, 20 cm with sand envelope and without sand envelope. The treatments requiring sand envelop were given a sand layer of 5 cm at the bottom of the trench. (Plate 3.8). Then the porous pipes were laid into the rows uniformly. (Plate 3.9) Again the porous pipes with sand envelope were given 5 cm depth of sand at the top. (Plate 3.10). Finally all the rows were covered with soil.

The ends of the porous pipes are let outside, above the surface to facilitate flushing of laterals if they become clogged. Both ends of the porous pipe laterals are marked by using stakes to identify the line of lateral installation.

Plate 3.4. Land Preparation

3.4.6. Preventive maintenance

The purpose of preventive maintenance was to keep the irrigation system from clogging. They can be clogged by suspended solids, Magnesium and Calcium precipitation, Manganese, Iron oxides, Sulphides, algae, bacteria, and plant roots. The system contained a water meter and two pressure gauges, one before the filter and another after the filter. These devices were given an inspection every day. They indicated whether the system was working properly. A low pressure reading on a pressure gauge meant that the pipe was leaking or broken. A difference in pressure between the filters meant that the system was not back flushed properly and that the filters are to be cleaned. The water quality was known so that problems can be anticipated.

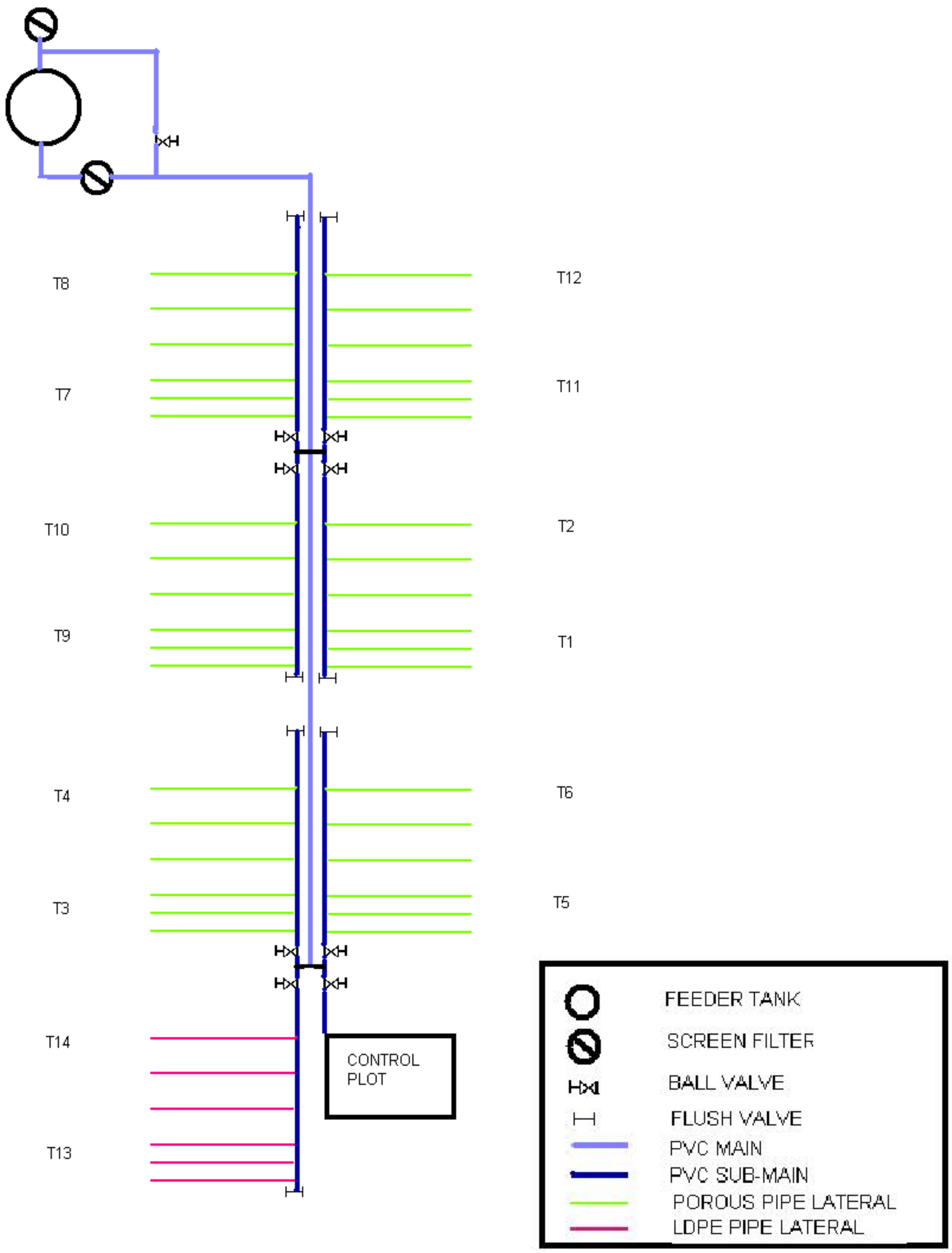

Figure 3.1 Field Layout of the experiment

3.4.7. Flushing Lines and Manifolds

Very fine particles pass through the filters and can clog the pores of the porous pipes. As long as the water velocity was high and the water was turbulent, these particles remain suspended. If the water velocity slows or the water becomes less turbulent, these particles may settle out. This commonly occurs at the distant ends of the lateral lines. If they are not flushed the line eventually will be filled with sediment from downstream to upstream end. Systems must be designed so that mains, sub-mains, manifolds and laterals can all be flushed with a valve installed at the very end. (Plate 3.5).

Plate 3.5.Flushing Device for Laterals

Lateral lines were flushed manually. It is important to flush the lines at least every week during the growing season.

3.4.8. Maintaining Filters

The filter is important to the system's success. Water must be filtered to remove suspended solids. There are three main types of filters: cyclonic, screen or disk filters and media filters. It is a common practice to install a combination of filters to work more effectively.

Plate 3.6. Filters and By-Pass Assembly

Plate 3.7. Feeder Tank with Float Valve

Plate.3.8.Sand Envelope

Plate.3.9. .Porous Pipes Installation

Plate 3.10.Porous Pipes with Sand Envelope

In our study, two screen filters were used. One was installed before the feeder tank called the inlet filter and another after it which is called outlet filter. When the pressure between the two pressure gauges in the inlet and outlet filters drops more than 0.05 kg/cm^2, the screen filter was flushed. The flushing can also be timed according to the irrigation time and the quantity of water.

The plate 3.6 shows the arrangement of the filters and the by-pass assembly for flushing the system.

3.4.11. Transplanting

Before transplanting the porous pipe irrigation was turned on so that it creates a moisture band surrounding it to facilitate transplanting. When the seedlings are 15-20 days of age, transplanting was done in the field. Copious irrigation water was given and without damaging the roots, the seedlings were slowly removed from the nursery. When transplanting in the field, plants were planted in a parallel line 10 cm away from the porous pipe lateral for the first row and 30 cm away from the porous pipe lateral for the second row. The plant to plant distance was kept at 15 cm and the row to row distance was maintained at 20 cm. After transplanting, artificial shading was given for two to three days to avoid sun burning of the young plants.

3.4.12. Irrigation

Manual watering was done for a period of one week during early mornings and late evenings to ensure that the roots get enough water for the seedlings to survive. The flow through a particular sub main was found out by closing the other sub main valves and keeping the valve alone open and noting the water meter reading. In this way we measured the discharge under field conditions for different depths of porous pipes. The water requirement for Amaranthus was calculated and the porous pipes irrigation system was turned on for that calculated amount of time so that the required quantity of water was delivered. For drip irrigation the water was given according to the calculated requirement. For the plants under control plot, irrigation was given when there was an evident visual sign of moisture stress.

3.4.12.1. Water requirement

The water requirement for the Amaranthus was calculated to provide the right amount of water to the plants. This was done considering the soil group, root depth, crop factor, crop coefficient and reference crop evapotranspiration under local conditions.

$$ETc = ETo*Kc$$

$$MAD = P'* AWC* Rd$$

$$I = MAD/(ETc-Gc) + Ts$$

$$Dn = I/(ETc-Gc)$$

Dg = Dn/efficiency

W.R = A*dg/1000

Where,

ETc = evapotranspiration for the crop (mm/day)

ETo = reference crop evapotranspiration (mm/day)

MAD = maximum allowable deficit (mm)

P’ = crop factor

Kc = crop coefficient

Ts = number of days to reach field capacity

AWC = available water holding capacity (mm)

I = irrigation interval (days)

Dn = net depth of irrigation (mm)

Dg = gross depth of irrigation (mm)

A = area (m^2)

Rd = root zone depth (m)

W.R = water requirement (m^3/ha)

Plate 3.11 Porous Pipe Discharge Pattern

3.4.13. Fertilizer application

The application of fertilizer was started 15 days after the crop was transplanted in the field. Every week, 250 gm of water soluble fertilizer was dissolved in the feeder tank so that the porous pipe irrigation treatments and the drip irrigation treatments were fertilized. Fertilizing the control plot was done by broadcasting 40 gm of water soluble fertilizer and irrigated.

3.5. SOIL MOISTURE DISTRIBUTION PATTERN

Soil moisture distribution pattern was obtained by measuring the soil moisture from different points in the cross sectional plane. A cross section of the soil perpendicular to porous pipe was cut to a depth of 1m and width 1.2m. (Plate 3.12)

Plate 3.12. Moisture Distribution of Porous Pipes

Soil samples were taken at different horizontal and vertical coordinates. Soil moisture measurements were made by gravimetric method. Soil samples were taken using soil augers. After taking soil samples, they were kept in moisture boxes and covered immediately with lids. The samples were weighed along with the moisture box and then placed in an oven at 105°C for 24 hrs. It was weighed again. The soil moisture content was expressed as percentage by weight on dry basis.

$$\text{Moisture content (\%)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

where,

W_1 = weight of empty container with lid, gm

W_2 = weight of empty container with lid and moist soil, gm

W_3 = weight of empty container with lid and dry soil, gm

Soil moisture contour maps were plotted by using computer software package 'Surfer' of windows version.

3.6. DISTRIBUTION EFFICIENCY

Direct control of porosity of the material during manufacture was not always possible and little was known about the discharge uniformity of the porous pipe. The distribution efficiency was highly correlated to discharge rate, depth and spacing of the porous pipes. The distribution and size of pores and the nature of flow pattern also influences it.

The distribution efficiency was calculated using the formula

$$E_d\ (\%) = \left[1 - \frac{\hat{Y}}{Đ}\right] 100$$

where,

E_d = water distribution efficiency (%)

Đ = average depth of water stored during irrigation (mm)

Ŷ = average numerical deviation from Đ

3.6.1. Determination of Water Use Efficiency

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

$$Ew = \frac{Y}{Wu}$$

where,

Ew = water use efficiency (kg/ha-mm)

Y = yield of the crop (kg/ha)

Wu = Total water utilized (mm)

3.7. COMPARISON OF IRRIGATION SYSTEMS

The comparison of porous pipe irrigation with drip irrigation and control were done to assess the feasibility of porous pipe irrigation under the following heads.

3.7.1. Biometric observations

Before the first harvest, the biometric observations were taken. From each row of the crop, three plants were selected and measurements of height of the plant, thickness of the stem and the canopy spread were made. The yield was recorded at each harvest from all the plants.

3.7.1.1. Height of the plant

The heights of plants grown under different treatments were taken as a biometric observation. The measurement was taken from the ground surface to the shoot tip on three plants on each row of the crop.

3.7.1.2. Thickness of the stem

Just before the first harvest thickness of the stem was measured on the selected plants. The reading was taken 2.5 cm above the ground level.

3.7.1.3. Canopy spread

The canopy spread was measured on the selected plants just before the first harvest. This was done by measuring the leaf tip to leaf tip distance at the crown of the plant. The canopy spread was a measure of the health of plants.

3.7.1.4. Yield

Harvesting of the crops was done treatment wise after attaining maturity. Harvesting was done just before the crop started flowering. After the first harvest, other harvests were done at an interval of 10 days.

The first yield was taken one month after transplanting. After that two more yields were taken. The total of the three harvests gave the total yield.

3.7.1.5. Root distribution

The root length and root zone length were measured at the time of crop removal. Root zone was the area of the root where the maximum root hairs which assist in the absorption exist. The maximum length of the roots was called the root length. The root length and root zone depth are recorded in selected plants in all the treatments.

3.7.1.6. Weeds

Weeds interfere with the growth of the crop by absorbing water and nutrients that was given for the crop. Periodical removal of the weeds was essential to maintain an optimum growth rate of crops. However, the cost for weeding is to be kept to a minimum considering the cost economics. Lesser number of weeding and mechanization in weeding achieve these objectives. Mechanization was not always possible when the holding was small. In our study, manual weeding was done.

3.8. COST OF INSTALLATION

The cost of installation of different irrigation systems for the crop was calculated and comparisons were made with different treatments.

3.9. STATISTICAL ANALYSIS

An ANOVA test was used to find out if there was a significant difference between three or more group means. The ANOVA analysis does not indicates between which means there was a significant difference. A post hoc test was necessary to find out between which means there was a significant difference.

The Tukey's Test is a post hoc test designed to perform a pair wise comparison of the means to see where there was significant difference. In our study Tukey's test to be performed only for the depth of placement of porous pipes since this involves 3 pairs. It was used to find out between which pairs of depth of placement there was significant difference**.**

The minimum pair wise difference needed for significance

$$X_{max} - X_{min} \geq T(\text{error (df)}) \times \frac{\sqrt{EMS}}{\sqrt{R}}$$

The independent variables in our experiment are sand envelope and without sand envelope, depth of placement of porous pipes and paired & double paired rows.

The dependent variables are height of plants, thickness of stem, canopy spread and the yield.

CHAPTER 4

RESULTS AND DISCUSSION

Experiments were conducted to evaluate the performance of precision porous pipes in the lab and field conditions. The moisture distribution pattern, pressure – discharge relationships, coefficient of manufacturer's variation of porous pipe irrigation system and biometric observations on growth and yield of crop were observed. The data obtained from the field tests were analysed to evaluate the performance of porous pipes installed at different depths below the soil. The results of the study conducted are discussed in this chapter.

4.1. Soil properties

4.1.1. Determination of Particle Size

The texture of the soil on which the crop was grown was found out by sieve analysis. It was found that 85.31% of the soil that was taken for sieve analysis was sand which had a size ranging between 2 mm to 0.25mm, 12.2 % of the soil was silt which had a size ranging from 0.1 to 0.002 mm. The remaining part of 2.47 % of the soil was clay. From the soil textural classification chart, the soil was found to be loamy sand. Appendix II shows the analysis of three samples.

4.1.2. Bulk density.

The bulk density of the soil in the experimental field found by core cutter method was 1.68 gm/cc. The details of the experiment are given in appendix III.

4.1.3. Infiltration rate

The performance of porous pipe subsurface irrigation was influenced by the infiltration rates of different types of soils.

The appendix IV shows the readings obtained in the double ring infiltrometer experiment. It was observed that the basic infiltration rate of soil was 5.2 cm/hr.

4.2. DISCHARGE STUDIES OF PRECISION POROUS PIPE

The discharge of precision porous pipes was evaluated in the laboratory. The quality of water used for laboratory study was tested for soluble and insoluble salts and impurities.

4.2.1. Water quality

Water quality is an important criterion for irrigation. The different solids present in water can influence the discharge of the porous pipes. The salts present in the water may lead to deposition and clogging over a period of time. Irrigation water containing less total dissolved solids was considered good for irrigation. The quality of water was assessed and the results are shown in table 4.1.

Table 4.1. Quality of water used for laboratory study

Parameter	Unit	Sample quality
Turbidity	NTU	3.50
pH	-	7.35
EC	dS/m	2.64
Alkalinity	mg/lit.	30.0
Total hardness	mg/lit.	182
Calcium	mg/lit.	36.2
Magnesium	mg/lit.	21.0
Chloride	mg/lit.	20.0
Iron	mg/lit.	0.15
Nitrate	mg/lit.	4.40
Bacteriological analysis		
No. of coliforms/100 ml	-	1100
Fecal coliform/100 ml	-	53.0
No. of E. coliforms/100 ml	-	6.00
Sulphate	mg/lit.	nil.
Phosphate	mg/lit.	nil.

4.2.2. Pressure discharge relationship

The pressure discharge relationship was useful to know the head requirement to operate the porous pipe irrigation system in the field. The pressure discharge relationship is useful to test the effectiveness of the porous pipes when it is to be installed in larger areas.

The relationship between pressure and discharge was analysed and it is presented in Appendix V.

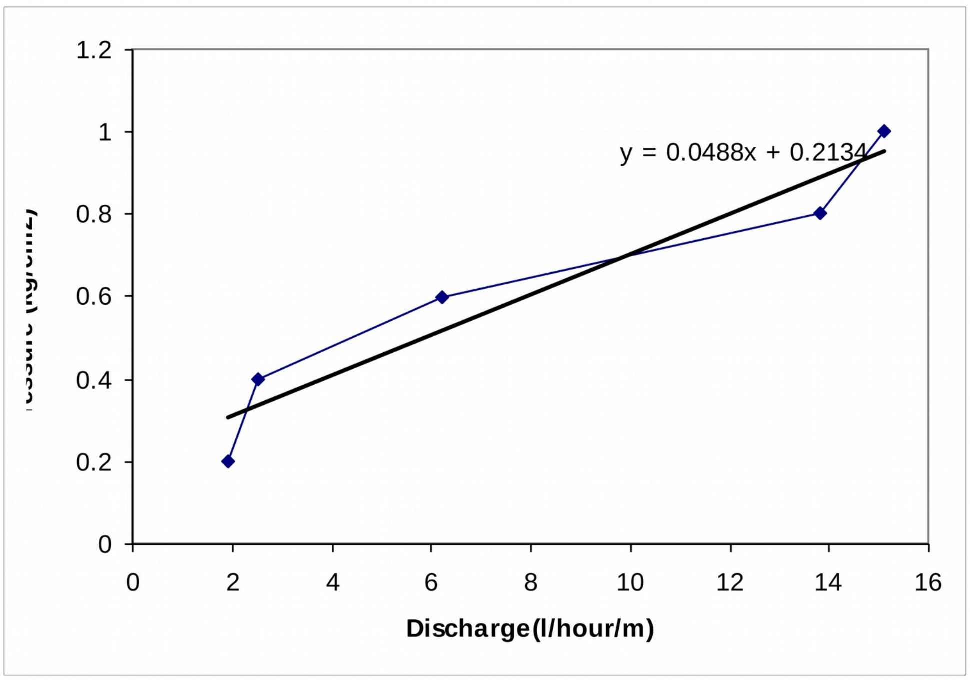

Figure 4.1 The Relationship between Pressure and Discharge of Precision Porous Pipe.

From the graph it was found that a discharge of 1.9 lph/m was obtained at an operating pressure of 0.2 kg/cm^2. This is the lowest amount of discharge observed with porous pipes. At this pressure, water is discharged very slowly without causing flooding. The water losses to deeper layers are negligible. Water can be taken to greater lengths of porous pipes since the water friction with the porous pipes was very less. This pressure can be obtained through gravity by placing the tank at an elevation of 2 m above the ground level. This will be economical for farmers without having to use expensive pumping system.

The relationship between the pressure and discharge in our study was given by the equation

$$Y = 0.0488 X + 0.2134$$

4.3. Determination of coefficients

4.3.1. Coefficient of manufacturing variation (Cv)

The variation in discharge was tested between six segments of 20 mm porous pipes under lab condition. The length of porous pipes tested were 4m each. The pressure applied was 0.3 kg/cm2. The data obtained during the experiment was presented in table 4.2.

Table 4.2. Variation of discharge in porous pipe under same pressure

Segments	**Segment Length (m)**	**Pressure (kg/cm2)**	**Discharge (lph/4m)**	**Discharge (lph/m)**
q_1	4	0.3	9.73	2.43
q_2	4	0.3	8.31	2.08
q_3	4	0.3	9.52	2.38
q_4	4	0.3	11.08	2.77
q_5	4	0.3	8.57	2.14
q_6	4	0.3	7.69	1.92

The coefficient of manufacturing variation determined using Larry G.J. (1998) equation was 13.98 %.

The value of coefficient of variation indicates an intrinsic variability of the product. This finding was in accordance to the study conducted by Teeluk and Sutton (1998).

4.3.2. Emission Uniformity

Table 4.3. Discharge variation along the length of porous pipe

Segment	Length (m)	Pressure (kg/cm2)	Discharge (lph/m)
1	1	0.3	2.51
2	1	0.3	2.42
3	1	0.3	2.39
4	1	0.3	2.14
5	1	0.3	2.04
6	1	0.3	1.91
7	1	0.3	2.05
8	1	0.3	1.82
9	1	0.3	2.01
10	1	0.3	2.14

The emission uniformity was found out to be 82.60 %.

The value of emission uniformity indicates that the discharge of the porous pipes was not uniform for a given pressure and it varies along its length.

4.3.3. Distribution efficiency

Gravimetric method was used to evaluate the soil moisture regime near the porous pipe which helped in monitoring the distribution of soil moisture as a function of depth as well as the horizontal distance from the center of the porous pipe.

Table 4.4.Distribution efficiencies under porous pipe and drip irrigation.

Sl.No	Treatment Name	Distribution Efficiency(%)
1	S_1D_1	88.19
2	S_1D_2	87.59
3	S_1D_3	87.36
4	S_2D_1	81.82
5	S_2D_2	87.21
6	S_2D_3	88.15
7	Drip	76.20

The average water distribution efficiency for porous pipes was calculated to be 86.72 %, 24 hours after irrigation whereas that of drip irrigation was 76.2 %.

The percent of soil moisture obtained in different subsoil conditions is given in Appendix VI.

4.4. FIELD STUDY

The water requirement of Amaranthus under local conditions was calculated to be 0.2 litre/day/plant. Watering was done for the plants in accordance with that data. However for control plot, the locally adopted surface irrigation method was adopted.

4.4.1. Soil moisture distribution pattern

For a subsurface irrigation the moisture distribution uniformity within the effective root zone of crop depends on the capillary action of water from the porous pipe and the lateral spread of water through the interconnected pores. Hydraulic conductivity of the subsoil is the primary factor influencing the soil moisture distribution.

The analysis of the data of moisture content 24 hours after irrigation was done and soil moisture contour maps for the longitudinal cross section of the soil were plotted using computer software package "Surfer" of windows version. The moisture content found at different coordinates is presented in appendix V. The subsurface water distribution pattern for a given soil depends on the rate and duration of water application and depth of pipe installation. The moisture distribution pattern under the porous pipes is shown in figure 4.2 to figure 4.7 and that under drip irrigation is shown in figure 4.8.

The moisture content observed at different depths was higher after the irrigation. It got reduced as the distance from the lateral pipe or emitter increased. The results agree with the findings reported by Philip (1971) and Kaul (1979).

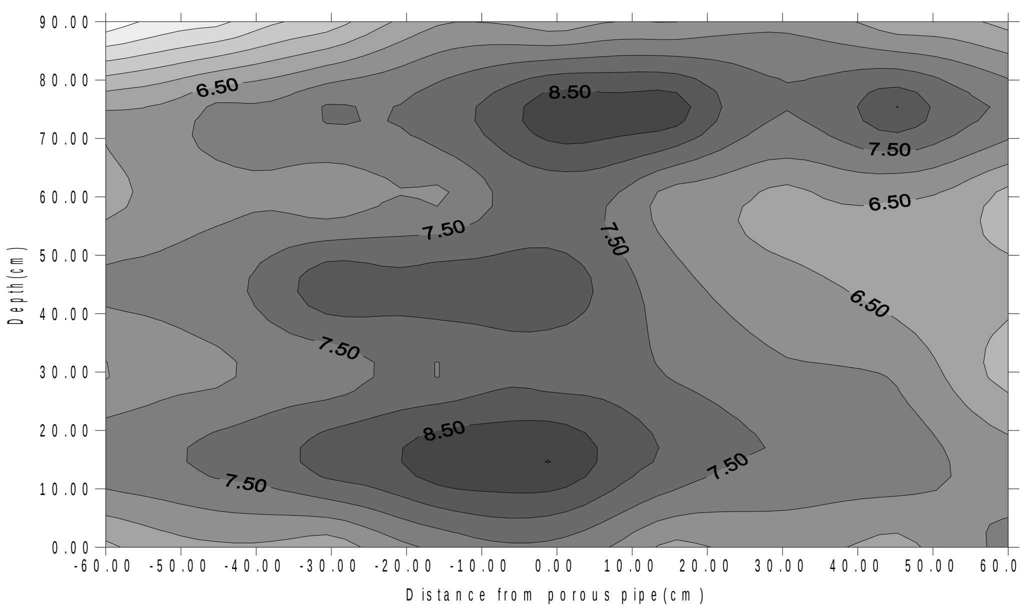

Figure 4.2. Moisture Distribution Pattern in Precision Porous Pipes Laid at 10 cm Depth with Sand Envelope, 24 hours after Irrigation

It was observed that in 10 cm depth placement of porous pipes with sand envelope (Figure 4.2), the water has risen due to capillarity up to the surface 24 hours after irrigation. The lower portion of the shoots was exposed to water most of the time. That may be the reason that the plants did not perform well in this treatment when compared to other treatments.

In 15 cm depth of placement of porous pipes with sand envelope(Figure 4.3) the maximum water content was found near about 30 cm depth, 24 hours after irrigation. The roots had enough water for its survival and also there was good drainage at the lower portion of the shoot system. The performance of the plants was good under this treatment.

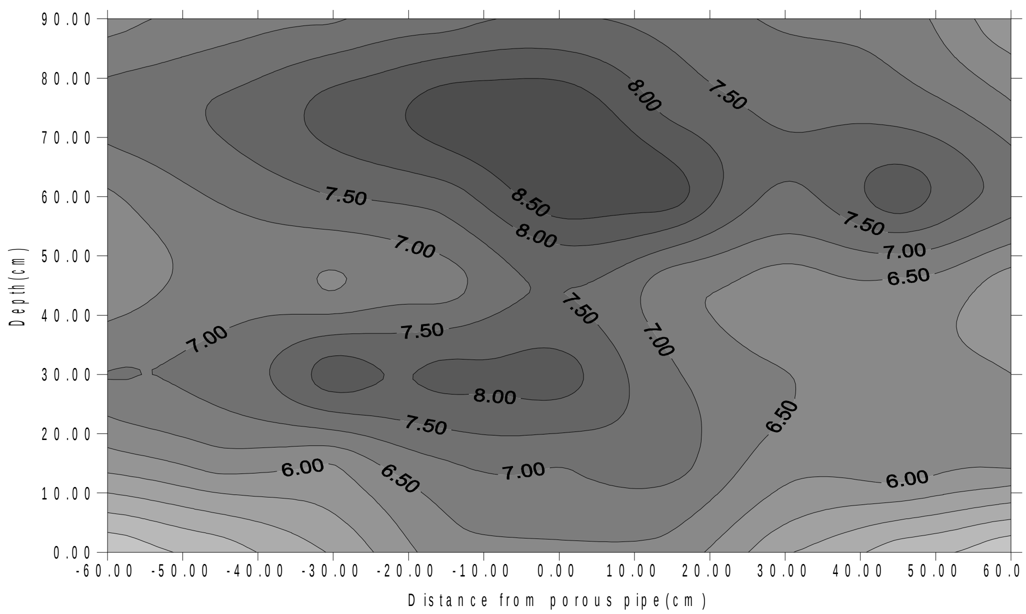

Figure 4.3. Moisture Distribution Pattern in Precision Porous Pipes Laid at 15 cm Depth with Sand Envelope, 24 hours after Irrigation

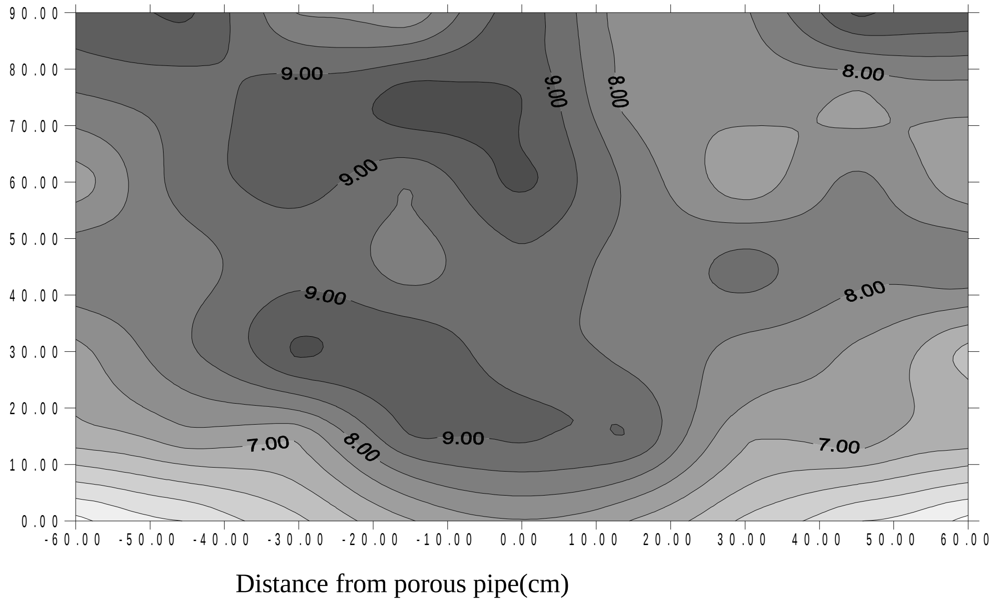

Figure 4.4. Moisture Distribution Pattern in Precision Porous Pipes Laid at 20 cm Depth with Sand Envelope,24 hours after Irrigation

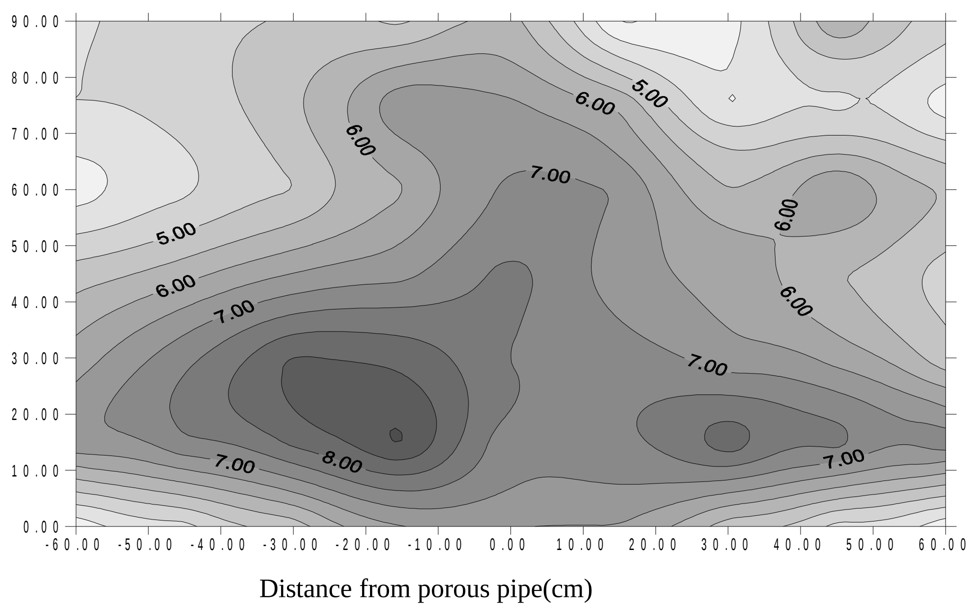

Figure 4.5. Moisture Distribution Pattern in Precision Porous Pipes Laid at 10 cm Depth without Sand Envelope,24 hours after Irrigation

In the treatment with porous pipes laid at 20 cm depth with sand envelope, (Figure 4.4), the water has moved to deeper horizons. Because of the capillary action the water rose to the root zone to feed the crops.   At the same time there was good drainage also near the shoot base. There was no water stagnation 24 hours after irrigation. The plants had performed well under this treatment.

The water distribution was uneven laterally in the treatment with porous pipe laid at 10 cm depth without sand envelope (Figure 4.5).   Moreover the water content was found concentrated near the base of the shoot. There was more moisture near the shoot and the performance was poor compared to the other treatments.

The highest amount of water was at a depth of 30 cm in the treatment with porous pipe laid at 15 cm depth without sand envelope (Figure 4.6). The water distribution was found to be even. Since there was good drainage at the top soil, the performance of the plants under this treatment was good.

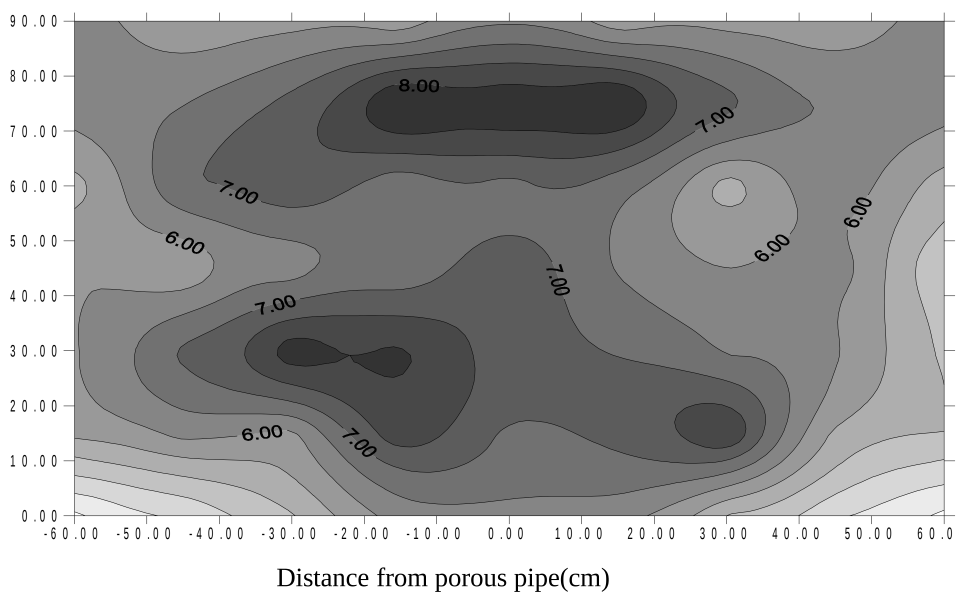

Figure 4.6. Moisture Distribution Pattern in Precision Porous Pipes Laid at 15 cm Depth without Sand Envelope,24 hours after Irrigation

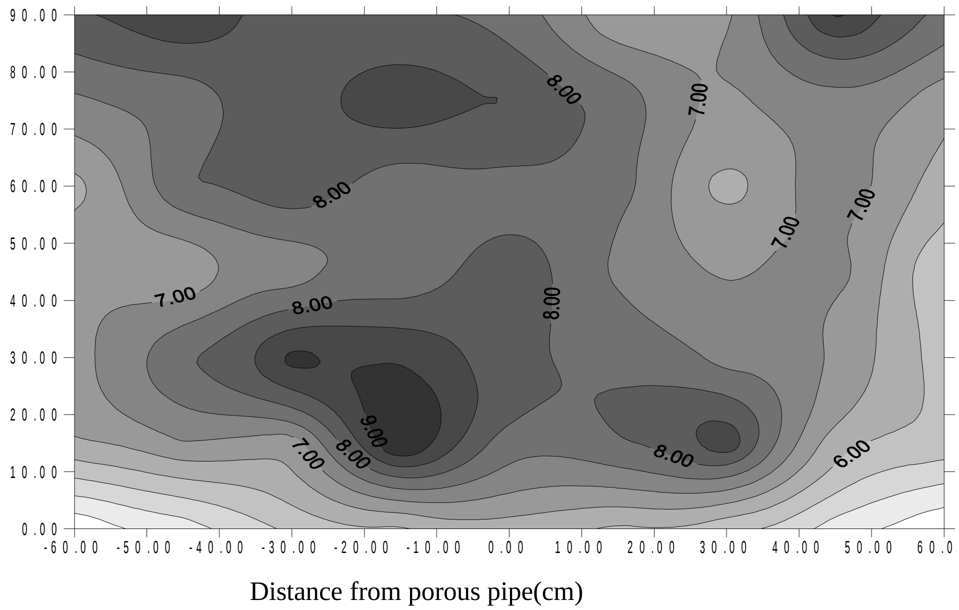

Figure 4.7. Moisture Distribution Pattern in Precision Porous Pipes Laid at 20 cm Depth without Sand Envelope,24 hours after Irrigation

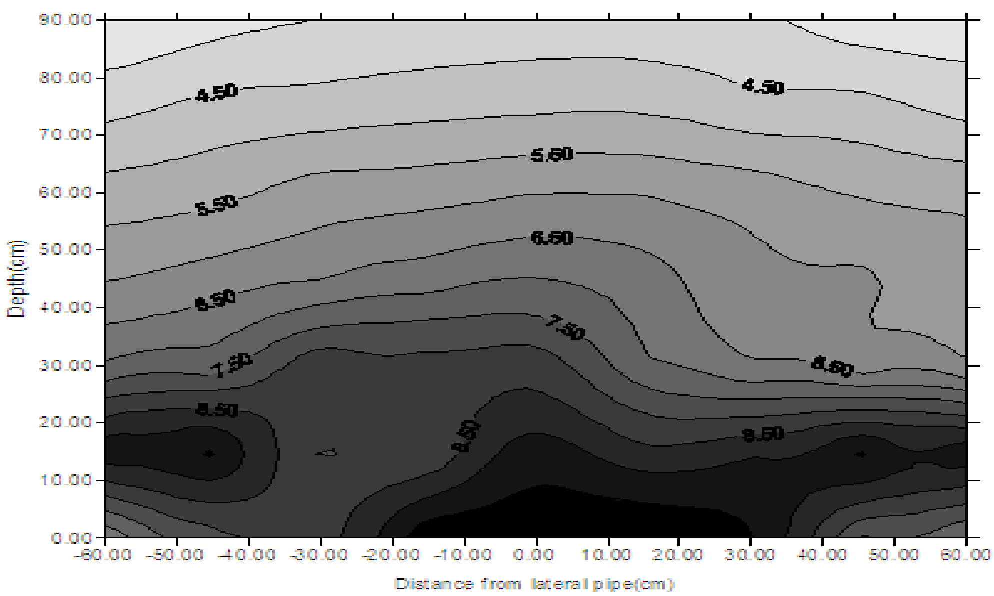

Figure 4.8. Moisture Distribution Pattern in Drip Irrigation, 24 hours after Irrigation

In the treatment with porous pipe laid at 20 cm depth without sand envelope (Figure 4.7), the water distribution was found to be even. The top 10 cm of the soil was well drained from excess moisture and since maximum roots are concentrated in this region, the performance of the plant was good.

In drip irrigation (Figure 4.8), there was no moisture stress on the plants. The water was evenly distributed from the surface. But due to surface evaporation, the water required for the drip irrigation was more than the porous pipe treatments.

4.5. Bio metric Observations

4.5.1. Height of plant

The height of the plants grown under various treatments were analysed using ANOVA with three way interaction.

Table 4.5. ANOVA Table for Height of Plant

Source	df	SS	MSS=SS/df	F Table	F Cal=MSS/EMS	Level
Envelope Type(S)	1	42.52	42.52	4.26	3.10	NS
Placement Depth(D)	2	510.48	255.24	5.61	18.61	**
Row Type(r)	1	1784.48	1784.48	7.82	130.12	**
Dr	2	331.18	165.59	5.61	12.07	**
SD	2	107.68	53.84	3.40	3.93	*
Sr	1	25.91	25.91	4.26	1.89	NS
SDr	2	34.42	17.21	3.40	1.25	NS
error=T*(R-1)	24	329.13	13.71			
TOTAL	35	3165.80			2836.67	

From the table 4.5 it is seen that

1. There is no significant difference among the treatments with and without sand envelope tested for the height parameter.

2. It is also seen that there is high significant difference among the three depth of placement of porous pipes tested for the height parameter.

3. There is high significant difference in the height for the type of row planting, whether it is paired or double paired row planting.

4. There is interaction between the depth of placement of porous pipes and the row spacing of porous pipes tested for height.

5. There is no interaction between the type of envelope and the row spacing.

6. There is no interaction between the three independent variables on the effective height.

4.5.2. Thickness of the Stem

The thickness of the stem of plants grown under different treatments was analyzed using ANOVA, and Tukey's post ANOVA test. The following table gives the details of the tests done.

Table 4.6. ANOVA Table for Thickness of the Stem

Source	**df**	**SS**	**MSS=SS/df**	**F Table**	**F Cal=MSS/EMS**	**Level**
Envelope Type(S)	1	4.62	4.62	7.82	16.99	**
Placement Depth(D)	2	40.37	20.18	5.61	74.31	**
Row Type(r)	1	45.32	45.32	7.82	166.83	**
Dr	2	7.44	3.72	5.61	13.69	**
SD	2	5.01	2.51	5.61	9.22	**
Sr	1	0.96	0.96	4.26	3.55	NS
SDr	2	1.99	1.00	3.40	3.67	*
error=T*(R-1)	24	6.52	0.27			
TOTAL	35	112.23			105.71	

From the table 4.6 it is seen that

1. There is high significant difference among the treatments with and without sand envelope tested for the thickness of stem.

2. It is also seen that there is high significant difference among the three depth of placement of porous pipes tested for the thickness of stem.

3. There is high significant difference in the thickness of stem for the type of row planting, whether it is paired or double paired row planting.

4. There is interaction between the depth of placement of porous pipes and the row spacing of porous pipes tested for thickness.

5. There is interaction between the type of envelope and the depth of placement of porous pipe on thickness.

6. There is no interaction between the type of envelope and the row spacing on thickness.

7. There is interaction between all the three independent variables tested for thickness at 5% significance level.

4.5.3. Canopy Spread

The canopy spread of plants grown under different treatments is another parameter tested for significance using ANOVA and Tukey's test. The results are given in table 4.7.

From the table it is seen that

1. There is high significant difference among the treatments with and without sand envelope tested for the canopy parameter.

2. It is also seen that there is high significant difference among the three depth of placement of porous pipes tested for the height parameter.

3. There is high significant difference in the type of row planting, whether it is paired or double paired row planting.

Table 4.7.ANOVA Table for Canopy Spread

Source	Df	SS	MSS=SS/df	F Table	F Cal=MSS/EMS	Level
Envelope Type(S)	1	63.77797	63.7779707	7.82	14.75609212	**
Placement Depth(D)	2	635.0914	317.545718	5.61	73.46947246	**
Row Type(r)	1	213.0789	213.078897	7.82	49.29933946	**
Dr	2	12.04205	6.02102623	3.4	1.393064358	NS
SD	2	19.81752	9.90875772	3.4	2.292555565	NS
Sr	1	3.111304	3.11130401	4.26	0.719851825	NS
SDr	2	11.74344	5.87172068	3.4	1.358520039	NS
error=T*(R-1)	24	103.7315	4.32214506			
TOTAL	35	1062.394			958.6626157	

4. There is no interaction between the depth of placement of porous pipes and the row spacing of porous pipes tested for height.

There is no interaction between the depth of placement and the type of envelope tested for height.

There is also no interaction between the type of envelope and the row spacing.

5. There is no interaction between all the three independent variables tested for canopy spread at 5% significance level.

4.5.4. Yield of Crop

Yield was compared between the crops grown under different treatments to find out the optimum depth of placement of precision porous pipes. Three replications were done in all the treatments.

The yield obtained in different treatments is given in table 4.8.

Table 4.8. Yield in Different Treatments

Treatment	Name	Area (m^2)	Actual Yield(kg)	Yield (kg/ha)
T_1	$S_1D_1r_1$	1.2	1.31	10916.67
T_2	$S_1D_1r_2$	4.8	1.65	3432.29
T_3	$S_1D_2r_1$	1.2	1.87	15541.67
T_4	$S_1D_2r_2$	4.8	4.43	9218.75
T_5	$S_1D_3r_1$	1.2	2.59	21583.33
T_6	$S_1D_3r_2$	4.8	4.31	8972.92
T_7	$S_2D_1r_1$	1.2	1.04	8625.00
T_8	$S_2D_1r_2$	4.8	1.45	3020.83
T_9	$S_2D_2r_1$	1.2	1.88	15625.00
T_{10}	$S_2D_2r_2$	4.8	4.38	9114.58
T_{11}	$S_2D_3r_1$	1.2	2.02	16833.33
T_{12}	$S_2D_3r_2$	4.8	4.80	9989.58
T_{13}	dr_1	1.2	2.08	17291.67
T_{14}	dr_2	4.8	8.02	16708.33
T_{15}	C	1.2	1.83	15220.83

The yield was found to be a maximum for the treatment $S_1D_3r_1$. This was followed by the treatment dr_1 and $S_2D_3r_1$ (Table 4.8). Hence the porous pipe irrigation with sand envelope and 20 cm depth of placement with paired row was considered the best for Amaranthus in loamy sand soil.

Inference was made from the statistical analysis using ANOVA with three way interaction. For comparing the significance of yield between any two means of the treatments, Tukey's test, a post ANOVA test was performed.

The results are given in table 4.9

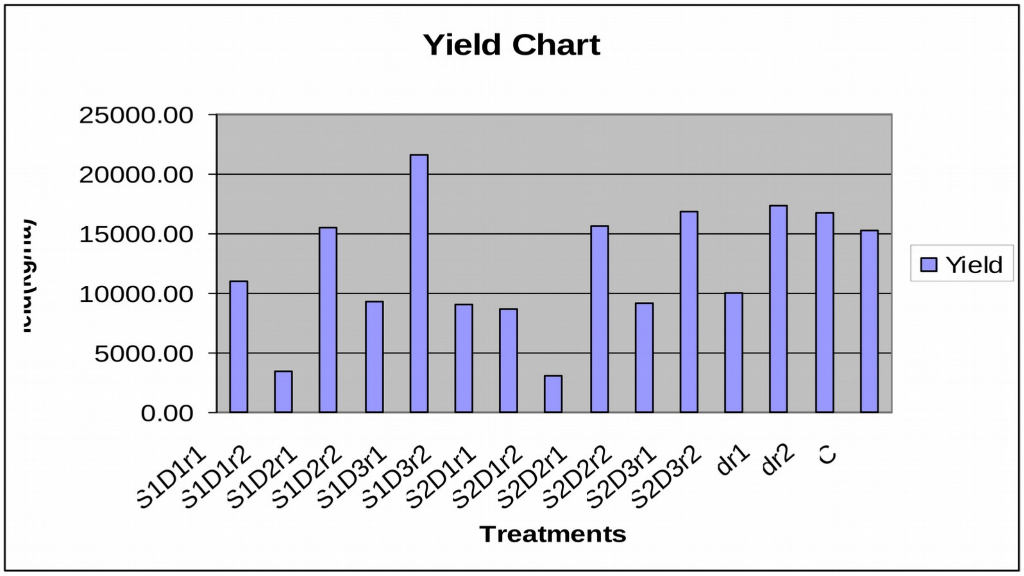

Figure 4.9. Yield in various Treatments

Table 4.9. ANOVA Table for Yield

Source	**Df**	**SS**	**MSS=SS/df**	**F Table**	**F Cal=MSS/EMS**	**Level**
Envelope Type(S)	1	56763.06	56763.06	4.26	5.14	*
Placement Depth(D)	2	5201889.18	2600944.59	5.61	235.30	**
Row Type(r)	1	4235.84	4235.84	4.26	0.38	NS
Dr	2	353462.51	176731.26	5.61	15.99	**
SD	2	25300.29	12650.15	3.40	1.14	NS
Sr	1	101389.17	101389.17	7.82	9.17	*
SDr	2	130239.18	65119.59	3.40	5.89	*
error=T*(R-1)	24	265293.50	11053.90			
Total	35	6138572.74			5873279.24	

From the table 4.9 it is seen that

1. There is no significant difference among the treatments with and without sand envelope tested for the yield parameter at 1% significance level.

2. It is also seen that there is highly significant difference among the three depth of placement of porous pipes tested for the yield parameter.

3. There is no significance in the type of row planting, whether it is paired or double paired row planting.

4. There is interaction between the depth of placement of porous pipes and the row spacing of porous pipes tested for yield. There is also interaction between the type of envelope and the row spacing.

5. There is no interaction between the type of envelope and the depth of placement of porous pipe tested for yield.

6. There is interaction between the type of envelope, type of row and the depth of placement of porous pipes.

Table 4.10. Tukey's Mean for Different Parameters

Depths	Mean Value of Yield(gm)	Mean Value of Height of Plants(cm)	Mean Value of Thickness of stem(mm)	Mean Value of Canopy Spread(cm)
Depth 10 cm	1946.80	62.15	15.96	56.60
Depth 15 cm	4070.00	89.00	19.00	76.95
Depth 20 cm	4580.50	81.89	23.96	86.87
Minimum Value for Significance	340.53	11.99	1.68	6.73

Since the difference in yield between each pairs was more than 340.53, there is significant yield difference between any two depths of spacing. The significance is given by

$$1946.8^{a}\ 4070^{b}\ 4580.5^{c}$$

It is seen that there was significant difference in the height of plants between 10 cm and 15 cm depth of placement of porous pipe but there is no significant difference in the height of plants between 15 cm and 20 cm depth of placement of porous pipe.

The significance is given by

$$62.15^{a} \quad 89^{b} \quad 81.89^{b}$$

Since the difference between each pairs was more than 1.68, there is significance difference in thickness of stem between any two depths of spacing.

The significance is given by

$$15.96^{a} \quad 19^{b} \quad 23.96^{c}$$

Since the difference between each pairs was more than 6.73, there is significance difference in between any two depths of spacing tested for canopy spread. The significance is given by

$$56.6^{a} \quad 76.95^{b} \quad 86.87^{c}$$

4.5.5. Root Zone and Root Length

Table 4.11.Root Zone and Root Length in Different Treatments

Treatment	**Description**	**Root zone depth(cm)**		**Root Length(cm)**	
		P1	**P2**	**P1**	**P2**
T_1	$S_1D_1r_1$	11	12	27	35
T_2	$S_1D_1r_2$	9	8.5	23	28
T_3	$S_1D_2r_1$	19	18	35	39
T_4	$S_1D_2r_2$	17	17.5	39	33
T_5	$S_1D_3r_1$	15	18	29	42
T_6	$S_1D_3r_2$	13	12	26	35
T_7	$S_2D_1r_1$	6	7.5	27	31
T_8	$S_2D_1r_2$	5.5	5	19	22
T_9	$S_2D_2r_1$	13	14	43	36
T_{10}	$S_2D_2r_2$	11	10	34	40.5
T_{11}	$S_2D_3r_1$	17	12	52	46

T_{12}	$S_2D_3r_2$	14	15	47	44
T_{13}	dr_1	15	13	48	45
T_{14}	dr_2	16	14	49	42
T_{15}	C	12	12	35	30

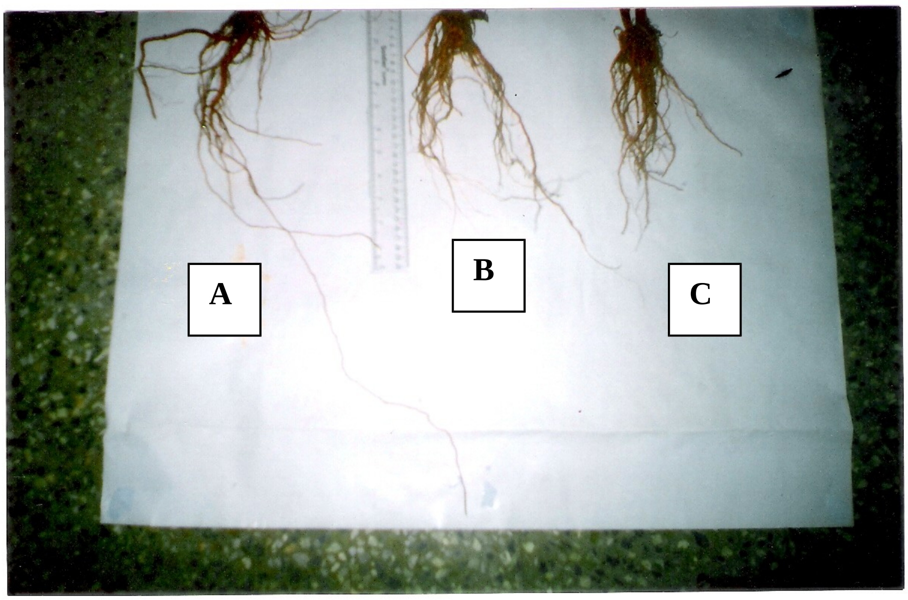

Plate 4.1. Root distribution of Porous pipe irrigated(A), Drip irrigated(B) and Surface irrigation(C).

It is found from the table 4.11. that the root zone depth is maximum in $S_1D_2r_1$ and $S_1D_3r_1$. It was found that in drip irrigation system, although the root zone depth was less, the root length was more and the yield was also more. In $S_2D_2r_1$, $S_2D_2r_2$, $S_2D_3r_1$ and $S_2D_3r_2$, the root length was a maximum but the root zone depth was less. Hence we cannot draw any conclusion relating the root zone depth, root length and the yield which is the most important dependent variable. More detailed study has to be made to reach any conclusion.

4.5.6.Weeding

Weeding was done at 15, 30 and, 45 days after transplanting of the crop in the field. Two m^2 of the area in each treatment where maximum density of weeds found was selected and the weeds in that area are counted.

The following table 4.12. shows the amount of weeds present during various stages of plant growth.

Table 4.12. Weed Count under Different Treatments

Treatment	**Name**	**Weed count at 15 Days(Nos)**	**Weed count at 30 Days(Nos)**	**Weed count at 45 Days(Nos)**
T_1	$S_1D_1r_1$	189	90	60
T_2	$S_1D_1r_2$	170	81	54
T_3	$S_1D_2r_1$	171	81	54
T_4	$S_1D_2r_2$	160	76	51
T_5	$S_1D_3r_1$	153	73	49
T_6	$S_1D_3r_2$	147	70	47
T_7	$S_2D_1r_1$	181	86	57
T_8	$S_2D_1r_2$	170	81	54
T_9	$S_2D_2r_1$	174	83	55
T_{10}	$S_2D_2r_2$	159	76	50
T_{11}	$S_2D_3r_1$	117	56	37
T_{12}	$S_2D_3r_2$	115	55	37
T_{13}	dr_1	243	116	77
T_{14}	dr_2	231	110	73
T_{15}	C	299	195	63

Weed growth was found to be a maximum in the surface irrigated treatment. This was followed by the drip irrigated treatment, $S_1D_1r_1$ and $S_2D_1r_1$. The subsequent weeding at 15 days interval revealed that the weed density kept on reducing. This was due to the fact that the weeds were uprooted before their flowering and hence its proliferation was controlled.

4.5.7. Water use efficiency

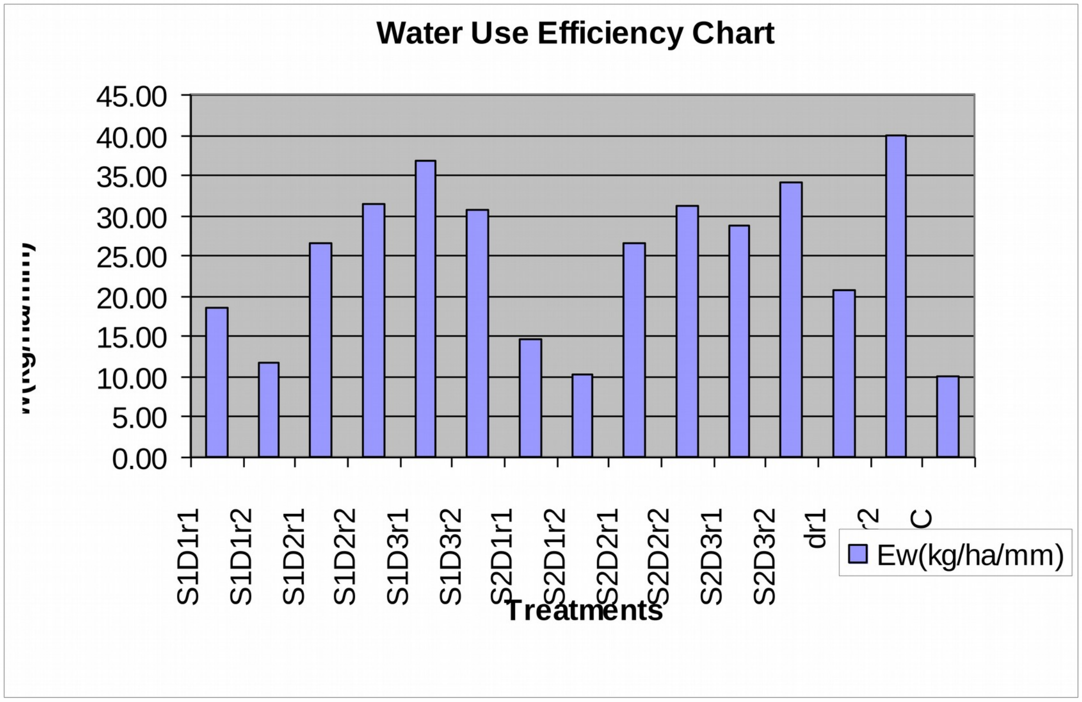

Figure 4.10. Water Use Efficiency in different treatments

From table 4.13 the water use efficiency was 36.74 kg/ha-mm in the treatment with sand envelope and paired row planting at a depth of placement 20 cm which was highest among porous pipe treatments. This was followed by the treatment without sand envelope and double paired row planting at a depth of placement 20 cm at 34.01 kg/ha-mm. The water use efficiency of treatment dr_2 was 39.8 kg/ha-mm which was much more than the water use efficiency of treatment dr1 which was 20.6 kg/ha-mm. It was 10.07 kg/ha-mm for the control treatment.

Hence it can be concluded that the drip irrigation with double paired row has performed better than the paired row.

Table 4.13.Water use efficiency of various treatments

Treatment	Name	Area	Actual	Yield	Water used	E_w
		(m^2)	Yield(kg)	(kg/ha)	(liters)	(kg/ha-mm)
T_1	$S_1D_1r_1$	1.20	1.31	10916.67	705.00	18.58
T_2	$S_1D_1r_2$	4.80	1.65	3432.29	1410.00	11.68
T_3	$S_1D_2r_1$	1.20	1.87	15541.67	705.00	26.45
T_4	$S_1D_2r_2$	4.80	4.43	9218.75	1410.00	31.38
T_5	$S_1D_3r_1$	1.20	2.59	21583.33	705.00	36.74
T_6	$S_1D_3r_2$	4.80	4.31	8972.92	1410.00	30.55
T_7	$S_2D_1r_1$	1.20	1.04	8625.00	705.00	14.68
T_8	$S_2D_1r_2$	4.80	1.45	3020.83	1410.00	10.28
T_9	$S_2D_2r_1$	1.20	1.88	15625.00	705.00	26.60
T_{10}	$S_2D_2r_2$	4.80	4.38	9114.58	1410.00	31.03
T_{11}	$S_2D_3r_1$	1.20	2.02	16833.33	705.00	28.65
T_{12}	$S_2D_3r_2$	4.80	4.80	9989.58	1410.00	34.01
T_{13}	dr_1	1.20	2.08	17291.67	1007.5	20.60
T_{14}	dr_2	4.80	8.02	16708.33	2015.00	39.80
T_{15}	C	1.20	1.83	15220.83	1813.10	10.07

4.5.8. Installation Cost

The cost of installation of different irrigation systems used in the study was evaluated. The details are given in table 4.14

The main cost variation in all the treatments came from the row to row spacing of the laterals or the porous pipes. In porous pipe treatments, the higher cost is due to the cost of the porous pipe and the closer spacing. It is seen that the cost per hectare of the porous pipes in paired row is Rs.3, 93,400 whereas it is Rs.2, 00,300 in the case of double paired row planting. In the case of drip irrigation, the cost involved for paired row planting was Rs.1, 27,700 per hectare whereas that of double Paired row planting was Rs. 65,450 per hectare. It was considered that the life of drip irrigation was only 6 years while the life of porous pipe irrigation was around 30 years under ground. Hence considering the life, lesser energy demand and lesser labour requirement for maintenance, porous pipe is advantageous over drip irrigation.

Table 4.14. Cost of Installation of Amaranthus For 1 Ha for Differerent Irrigation Systems

Treatment	Name	Main Pipes,63mm		Sub Main Pipes,40mm		Lateral		Emitter		Cost of other	Labour	Total Cost
		Length(m)	Cost(Rs)	Length(m)	Cost(Rs)	Length(m)	Cost(Rs)	nos	Cost(Rs)	Accessories(Rs)	Cost(Rs)	per ha(Rs)
T_1	$S_1D_1r_1$	100	3200	200	4000	20000	360000			1200	25000	393400
T_2	$S_1D_1r_2$	100	3200	200	4000	10000	180000			600	12500	200300
T_3	$S_1D_2r_1$	100	3200	200	4000	20000	360000			1200	25000	393400
T_4	$S_1D_2r_2$	100	3200	200	4000	10000	180000			600	12500	200300
T_5	$S_1D_3r_1$	100	3200	200	4000	20000	360000			1200	25000	393400
T_6	$S_1D_3r_2$	100	3200	200	4000	10000	180000			600	12500	200300
T_7	$S_2D_1r_1$	100	3200	200	4000	20000	360000			1200	25000	393400
T_8	$S_2D_1r_2$	100	3200	200	4000	10000	180000			600	12500	200300
T_9	$S_2D_2r_1$	100	3200	200	4000	20000	360000			1200	25000	393400
T_{10}	$S_2D_2r_2$	100	3200	200	4000	10000	180000			600	12500	200300
T_{11}	$S_2D_3r_1$	100	3200	200	4000	20000	360000			1200	25000	393400
T_{12}	$S_2D_3r_2$	100	3200	200	4000	10000	180000			600	12500	200300
T_{13}	dr_1	100	3200			20000	80000	25000	37500	4500	2500	127700
T_{14}	dr_2	100	3200			10000	40000	12500	18750	2250	1250	65450
T_{15}	C	100	3200								500	3700

CHAPTER 5

SUMMARY AND CONCLUSION

The study entitled "Feasibility Studies on the Use of Precision Porous Pipes for Subsurface Irrigation" was conducted in KCAET, Tavanur.

Subsurface irrigation using porous pipes is a relatively new technology. It has a number of advantages. Porous pipe is designed to be the most efficient method of irrigation today. Porous pipe can be considered as a continuous emitter which produces a rectangular moisture band at the root zone. It uses the principle of low flow and low pressure technology to introduce moisture to the soil to absorb it at its natural rate.

The discharge evaluation of porous pipe irrigation was done in the laboratory. Field study was conducted to find out the moisture distribution and the optimum depth of installation for the crop.

The type of soil found in the study area was loamy sand. It has a bulk density of 1.68 gm/cc and the infiltration rate of the soil was 5.2 cm/hr. The coefficient of variation of the porous pipe was 13.98 % and the emission uniformity was 82.60 %.

The chosen crop for the study was *Amaranthus sp* and the variety chosen was Kannara local. The study was comprised of 15 treatments. There were 12 treatments involving porous pipes and 2 treatments involving drip irrigation and one control plot for comparison. The size of the porous pipe used for the study was 22 mm outer diameter. LDPE lateral of size 16 mm and drippers with capacity 4 lph were used for drip irrigation. The total cultivated area was 53.6 m^2.

The water requirement of Amaranthus under local conditions was calculated to be 0.2 litre/day/plant. Watering was done for porous pipe treatments and drip irrigation treatments at this rate. However for control plot, the locally adopted surface irrigation method was adopted.

The soil moisture distribution revealed that the moisture was distributed up to the surface in case of the installation at shallow depth ie at 10 cm with and without sand envelope. But this was not preferred by the plants as it needed water only at its root zone. This finding was evident from the lower yield and the lower water use efficiencies in these treatments.

The average distribution efficiency of porous pipe in the field was found to be 86.72%, 24 hours after irrigation and it was 76.2 % for drip irrigation.

Among porous pipe treatments, the water use efficiency was highest in the treatment with sand envelope and paired row planting at the depth of placement 20 cm at 36.74 kg/ha-m. This was followed by the porous pipe treatment without sand envelope and double paired row planting at a depth of placement 20 cm at 34.01 kg/ha-m.

The water use efficiency of drip irrigated treatment with paired row planting was 20.6 kg/ha-mm and for double paired row planting it was 39.8 kg/ha-mm . It was 10.07 kg/ha-mm for the control treatment.

Statistical analysis was performed using ANOVA with three way interaction and Tukey’s test for the yield, plant height, stem thickness and canopy spread.

From the statistical analysis, we find that there is no significant difference in yield between the treatments with and without sand envelope. Hence we conclude that for amaranthus, sand envelope is not essential in sandy loam soil.

Moreover the maximum yield of 21.58 tonnes/ha was obtained from porous pipe irrigation treatment with sand envelope and paired row planting at a depth of placement 20 cm. Hence we can conclude that for Amaranthus, the depth of placement of porous pipe preferred for the maximum yield was 20 cm in sandy loam soil. Further study has to be done by increasing the depth of placement of porous pipes. Porous pipe irrigation may provide better results for other crops having a greater root zone depth.

Weed growth was found to be a maximum in the surface irrigated treatment. This was followed by the drip irrigated treatment and the treatment involving porous pipes placed at 10 cm depth with paired row planting. The subsequent weeding at 15 days interval revealed that the weed density kept on reducing. This was due to the fact that the weeds were uprooted before their flowering and hence its proliferation was controlled.

It was found that the root zone depth was a maximum in the treatment with sand envelope and paired row planting at a depth of placement 15 cm followed by the treatment with sand envelope and paired row planting at a depth of placement 20 cm. It was found that in drip irrigation system, although the root zone depth was less, the root length was more and the yield was more compared to other treatments. In the treatments without sand envelope and at depth of placement 15 and 20 cm the root length were more but the root zone depth was lesser than other treatments . Hence we cannot draw any conclusion relating the root zone depth, root length and the yield which was the most important dependent variable. More detailed study has to be made to reach any conclusion.

After the experimental study certain conclusions were drawn.

- There must be a flushing device for each lateral in order to flush out the impurities from the irrigation water. In spite of the fact that porous pipe irrigation system was fed by gravity, there must be an arrangement by which high pressure water of 1 to 1.5 kg/cm^2 is let in to the system for flushing.

- The ends of each lateral must be brought to the surface to facilitate flushing and to identify the line of installation.

- The head for operating the porous pipe system was provided by raising the feeder tank to a height of 1 m above ground level. The water level in the tank was 1 m. Hence we provided a total head of 2 m, and the water flows out by gravity. At this height the pressure in the system was 0.2.kg/cm^2 and the corresponding discharge calculated from the lab study was 1.9 lph/m and for the same pressure the discharge in the field was 1.27 lph/m.

The cost of installation of different irrigation systems used in the study was analysed. The main cost variation in any treatments occurred due to the close row to row spacing of the porous pipes or the laterals. It is seen that the cost per hectare of the porous pipes in paired row is Rs.3, 93,400 whereas it is Rs.2, 00,300 in the case of double paired row planting. It was considered that the life of drip irrigation was only 6 years while the life of porous pipe irrigation was around 30 years under ground.

Hence, considering its life, lesser energy demand when watering and lesser labour requirement for maintenance, porous pipe is advantageous over drip irrigation.

REFERENCES

Bush, C.D and W.R. Kneeebone. 1996. Subsurface irrigation with perforated plastic pipe. *Transactions of ASAE*. 1996.1; 91-92.

Camp, C.R. 1998. Subsurface Drip irrigation: Review, *Transactions of ASAE*, Vol. 41(5) 1353 -1367.

Center for Irrigation Technology News. 1995. Porous pipe, *Irrigation Journal.* Vol 45 (7) Nov to Dec 1995.

Charles Lee. 1920 .U.S patent No. 00607832. on Subsurface irrigation.

Christiansen, J.E. 1942. Irrigation by Sprinkling, University of California, *College of Agricultural Expt. Station.* Bull. 620.

Chrisiansen, J.E. 1942. Hydraulics of sprinkling systems for irrigation. *Transactions of the ASCE*, 107: 221 -239.

Dhotre, R.S, Dahiwalker S.D and Rajput B.K.2005. Hydraulic studies of porous pipe irrigation system for Sugarcane, Department of Irrigation And Drainage Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, SW-2005-PI-15.

Eldom.G.Hanson,B.C.Williams, D.D. Fangmeir and Ottoc. 1970. Influence of Subsurface irrigation on crop yields and water use. *Proceeding of the National Irrigation Symposium.* Nov: 10 -13, pp.D1- D13. St.Joseph, Mich : ASAE.

Gajare, V. K. 1982. Effect of irrigation frequency on crop growth and cabbage by drip method of irrigation M.Sc (Ag) Thesis submitted UAS, Bangalore.

Goldberg and Shumeli, (1969). Trickle irrigation – A method for increased agriculture production under the conditions od saline water and adverse soil. *Arid Lands Conference, 1969, Tulson, ARIZ.*

Goldberg and Shumeli, 1970. Effect of trickle irrigation. Intervals on distribution and utilization of soil moisure in a vineyard. *Soil. Sci. Soc. Am. J.* 35: 127 -130.

Goel, A.K., R.K. Gupta and Rajinder Kumar.1993. Effect of drip discharge rate on soil moisture pattern. *Journal of Water Managenment* 1 (1) : 50-51.

Gospodinova, M. and D. Doctchev. 1994. Increase of efficiency of irrigation rate by subsoil micro irrigation of apple trees using leaky pipe micro pipelines. 1994. 17^{th} ICID *European Regional Conference of Irrigation and Drainage.*

Hanson and Williams .1985. Influence of subsurface irrigation on cotton yield and water use. *Journal of ASAE*, 12 : (68 – 70).

Hart, W.E. and W.N. Reynolds. 1965. Analytical design of sprinkler systems. *Transactions of the ASAE*, 8(1) : 85,89.

Kaul, R. K 1979, Hydraulics of moisture advance in drip irrigation, *Ph.D. thesis submitted to I.A. R.I.* New Delhi, India.

Kataria, D.P. and A.M. Michel.1990. Comparative study of drip and furrow irrigation methods. *In Proc.XI International congress on the use of plastic in agricultural New Delhi*. 13 : 19 -27.

Keller, J. and D. Karmeli. 1974. Trickle irrigation design parameters. *Transactions of the ASAE,* 17: 678 – 684.

Khepar, S.D., P.K. Neog and M.P Kaushal.1983. Moisture and salt distribution pattern under drip irrigation. *II National Seminar on drip irrigation. Coimbatore.* March 1983 : 76 - 85.

Koumanov, K.S., Hopmans, J.W. and Schwankl, L.J. 1997. Application efficiency of micro sprinkler irrigation of almond trees. *Journal of Agricultural water management.* Pa : 73 -80.

Kruse, E.G. 1978. Describing irrigation efficiency and uniformity. *Journal of irrigation and drainage division,* ASAE 104 (IR 1): 35 – 41.

Larry, G. James. 1998. Principles of Farm Irrigation System Design. *John Wohley and Sons, New York.*

Lamn, F.R., W.E. Spurgeon, D.H. Rogers and H.L. Manges. 1995. Corn production using subsurface drip irrigation. *In : F.R. Lamm (ed.) Micro irrigation for changing world. Conserving resources/ protecting the environment. ASAE, St. Joseph,* M.I.P: 388 – 394.

Lomax, K.M., J.D. wood and F.S. Guacelli.1998. Emission characteristics of porous tubing. *Journal of Agricultural Water Management,* 1988. 15 : 197 – 207.

Manges, H.I., W.E. Spurgeon, Z.M. Haung and D.J. Tomsicek.1995. Subsurface drip line spacing and plant population for corn production. *In : F.R. Lamn (ed.) Micro – irrigation for changing world: Conserving resources / Protecting the environement. ASAE, St. Joseph, MI*. p : 382 – 387.

Merman , M.M. and I.C. Smith. 1996. Irrigation systems for optimum crops. *Grower talks.*1996.60 : 3,32,34 -37.

Mohammad, F.S. 1998. Potential of subsurface irrigation system for water conservation in an arid climatic environment international. *Agricultural Engineering Journal.* 1998. 7: 1, 23 – 36.

Mohammad, F.S. 1998. Porous pipe subsurface irrigation, *Journal for Scientific research – Agricultural Sciences,* Sulten – Qaboos University 1998 (3). 2, 49 – 57.

Murugaboopathi, C., M. Tomita, E. Yamaji and S. KoIde. 1991. Prospect of large sized paddy field using direct seeding supported by Subsurface Irrigation system. *Transactions of ASAE* 0001- 23500/91/3405 - 2040.

Murihead, W.A., Humphery, F. and Jayawardone, N.S. and Moll J.L. 1996. Shallow subsurface drainage in an irrigated vertisol with a perched water table. *Journal of Agriciltural management* 30 (1996). 261 – 283.

Nagarajan, M. 2002. Performance evaluation of subsurface irrigation using precision porous pipe. M.E (Ag) Thesis submitted to Tamil Nadu Agricultural University, Coimbatore.

Nayanakantha, N.M.C. and Seneviratne, P.2003.Influence of a Porous Pipe Micro-Irrigation System on growth of rubber seedlings, Rubber Research Institute, Sri Lanka.

Pair, C.H., W.F. Hine, K.R. Frost, R.E. Sneed and T.J. Schitx .1983. Irrigation in fifth edition. *The irrigation Association Silver Spring, M.D:* 25-36.

Philp, J.R. 1971. General theorem on sandy infiltration from surface source with application to point and line source. *Soil Sci. Soc. American Proceedings,* 35 : 867 – 871.

Prasher, S.O. 1995. Performance of a subsurface irrigation in clay soil. Proceedings Kansas city, Missori, USA.*Transactipons of ASAE* 5- 8. March, 1995,159 – 162.

Phene, C.J., M.F. Blume, M.M.S. Hile, D.W. Meek and J.V. r. 1983. Management of subsurface trickle irrigation systems. *Transctions of ASAE.* 1983. 83 : 2598.

Phene, C.J.,K.R. Davis, R.B. Hutmacher and R.L. Mccormick, 1987. Advantages of subsurface drip irrigation of processing tomatoes. *California Tomato Research Institute – News and views* 9 (1); 1, 4 - 5.

Phene, C.J.,R. Yue, I-Pai Wu, J.E.Ayars, R.A. Schoneman, B.Meso.1992. Distrobution uniformity of subsurface drip irrigation systems. *Transactions of ASAE* Paper No. 92-2569, 14 PP. St.Joseph, Mich.: ASAE.

Roy L.Fox, John T. Phelan and Wayae D.Criddle. 1956. Design of subsurface irrigation systems. *Transactions of ASAE.*37 (2) : 103 – 108.

Saiad Mostoghim .1982. Effect of discharge rate on distribution of moisture in heavy soils irrigated from trickle source. *Transactions of ASAE.* 25 (2) : 975 – 979.

Schwankl,L. J., Edstorm J.P. and Hopmans J.W.1990. Performance of micro irrigation systems in almonds. *Proceedings of 7th International conference on water and irrigation.* Tel.Aviv. Israel. 35 : 123 -146.

Smajstrla, A.G. 1994. Field studies of porous pipe micro irrigation laterals. *Transactions of ASAE* paper No: 942172, pp 10.

Sohrabi, T and N. Gazori. 1997. Subsurface irrigation with porous pipe. *Iranian Journal of Agricultural sciences.*1997. 28: 3, 145 – 156.

Strickland, E.E., J.T. Ligon, C.W. Doty and T.V. Wilson. 1981. Water and energy requirements for subsurface irrigation and center – pivot irrigation. *Transactions of ASAE.* 1981. 81; 2069.

Suseela, P. and Rangaswamy, M.V, WRMU, KAU, Vellanikara.2005. Porous pipe- A tool for subsurface Micro Irrigation. SW-2005-PI-24.

Teeluck, M and B.G Sutton. 1998. Discharge characteristics of a porous pipe micro irrigation lateral. *Journal of Agricultural water management.* 1998. 38 : 2, 123 -134.

Visalakshi, K. P., Reena M., Bridgit T. K., Devadas V. S., Mini A. and Suseela P.2005. *Three decades of research on water management in Kerala Agricultural University.*

Warrick, A.W and U.Shani. 1996. Soil – limiting flow from surface emitters. *Journal of Irrigation and drainage Engineering.* 1996, 122: 5, 296 – 300.

Watkins, R.K., O.K.Shupe and Willardson, L.S.1974. Structural Performance of Buried Plastic Tubing, Utah State University, Logan.

Whitney, L.F. 1970. Review of subsurface irrigation in the Northeast. *In Proc. National Irrigations Symposium,* pp. F1 - F8. St. Joseph, Mich : ASAE.

Whitney, L.F. and Dr. Willianm H. Michell. 1966. Possibilities and pitfalls of subsurface irrigation. *Compliation of papers National Irrigation Symposium.* Nov: 1970. Pa. 10 -13.

Wu, I.P. and H.M. Gatin. 1975. Hydraulics and uniformity for drip irrigation. *Journal of the Irrigation and Drainage Division,* 99 (2): 157 – 168.

Zetzsche, J.B. and Newman. 1970. Evaluation of subsurface irrigation with plastic pipe. *Journal of Agricultural Engineering.* 47 (2): 74 – 75.

APPENDIX I

Temperature and Rainfall Data in KCAET.,Tavanur

Date	Dry.Temp (◦C)	Wet.Temp (◦C)	Max Temp (◦C)	Min.Temp (◦C)	Rainfall(mm)
1-Mar-06	27	25	34	23	
2-Mar-06	27	25	34	23.5	
3-Mar-06	27	25	34	24	
4-Mar-06	25.5	23.5	34.5	23	
5-Mar-06	29	25	34	24	
6-Mar-06	29	26	34.5	23	
7-Mar-06	28.5	25.5	34	24	
8-Mar-06	28	25.5	34.5	25	
9-Mar-06	29.5	25.5	34	24	
10-Mar-06	25.5	23.5	34	24	18
11-Mar-06	28.5	25	34.5	24.5	
12-Mar-06	27	24	34	21.5	
13-Mar-06	26	22	38.5	23	
14-Mar-06	26	23	33.5	22	
15-Mar-06	27	23.5	34	20.5	
16-Mar-06	26.5	24	33	21.5	
17-Mar-06	26	24	33	22	
18-Mar-06	27	25	33	22.5	
19-Mar-06	29	23.5	32.5	21.3	
20-Mar-06	29	25	33.5	22.5	
21-Mar-06	29.5	25.5	34	24.5	
22-Mar-06	28.5	26.5	37	25	
23-Mar-06	29	26	35.5	25	
24-Mar-06	28	25	34	25.5	
25-Mar-06	29.5	26	34	24.5	
26-Mar-06	29	26.5	34	25.5	
27-Mar-06	27.5	25.5	34	25	
28-Mar-06	29	25.5	34	24.5	
29-Mar-06	29	26	33.5	24.5	
30-Mar-06	28	26	34	24.5	
31-Mar-06	28	25	34	23	
1-Apr-06	28.5	26	33.5	25	
2-Apr-06	29.5	26.5	34	24.5	
3-Apr-06	29	26	34	25	
4-Apr-06	29	26	34	25.5	
5-Apr-06	29	26	34	25	
6-Apr-06	30	27	34	25	
7-Apr-06	30	27	34	25.5	
8-Apr-06	30	26	34.5	25.5	

9-Apr-06	31	27	34	26	
10-Apr-06	30.5	26.5	34.5	25.5	
11-Apr-06	30.5	27	34.5	25.5	
12-Apr-06	30.5	26.5	34.5	26	
13-Apr-06	29.5	26.5	34.5	26	
14-Apr-06	30.5	26	34.5	25.5	
15-Apr-06	28	24	34.5	24	
16-Apr-06	30.5	25.5	34	24.5	
17-Apr-06	28	25.5	34	23.5	20
18-Apr-06	28.5	26	34	23.5	
19-Apr-06	28	26	34	23.5	
20-Apr-06	29	25.5	34	25	
21-Apr-06	26	24.5	34.5	24.5	
22-Apr-06	29.5	26	34.5	24.5	
23-Apr-06	29.5	26	33	25	
24-Apr-06	30	26.5	33.5	26	
25-Apr-06	30	26	33.5	25.5	
26-Apr-06	29	25.5	34	25	
27-Apr-06	30	26.5	34	26.5	
28-Apr-06	29.5	26.5	34	26	
29-Apr-06	30	25.5	33.5	25	
30-Apr-06	29	25.5	34	25	
1-May-06					
2-May-06					
3-May-06	29	25	33	25	
4-May-06	30	27	34	26	
5-May-06	31	35	35	23	15.4
6-May-06	29.5	26.5	33	25	
7-May-06	29.5	27	34	26	
8-May-06	27.5	26.5	33.5	24	14.6
9-May-06	30	27	33	25	
10-May-06	29.5	26.5	33	25	
11-May-06	30	27	34	25.5	
12-May-06	28.5	27	34	26.5	
13-May-06	29.5	27	35	26	
14-May-06	27.5	26	33	25.5	
15-May-06	30	26.5	33.5	25.5	
16-May-06	30	27	34	26.5	
17-May-06	25	24	34.5	21	22.2
18-May-06	27.5	27	31	23	0.4
19-May-06	24	23.5	32	22	16.8
20-May-06	28	26	30.5	23	
21-May-06	30	28	32	24	
22-May-06	29	27	33	24	2.9
23-May-06	29	26	32	24	
24-May-06	26	25.5	32.5	22.5	60

25-May-06	25.5	25.5	32	22	20
26-May-06	25	24.5	28.5	22	28
27-May-06	24	24	31	21.5	53.8
28-May-06	25	25	26	22	122.8
29-May-06	24	23.5	27.5	21.5	94.2
30-May-06	24	24	29	21	81
31-May-06	26	25.5	26	23	47

APPENDIX II

Sieve Analysis

	Mass Retained(gm)		
Sieve Size	**Sample 1**	**Sample 2**	**Sample 3**
4.75 mm	513.00	442.00	392.00
2.36 mm	191.00	196.00	190.00
2.00 mm	19.00	43.00	47.00
1.18 mm	64.00	88.00	104.00
1.00 mm	6.00	8.00	12.00
0.60 mm	21.00	21.00	37.00
0.425 mm	16.00	15.00	23.00
0.300 mm	7.00	5.00	9.00
0.212 mm	15.10	9.30	16.40
0.150 mm	2.80	3.30	4.10
0.075 mm	12.00	15.30	17.20
0.063 mm	3.60	5.60	6.10
0.045 mm	2.80	5.00	4.70
<0.045 mm	4.30	4.80	5.50
Total	877.60	861.30	868.00
	% Mass Retained		
Sieve Size	**Sample 1(%)**	**Sample 2(%)**	**Sample 3(%)**
4.75 mm	58.45	51.32	45.16
2.36 mm	21.76	22.76	21.89
2.00 mm	2.16	4.99	5.41

1.18 mm	7.29	10.22	11.98
1.00 mm	0.68	0.93	1.38
0.60 mm	2.39	2.44	4.26
0.425 mm	1.82	1.74	2.65
0.300 mm	0.80	0.58	1.04
0.212 mm	1.72	1.08	1.89
0.150 mm	0.32	0.38	0.47
0.075 mm	1.37	1.78	1.98
0.063 mm	0.41	0.65	0.70
0.045 mm	0.32	0.58	0.54
<0.045 mm	0.49	0.56	0.63
	100.00	100.00	100.00
	Cumulative %Mass Retained		
Sieve Size	**Sample 1(%)**	**Sample 2(%)**	**Sample 3(%)**
4.75 mm	58.45	51.32	45.16
2.36 mm	80.22	74.07	67.05
2.00 mm	82.38	79.07	72.47
1.18 mm	89.68	89.28	84.45
1.00 mm	90.36	90.21	85.83
0.60 mm	92.75	92.65	90.09
0.425 mm	94.58	94.39	92.74
0.300 mm	95.37	94.97	93.78
0.212 mm	97.09	96.05	95.67
0.150 mm	97.41	96.44	96.14
0.075 mm	98.78	98.21	98.12
0.063 mm	99.19	98.86	98.82
0.045 mm	99.51	99.44	99.37
<0.045 mm	100.00	100.00	100.00

APPENDIX III

Determination of Bulk Density by Core Cutter Method

Sl.No	Description	Value
1		10 cm

	Diameter of core cutter	
2	Height of core cutter	12 cm
3	Mass of core cutter without dolly	991 g
4	Mass of core cutter with soil	3057 g
5	Mass of container	16 g
6	Mass of container with soil sample	29 g
7	Mass of container with dry soil sample	26 g
8	Volume of core cutter	942 cc
9	Water content	30%
10	Bulk density of soil	2.1 g/cc
11	Dry density of soil	1.68 g/cc

APPENDIX IV

Cylinder Infiltrometer Test Data

Time	**Interval**	**Initial reading**	**Final Reading**	**Infiltration**	**Rate of Infiltration**
	(min)	(cm)	(cm)	(cm)	(cm/hr)
5 min	5	4.2	4.8	0.6	7.2

10 min	5	4.8	5.45	0.65	7.8
15 min	5	5.45	6.05	0.6	7.2
20 min	5	6.05	6.55	0.5	6
25 min	5	6.55	7.1	0.55	6.6
85 min	60	2.9	8.6	5.7	5.7
170 min	75	8.6	15.1	6.5	5.2
230 min	60	15.1	20.3	5.2	5.2

APPENDIX V

Pressure Discharge Relationship under Lab Condition for 22mm Precision Porous Pipe

Pressure	**Time**	**Cumulated**	**Length of**	**Discharge**			
Kg/cm^2	**(min)**	**time(min)**	**lateral(m)**	**litre**	**l/min**	**lph**	**lph/m**
0.2	7	7	4	0.89	0.13	7.63	1.91
0.2	7	14	4	0.88	0.13	7.54	1.89
0.2	7	21	4	0.93	0.13	7.97	1.99
0.2	7	28	4	0.9	0.13	7.71	1.93
0.4	7	7	4	1.35	0.19	11.57	2.89
0.4	7	14	4	1.2	0.17	10.29	2.57
0.4	7	21	4	1.18	0.17	10.11	2.53
0.4	7	28	4	1.19	0.17	10.20	2.55
0.4	7	35	4	1.18	0.17	10.11	2.53
0.6	10	10	4	5.21	0.52	31.26	7.82
0.6	10	20	4	4.19	0.42	25.14	6.29
0.6	10	30	4	4.14	0.41	24.84	6.21
0.6	10	40	4	4.16	0.42	24.96	6.24
0.6	10	50	4	4.15	0.42	24.90	6.23
0.8	10	10	4	9.98	1.00	59.88	14.97
0.8	10	20	4	9.6	0.96	57.60	14.40
0.8	10	30	4	9.34	0.93	56.04	14.01
0.8	10	40	4	9.22	0.92	55.32	13.83

0.8	10	50	4	9.22	0.92	55.32	13.83
1	10	10	4	10.21	1.02	61.26	15.32
1	10	20	4	10.11	1.01	60.66	15.17
1	10	30	4	10.13	1.01	60.78	15.20
1	10	40	4	9.99	1.00	59.94	14.99
1	10	50	4	10.07	1.01	60.42	15.11

APPENDIX VI

Moisture Percentage of Subsoil

Horizontal (cm)	Vertical (cm)	S1D1 (%)	S1D2 (%)	S1D3 (%)	S2D1 (%)	S2D2 (%)	S2D3 (%)	Drip (%)
-60	90	3.65	6.26	9.35	4.41	7.26	8.44	3.53
-45	90	4.33	6.68	9.61	4.83	7.57	8.94	3.83
-30	90	5.20	6.91	7.93	5.06	6.81	8.18	4.01
-15	90	6.48	7.24	7.58	4.89	6.64	8.01	4.15
0	90	6.11	7.53	9.32	5.68	6.42	7.79	4.21
60	90	5.81	5.56	9.35	4.71	6.45	7.82	3.71
45	90	6.12	6.82	9.61	5.97	7.71	9.08	3.74
30	90	6.87	6.91	7.93	3.79	5.53	6.90	4.11
15	90	6.44	7.29	7.58	3.44	5.18	6.55	4.22
0	90	7.11	7.53	9.32	5.68	6.42	7.79	4.21
-60	75	6.55	7.34	8.44	4.49	6.24	7.41	4.34
-45	75	7.21	7.58	8.68	4.73	6.48	7.65	4.66
-30	75	7.65	8.26	9.36	5.41	7.16	8.33	4.70
-15	75	7.86	8.87	9.86	6.92	8.66	8.83	4.82
0	75	9.08	8.94	9.54	6.59	6.34	8.51	4.90
60	75	7.48	6.57	7.67	3.72	5.47	6.64	4.34
45	75	8.59	7.26	7.35	4.41	6.15	7.32	4.69
30	75	7.50	7.33	7.73	3.98	5.73	6.90	4.65
15	75	8.96	7.79	7.69	5.94	4.69	7.86	4.99
0	75	9.08	8.94	9.54	6.59	6.34	8.51	4.89
-60	60	6.24	6.40	7.15	3.72	5.30	6.32	5.23
-45	60	6.81	7.06	8.80	4.41	6.95	7.97	5.31
-30	60	6.51	7.50	9.25	4.98	7.40	8.42	5.72
-15	60	6.85	7.71	8.46	5.94	6.61	7.63	5.88
0	60	7.63	8.93	9.67	7.08	6.82	7.84	5.99

60	60	5.76	7.33	7.08	5.48	5.23	6.25	5.43
45	60	6.52	8.44	8.19	6.59	6.34	7.36	5.46
30	60	6.25	7.35	7.09	5.50	5.24	6.26	5.78
15	60	6.71	8.81	8.35	6.96	6.70	7.72	5.96
0	60	7.63	8.93	9.67	7.08	6.82	7.84	5.99
-60	45	7.21	6.09	8.56	5.24	5.98	6.93	5.98
-45	45	7.34	6.66	8.13	5.81	5.55	6.50	6.23
-30	45	8.55	6.36	8.83	6.51	6.25	7.20	6.46
-15	45	8.33	6.70	8.17	6.85	6.59	7.54	6.73
0	45	8.47	7.48	8.96	7.63	7.38	8.33	7.02
60	45	6.16	5.61	8.56	4.76	4.51	5.46	5.88
45	45	6.31	6.37	8.13	5.52	6.26	7.21	6.10
30	45	6.68	6.10	8.83	6.25	6.00	6.95	6.12
15	45	7.22	6.56	8.17	6.71	6.45	7.40	6.77
0	45	8.47	7.48	8.81	7.63	7.38	8.33	7.02
-60	30	6.41	7.06	7.30	6.21	5.95	6.82	7.06
-45	30	6.83	7.19	8.44	7.34	7.09	7.96	7.19
-30	30	7.06	8.40	9.65	8.55	8.30	9.17	8.40
-15	30	7.39	8.18	9.42	8.33	8.07	8.94	8.18
0	30	7.68	8.32	8.57	7.47	7.22	8.09	8.32
60	30	5.71	6.01	6.26	5.16	4.91	5.78	6.01
45	30	6.97	6.16	7.41	6.31	6.06	6.93	6.16
30	30	7.06	6.53	7.78	6.68	6.43	7.30	6.53
15	30	7.44	7.07	8.31	7.22	6.96	7.83	7.07
0	30	7.68	8.32	8.57	7.47	7.22	8.09	8.32
-60	15	7.49	5.72	6.82	6.87	5.62	6.44	9.35
-45	15	7.73	6.27	7.36	7.42	6.16	6.98	9.61
-30	15	8.41	5.97	7.07	8.12	5.87	6.69	7.93
-15	15	9.02	6.95	9.04	9.10	8.84	9.66	7.98
0	15	9.09	7.00	9.10	7.15	6.90	7.72	9.32
60	15	6.72	6.12	6.82	7.27	5.02	5.84	9.35
45	15	7.41	6.50	7.36	7.65	5.40	6.22	9.61
30	15	7.48	6.17	7.07	8.32	8.06	8.88	8.93
15	15	7.94	7.23	9.04	7.38	7.13	7.95	8.58
0	15	9.09	7.00	9.10	7.15	6.90	7.72	9.32
-60	0	5.87	3.50	4.33	3.65	3.39	4.06	6.53
-45	0	6.42	4.18	5.01	4.33	4.07	4.74	7.81
-30	0	6.12	5.05	5.89	5.20	4.95	5.62	8.24
-15	0	7.10	6.33	6.95	6.48	6.22	5.89	9.89
60	0	7.15	3.50	4.33	3.65	4.85	4.06	7.01
45	0	6.27	4.18	5.01	4.33	5.55	4.74	7.45
30	0	6.65	5.05	5.89	5.20	5.87	5.62	9.55
15	0	6.10	6.33	6.95	6.48	7.61	5.89	9.89

APPENDIX VII

Flood Irrigation-Water Used

Date	Quantity	Interval	Water Given	Water given	Rainfall
	(l)	(days)	(l/pl/irrig)	(l/ pl/day)	(mm)
15-Mar-06	200	2	2.5	1.3	
17-Mar-06	210	2	2.6	1.3	
19-Mar-06	220	2	2.8	1.4	
21-Mar-06	190	2	2.4	1.2	
23-Mar-06	190	2	2.4	1.2	
25-Mar-06	200	2	2.5	1.3	
27-Mar-06	210	2	2.6	1.3	
30-Mar-06	190	3	2.4	0.8	
1-Apr-06	185	2	2.3	1.2	
2-Apr-06	160	1	2.0	2.0	
4-Apr-06	160	2	2.0	1.0	
6-Apr-06	160	2	2.0	1.0	
8-Apr-06	160	2	2.0	1.0	
12-Apr-06	160	4	2.0	0.5	
14-Apr-06	160	2	2.0	1.0	
16-Apr-06	160	2	2.0	1.0	
17-Apr-06					20
18-Apr-06					
20-Apr-06	160	2	2.0	1.0	
22-Apr-06	160	2	2.0	1.0	
24-Apr-06	160	2	2.0	1.0	
26-Apr-06	160	2	2.0	1.0	
28-Apr-06	160	2	2.0	1.0	
30-Apr-06	160	2	2.0	1.0	
2-May-06	160	2	2.0	1.0	
4-May-06	160	2	2.0	1.0	
5-May-06					15.4
6-May-06					
8-May-06					14.6
10-May-06	160	2	2.0	1.0	
12-May-06	160	2	2.0	1.0	
14-May-06	160	2	2.0	1.0	
16-May-06	160	2	2.0	1.0	
17-May-06					22.2
18-May-06					0.4
19-May-06					16.8

20-May-06					
22-May-06					2.9
23-May-06					
24-May-06					60
25-May-06					20
26-May-06					28
27-May-06					53.8

APPENDIX VIII

Drip Irrigation-Water Used

Date	Time	Quantity	Discharge	Discharge	Water Given	Interval	Water given	Rain fall
	(hr)	(l)	(lph)	(lph/dripper)	(l/pl/irrig.)	(days)	(l/day/pl)	(mm)
15-Mar-06	3.5	200	57.14	2.38	0.85	4	0.21	
19-Mar-06	3.5	205	58.57	2.44	0.88	4	0.22	
23-Mar-06	3.5	205	58.57	2.44	0.88	4	0.22	
27-Mar-06	3.5	196	56.00	2.33	0.84	4	0.21	
31-Mar-06	3.5	209	59.71	2.49	0.89	4	0.22	
4-Apr-06	3.5	213	60.86	2.54	0.91	4	0.23	
8-Apr-06	3.5	190	54.29	2.26	0.81	4	0.20	
12-Apr-06	3.5	220	62.86	2.62	0.94	4	0.24	
16-Apr-06	3.5	210	60.00	2.50	0.90	4	0.22	
17-Apr-06								20
20-Apr-06	3.5	225	64.29	2.68	0.96	4	0.24	
24-Apr-06	3.5	212	60.57	2.52	0.91	4	0.23	
28-Apr-06	3.5	220	62.86	2.62	0.94	4	0.24	
2-May-06	3.5	210	60.00	2.50	0.90	4	0.22	
6-May-06	3.5	230	65.71	2.74	0.98	4	0.25	
8-May-06								14.6
10-May-06	3.5	220	62.86	2.62	0.94	4	0.24	
14-May-06	3.5	230	65.71	2.74	0.98	4	0.25	
16-May-06	2	100	50.00	2.08	0.43	2	0.21	
18-May-06								0.4
20-May-06		200			0.85	4	0.21	
22-May-06								2.9
24-May-06		200			0.85	4	0.21	60
25-May-06								20
26-May-06								28
27-May-06		135						53.8

APPENDIX IX

Precision Porous Pipe Irrigation-Water Used

Date	Period	Interval	Total water	Discharge		Water Given	Water Given	Rainfall
	(hour)	(days)	used(l)	(l/m)	(l/m/h)	(l/irrigation)	(l/day/pl)	(mm)
15-Mar-06	4	2	479.17	6.66	1.66	0.37	0.18	
17-Mar-06	4	2	399.17	5.54	1.39	0.31	0.15	
19-Mar-06	4	2	498.33	6.92	1.73	0.38	0.19	
21-Mar-06	4	2	534.17	7.42	1.85	0.41	0.21	
23-Mar-06	4	2	482.50	6.70	1.68	0.37	0.19	
25-Mar-06	4	2	456.67	6.34	1.59	0.35	0.18	
27-Mar-06	4	2	535.00	7.43	1.86	0.41	0.21	
29-Mar-06	4	2	469.00	6.51	1.63	0.36	0.18	
31-Mar-06	4	2	454.00	6.31	1.58	0.35	0.18	
2-Apr-06	4	2	478.00	6.64	1.66	0.37	0.18	
4-Apr-06	4	2	486.00	6.75	1.69	0.38	0.19	
6-Apr-06	4	2	450.00	6.25	1.56	0.35	0.17	
8-Apr-06	4	2	420.00	5.83	1.46	0.32	0.16	
10-Apr-06	4	2	432.50	6.01	1.50	0.33	0.17	
12-Apr-06	4	2	362.50	5.03	1.26	0.28	0.14	
14-Apr-06	4	2	431.25	5.99	1.50	0.33	0.17	
16-Apr-06	4	2	486.25	6.75	1.69	0.38	0.19	
18-Apr-06	4	2	443.75	6.16	1.54	0.34	0.17	
20-Apr-06	4	2	407.50	5.66	1.41	0.31	0.16	
22-Apr-06	4	2	378.13	5.25	1.31	0.29	0.15	
24-Apr-06	4	2	420.00	5.83	1.46	0.32	0.16	
26-Apr-06	4	2	492.50	6.84	1.71	0.38	0.19	
28-Apr-06	4	2	458.75	6.37	1.59	0.35	0.18	
1-May-06	4	3	333.75	4.64	1.16	0.26	0.09	
2-May-06	4	1	205.00	2.85	0.71	0.16	0.16	
4-May-06	4	2	420.50	5.84	1.46	0.32	0.16	
5-May-06		1	280.00					15.4
8-May-06		3	840.00					14.6
12-May-06	4	4	467.50	6.49	1.62	0.36	0.09	
14-May-06	4	2	465.00	6.46	1.61	0.36	0.18	
15-May-06								2.9
16-May-06	4	2	372.50	5.17	1.29	0.29	0.14	
17-May-06			280.00					22.2
18-May-06			280.00					0.4
19-May-06			280.00					16.8
20-May-06	4	1	280.00			0.22	0.22	
22-May-06		2	560.00			0.43	0.22	2.9
24-May-06		2	560.00					60

25-May-06			280.00					20
26-May-06			280.00					28
27-May-06			280.00					53.8

FEASIBILITY STUDIES ON THE USE OF PRECISION POROUS PIPES FOR SUB SURFACE IRRIGATION

By

Eugine Spicer. J

ABSTRACT OF A THESIS

Submitted in partial fulfillment of the requirement for the degree

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in
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ABSTRACT

Irrigation technology envisages the development of irrigation systems that uses water more effectively for plants. The process of subsurface drip irrigation was conceived with this objective. One of the subsurface irrigation types is the porous pipe irrigation. This is a relatively new technology and an evaluation is necessary to assess the suitability for Indian crops and conditions. With this objective, the discharge evaluation of porous pipe irrigation was done in the laboratory and field for Amaranthus spp., to find out the moisture distribution and the optimum depth of installation. The study was conducted at KCAET, Tavanur entitled "Feasibility Studies on the Use of Precision Porous Pipes for Subsurface Irrigation".

The chosen variety for the field study was Kannara local which was popular in the region. Three depths of placement of porous pipes were chosen for the study ie 10, 15 and 20 cm with and without sand envelope. The treatments also comprised paired and double paired row with three replications each. A drip irrigation plot with two treatments and a control plot were kept for comparing the yield, water use efficiency and the cost economics.

The type of soil found in the study area was sandy loam. It has a bulk density of 1.68 gm/cc and the infiltration rate of the soil was 5.2 cm/hr. The coefficient of variation of the porous pipe was 13.98% and the emission uniformity was 82.60 %. Among porous pipe treatments, the water use efficiency was highest in the treatment with sand envelope and paired row planting at the depth of placement 20 cm. The water use efficiency of drip irrigated treatment for double paired row planting was higher than that for porous pipe irrigated treatments.

The average distribution efficiency of porous pipe in the field was 86.72%, 24 hours after irrigation and that of drip irrigation was 76.2 %. The optimum operating pressure for porous pipe irrigation system under field conditions was found to be 0.2 kg/cm^2 when the discharge was a minimum with less energy requirement. The discharge in the field under this condition was 1.27 lph/m.

From the statistical analysis, we find that there is no significant difference in yield between the treatments with and without sand envelope. Hence we conclude that for amaranthus, sand envelope is not essential in sandy loam soil. The maximum yield of Amaranthus was obtained from porous pipe irrigation from 20 cm depth of spacing with sand envelope in paired row planting in sandy loam soil.

The cost of installation of different irrigation systems was evaluated. It was found that the porous pipe irrigation with paired row spacing incurred the maximum expenditure.