SOIL WATER BALANCE STUDIES IN SUBSURFACE DRIP IRRIGATION FOR AMARANTHUS

by

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THESIS

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DECLARATION

I hereby declare that this project report entitled **"Soil Water Balance Studies in Subsurface Drip Irrigation for Amaranthus"** is a bonafide record of research done by me during the course of academic programme in the Kerala Agricultural University and that the report has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title of any other university or society.

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CERTIFICATE

Certified that this project report entitled**"Soil Water Balance Studies in Subsurface Drip Irrigation for Amaranthus"** is a bonafide record of research work done independently by **Miss. Neetha Shaju** (2014-18-109) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship, associateship, or other similar title of any other University or Society to her.

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Neetha Shaju

Dedicated to
The Profession
of
Agricultural Engineering

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SYMBOLS AND ABBREVIATIONS

%	: Percentage
&	: And
/	: Per
^{0}C	: Degree Celsius
ANOVA	: Analysis of Variance
ASAE	: American Society of Agricultural Engineers
C.D	: Coefficient of deviation
cm	: Centimeter (s)
CTCRI	: Central Tuber Crops Research Institute
CWRDM	: Centre for Water Resources Development and Management
D	: Depth of installation
Dept.	: Department
DI	: Drip irrigation
DP	: Deep percolation
E	: Evaporation
ET	: Evapotranspitration
et. al.	: And co workers
FI	: Full Irrigation
g	: Gram

ha	: Hectare
hr	: Hour (s)
i.e.	: That is
i/c	: In charge
ICAR	: Indian Council of Agricultural Research
IWUE	: Irrigation Water Use Efficiency
KAU	: Kerala Agricultural University
K_C	: Crop Coefficient
KCAET	: Kelappaji College of Agricultural Engineering and Technology
kg	: kilogram
kg/cm^2	: kilogram per square centimeter
kg/ha-m	: kilogram per hectare meter
km^2	: Square kilometer
K_P	: Pan evaporation factor
LDPE	: Low Density Poly Ethylene
LLDPE	: Linear low-density polyethylene
lph	: Litre per hour
lps	: Litre per second
LWRCE	: Land and Water Resources and Conservation Engineering

m	: Metre (s)
M ha	: Million hectares
max	: Maximum
Mg/ha	: Mega gram per hectare
Min	: Minimum
min	: Minutes
ml	: Milliliters
mm	: Millimeter (s)
mm/day	: Millimeter per day
N	: Percentage finer
N/A	: Not applicable
no.	: Number
PFDC	: Precision Farming Development Centre
Proc.	: Proceedings
PVC	: Poly Venyl Chloride
SAM	: Surface Alternate Middle
SDI	: Subsurface drip irrigation
SE(d)	: Standard error of a difference between 2 means
SE(m)	: Standard error of the mean
sec	: Second
SIR	: Surface in Row

SSIR : Subsurface in Row

SSPIS : Subsurface Pad Irrigation System

t/acre : Tones per acre

t/ha : Tones/hectare

T_1 : Treatment 1

T_2 : Treatment 2

T_3 : Treatment 3

T_4 : Treatment 4

T_5 : Treatment 5

T_6 : Treatment 6

T_7 : Treatment 7

T_8 : Treatment 8

T_9 : Treatment 9

TDR : Time - domain Reflectometry

USDA : United States Department of Agriculture

vs : Versus

WR : Water requirement

WUE : Water use efficiency

Introduction

CHAPTER I

INTRODUCTION

Water is changing into a progressively scarce resource worldwide. Aridity and drought are the natural causes for scarceness. Population is growing and therefore the demand for water faces a raised opposition among water consumer sectors and regions. Rain is not always sufficient to meet the demands for water in several regions and sometimes it may not contribute adequate quantity of water to the resources. The standard of water required is progressively high but the degradation of water resources makes it unprocurable for more necessities. Thus agriculture is forced to search out new approaches to deal with water scarceness.

India features a great diversity and variety of climate and weather conditions. These conditions change from excessive of hot to excessive of cold and from extreme dryness to excessive rainfall. Irrigation is crucial to overcome the uncertainty of monsoon rainfall, irregularity in distribution of rainfall throughout the year and excessive rainfall causing flood. Due to this irregularity in the distribution of rainfall, irrigation practices are essential for cultivating the crops particularly in Rabi and summer season.

Irrigation is the method of applying water to the plants at regular intervals. It helps in growing agricultural crops, preserving landscapes and conjointly helps in growing plants in dry areas by artificially making use of water. Irrigation has been recognized as an essential factor for enhancing agricultural production. Many of the countries use more water for irrigating field than for other purposes. About 70 percent of total water taken from waterway, lake and groundwater systems helps irrigated crops. Improvement of irrigation has been a key plan for the development of the country. Effective execution of irrigation programmes enhances agricultural production in a greater extent.

Water assets of India are limited. The average annual rainfall of India is 1083 mm. Total geographical area of India is 329 M ha, out of which total cropped area is 183 M ha and the net sown area is 141 M ha. The gross irrigated area is 75.3 M ha and the net irrigated area is 55.1 M ha. Average annual rainfall of Kerala is 3055 mm. Normal and actual rainfall in the state is 97.5 mm and 45.9 mm respectively (Annual climate summary-2015). According to India Meteorological Department, it shows deficient condition. In Kerala the gross irrigated area is 0.62 M ha and the net irrigated area is 0.44 M ha (Agricultural statistics, 2013-2014). This could be attributed mainly to the spread of irrigation. Cropping pattern of an area depends upon many factors including the type of soil, climate, water availability, food grain requirement, market demand and net rate of financial gains.

There are various approaches of irrigation adopted worldwide in these days. It is generally classified as surface and subsurface irrigation. The efficiency of surface irrigation method is only about 20 to 50 percent. Additionally, it may cause erosion, salinisation and water logging problems. Two fundamental features to be considered in irrigation are uniform water distribution within the field and accurate amount of water application with the aid of accurate delivery control. These requirements can be accomplished by adopting drip/micro irrigation techniques.

Micro irrigation technique is one of the most efficient and low cost approach of water application directly into soil at the root zone of plants. About 8.1 percent of cultivated lands in India make use of this system of irrigation. Maharashtra (0.48 M ha), Andhra Pradesh (0.36 M ha) and Karnataka (0.17 M ha) account for more than 70 percent of the total area under drip irrigation. It is also expected that the projected area of 1 M ha (i.e. 1 percent of irrigated area) will be brought under micro irrigation within the subsequent 5 years and about 10 M ha within 12 months 2020 / 2025 AD. About 55 percent of the total area of Kerala State with a humid tropical climate is under agriculture. Irrigated area in Kerala is estimated to be 1, 55,130 ha and the irrigated area in the plantation crops constitute only about 2.8 percent of the total irrigated area in the State. The area under micro irrigation in Kerala is as low as 6000 ha. Greater part of the farmers adopting micro irrigation in Kerala (52%) is marginal farmers, whereas nearly all of farmers in Andhra Pradesh (70.67%), Karnataka (66%), Orissa (62.67%) and Punjab (55.34%) are small scale farmers. (Horticultural mission, 2010)

Micro irrigation which includes most often drip and micro sprinklers is an effective tool for conserving water resources. It is an irrigation technique with high frequency application of water in and around the root zone of plant system that consists of a network of pipes together with suitable emitting devices. It allows a small and uniform flow of water with a constant discharge; it does not change significantly throughout the field. Also it is possible for the irrigation to limit the irrigation closely to the consumptive use of plants. Thus it minimizes the losses such as deep percolation, runoff and soil evaporation. It also permits the utilization of fertilizers, pesticides and other water-soluble chemical substances together with irrigation water for better crop response.

It has been observed that the micro irrigation saves water up to 70 percent, fertilizer up to 30 percent and thereby increases the yield up to 100 percent. It also prevents the weed growth, saves energy and improves the quality of the produce. However there are constraints within the progress of micro irrigation systems. Micro irrigation is in general perceived as a technology-driven movement, hence receives resistance from certain quarters. The initial cost of establishing micro irrigation system is high, generally not viable for poor farmers.

Now these constraints are being solved to some extent. There are lot of schemes that supplies financial assistance to the farmers up to the extent of 90 percent of the capital cost of the system for a hectare, for small or marginal and women farmers, and 70 percent of the cost for other categories of farmers. The cost of incentive is shared in the ratio of 71 per cent by Central and 29 per cent by the State Governments. The Scheme will cover all categories of farmers regardless of the size of land holding. However, while selecting the beneficiaries, care will be taken to ensure that the small and marginal farmers are given priority for supplying the system (National Mission for Sustainable Agriculture, 2014).

Micro irrigation system is generally classified on the basis of its installation in the field i.e., surface method or subsurface method. Drip irrigation refers to frequent application of small quantities of water on or below the soil surface as drops, tiny streams through emitters of pre-determined discharge placed along a water delivery line i.e., lateral or emitting pipe. It embodies the philosophy of irrigating the plant root zone rather than entire land, as done in conventional surface irrigation methods. It includes a head control unit, water conveyance system and water distribution system. The advantages of surface drip irrigation are well proved and documented.

Subsurface drip irrigation (SDI) is an advanced and recent innovative variation of traditional drip irrigation where the tubing and emitters are buried beneath the soil surface. Apart from having all benefits of surface drip irrigation it has some additional advantages. Major advantages of subsurface drip irrigation are improvement in soil water status for crop which results in faster maturity of crops, saving of scarce and precious resources and improving irrigation efficiency by about 33-55 per cent over conventional drip irrigation. Since the surface of soil remains dry, weed problem is almost negligible. Heavy textured soils are well suited for subsurface drip irrigation where applicability of surface drip irrigation has been found to be difficult (Karimi *et al.*, 2015). Soils having very high water intake capacity and stones in substratum are not suitable for subsurface drip irrigation. Subsurface drip has got additional advantage of applying domestic effluent with least contamination risk of agricultural produce and field workers. Hence subsurface drip irrigation with domestic waste water is a promising option nowadays. It also holds the promise of reducing weed growth, fertilizer and chemical use, labour requirement and optimizing water use. This system is very efficient with an application efficiency of 95 percent. Therefore, very little or no water is wasted and less water is required to produce crops using SDI compared with other irrigation methods. This is important during drought periods when water availability is limited.

As far as Indian economy is concerned, growing vegetable yields a far higher financial gain per ha than any other type of farming. Tomato, brinjal, okra (Ladies Finger), cabbage, cucumber, amaranthus etc. are some of the vegetables grown in India. In several areas of India, vegetable is taken as a third crop in paddy field during summer season. Irrigation is an essential practice for this. But the irrigation is frequently interrupted due to the scarcity of water during the season. In this context, drip irrigation is an effective technique that can be resorted to improve the vegetable production. So during summer season, the goal is to make use of the available water effectively as well as to conserve whatever moisture available in the soil.

Vegetable production in Indian agriculture has greater scope for growing the income of the marginal and small scale farmers. The vegetable growers are looking for new ways to achieve superior quality produce with higher yields. Amaranthus [*Amaranthus hypochondriacus, A. cruentus* (Grain type) & *A. tricolor* (Vegetable type)] is an herbaceous annual plant with upright growth habit, cultivated for both its seeds and leaves. Both leaves and seeds contain protein of a strangely high quality.

Kerala, which lies in the humid subtropics, gets a rainfall of an average of 300 cm per year, out of which almost 70 percent is received from the Southwest monsoon. Throughout Kerala, especially in northern regions, it is relatively dry during the periods from December to May. The amount and distribution of rainfall in many parts are not sufficient to meet the total water requirement of crops. Kerala being dominated by plantation crops in two-third of the cropped area and as a result of uneven topography, drip irrigation is anticipated to have high demand. According to the latest available data 89.63 percent of total cropped area is covered by plantation and horticultural crops. The average size of land holding in the state is 0.33 ha and the man to land ratio is fastly declining. The per capita net zone area is 0.09 ha and gross cropped area is 0.11 ha. It is also reported that 85 percent of the coconut, 79 percent of arecanut, 76 percent of pepper, 60 percent of cashew, 55 percent of rubber, 45 percent of coffee and 86 percent of banana are grown in holdings less than 2 ha. Therefore nature of farming is homestead with a mixture of crops in each tiny holding except for crops like rubber, cardamom and tea. The irrigation method suitable for these crops in homestead condition is minor irrigation with emphasis on drip or micro sprinkler irrigation (CTCRI, Annual report, 2014-2015)

More over the soils of Kerala State being good in infiltration with low water holding capacities, surface methods of irrigation are inefficient that results frequent irrigation and excess wetting of soils by wasting water. The adoption of sprinkler and drip irrigation in such conditions improve the irrigation efficiency significantly over the surface methods. The water bodies, especially wells in the coastal regions have high salt content. Hence adoption of drip irrigation opens the chances of utilizing the saline water for irrigating crops like coconut. In most of the homestead farms in Kerala, irrigation is well - water based and the quality of water is excellent. This helps in reducing the crisis of clogging. Additionally, this is a water scarce condition. It is necessary to preserve the available moisture. Hence there is ample scope for implementation of this advanced technique of subsurface drip irrigation in Kerala.

Understanding of moisture distribution is essential for efficient irrigation practices. Soil water balance equation is being used to describe the flow of water in and out of the system. It makes use of a simple accounting scheme to predict soil-water storage, evaporation, and water surplus.

The current status and trends in water resource availability in an area over a specific period of time can be determined by estimating soil water balance. Furthermore, water balance estimates strengthen water management decision-making, by analyzing and improving the validity of visions, scenarios and strategies.

This study has undertaken to evaluate the performance of subsurface drip irrigation for amaranth in sandy clay loam soil with the following specific objectives:

- To study the moisture distribution pattern under SDI with and without crop
- To determine the optimum depth of installation and spacing of laterals
- To estimate the soil water balance under SDI

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Subsurface drip irrigation (SDI) is an advanced and recent innovative variation of traditional drip irrigation where the tubing and emitters are buried beneath the soil surface. The major advantages of subsurface drip irrigation are improvement in soil water status for crop which results in faster maturity of crops, saving of scarce and precious resources and improving irrigation efficiency by about 33-55 per cent over conventional drip irrigation. Since the surface of soil remains dry, weed problem is almost negligible.

In this chapter, available literature relevant to this study are reviewed and presented under the following subheadings:

1. Water requirement of crops under subsurface drip
2. Soil moisture distribution under SDI
3. Wetting front advancement under SDI
4. Effect of depth of installation under SDI on crop growth
5. Managing challenges in SDI
6. Soil water balance studies under SDI
7. Studies on deep percolation
8. Comparison with other irrigation systems

Subsurface drip irrigation is defined by ASAE as "application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation.

2.1 IRRIGATION REQUIREMENT OF CROPS UNDER SUBSURFACE DRIP IRRIGATION SYSTEM

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

Camp *et al.* (1989) evaluated three micro irrigated lateral placements and two irrigation application modes for corn in a coarse textured Southeastern coastal plain soil. Tubing placements were Surface in Row (SIR), Subsurface in Row (SSIR) and Surface Alternate Middle (SAM). Study revealed that the yields were drastically lower for Surface Alternative Middle (SAM) irrigation treatments. The SSIR treatment required the least amount of irrigation water of about 0 to 50 mm out of about 350 mm annual requirement in each year. The SIR and SAM treatments required 38 mm and 25 mm more irrigation than SSIR treatment during the year 1985, 1986 and 1987. For the three years, the maximum differences in irrigation amounts were 38, 50 and 25 mm respectively. The corn yield was also high in SSIR.

Caldwell *et al.* (1994) carried out an experiment to evaluate the effect of frequency of irrigation for subsurface drip irrigated corn on the production of subsurface drip irrigated corn using four-time based treatments and four soil-water depletion based treatments. Corn yield obtained were 12.9 to 14.1 t/ha. It revealed that frequency of irrigation had no effect on corn yield as long as average available soil water deficit was less than 20 percent. Time based irrigation of seven days and depletion based irrigations of 50.8 mm lead to less drainage below the root zone and higher irrigation water use efficiencies than more frequent irrigations. Frequency of irrigation had no effect on crop water use efficiency.

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

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

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

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

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

2.2 SOIL MOISTURE DISTRIBUTION UNDER SDI

Camp *et al.* (1989) evaluated three micro irrigation lateral placements and two irrigation allocation modes for Corn in Coarse Textured Southeastern Coastal Plain Soil. Tubing placements were Surface in row (SIR), Subsurface in Row (SSIR) and Surface Alternate Middle (SAM). Analysis done on tensiometer data showed that there were steady difference in wetting patterns between SAM and other two placements. Wetting patterns also indicated that there was no difficulty for

SSIR treatment in delivery of water upwards from emitter to higher portions of the root system.

Kataria and Michael (1990) observed that the maximum moisture content was observed at the surface layer up to 10 cm depth under drip irrigation in tomato 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) revealed from the performance of a subsurface irrigation system in a clay soil under field conditions from 1989 to 1991, that subsurface irrigation could be practiced successfully in some clay soils of Quebec. 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, 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 formation of well –defined macro pores allowing the rainfall to move below the root zone without wetting it.

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

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

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

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

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

Moisture distribution pattern is one of the basic requirements for efficient design and management of an irrigation system. The knowledge of moisture distribution pattern helps in the effectiveness of drip irrigation (Yaragattikar *et al.*, 2003). Extent of soil wetted volume in an irrigation system determines the sufficient amount of water needed to wet the root zone.

Increasing the emitter spacing allows larger emitter passageways that results in reduced clogging. It also allows longer length of run or increased zone size by decreasing drip line nominal flow rate per unit of length (Lamm and Camp, 2007). Excessive emitter spacing will cause inadequate distribution of water in the root zone.

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

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

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

Nisha *et al.* (2007) studied moisture distribution under subsurface drip irrigation at five lateral depths viz. 0, 5, 10, 15 and 20 cm and three levels of irrigation (1.0, 1.5 and 2.0 lit/day/plant). They reported that soil moisture distribution pattern was found to follow a bulb shape in all the contours. Maximum moisture content observed at the emitter position was 19, 24, 25, 22 and 22 % respectively for 0, 5, 10, 15 and 20 cm depths of installation half an hour after irrigation. Maximum depletion was found at zero depth of installation after 24 hrs of irrigation, while the same was considerably reduced in deeper installations. The best moisture distributions were observed at 10 and 15 cm depths of installation after 24 hrs of irrigation.

According to Arbat *et al*. (2010) the number of drip emitters needed and the distance between them is determined by the size of the drip zone and the type of soil. Emitter spacing of 0.3 to 0.7 m is generally recommended for SDI. If plant has a large drip zone, like a tree, it requires more emitters than for a small shrub. Evidently the size of the drip zone will be smaller when the plant is young and will increase in size as the plant grows. Therefore more emitters are necessary to water the drip zone of the plant when it is mature. The volumetric water content in the soil profile was maintained at greater than 0.19 cm^3/cm^3. There were little or slight differences in volumetric water contents adjacent to the emitter and at the midpoint between emitters for emitter spacing ranging from 0.3 to 1.2 m.

Douh *et al.* (2013) carried out a study in maize under subsurface drip irrigation and they revealed that soil moisture would be relatively more stable for subsurface drip irrigation buried at 35 cm (T3) than those buried at 5 cm (T1) and 20 cm (T2). There was greater increase in volumetric soil water content for T3 than for T1 and T2 with statistically significant increases.

2.3 WETTING FRONT ADVANCEMENT UNDER SDI

Al-Ghobari *et al.* (2012) conducted a study on wetting pattern affected by irrigation scheduling in arid region in tomato crop under both drip irrigation (DI) and subsurface drip irrigation (SDI) systems. Vertical movement of soil moisture was found to be higher than horizontal movement in both the systems. Average coefficients of uniformity values for the DI and SDI systems were 84.32 and 88.72 percent, respectively. Coefficients of uniformity for SDI were higher by approximately 4.40 percent than for DI for all irrigation scheduling techniques, although there was variation in coefficient of uniformity values between the DI and SI systems with all three techniques.

Abass *et al.*, (2013) conducted a research to study the feasibility of saving water by studying the distribution pattern of soil moisture content in soil under subsurface irrigation systems. Experiments were designed for two levels of irrigation 4 lph for two hours of application time (Level1 - 100%) and for one hour (Level2 - 50%). In the study, soil moisture content was measured at various depths by soil moisture sensors that did not cause any disturbances to crop root zone while measuring. Moisture contents were measured at different depths both parallel and perpendicular to the lateral line. Data shows that after irrigation the soil moisture content increased in both horizontal and vertical directions near to field capacity all over the soil profile. And also, contour lines were close together especially perpendicular to the drip line, but the contour lines below the dripper line were more widely separated.

Ismail *et al.* (2006) developed a computer model to simulate surface and subsurface drip irrigation system. It was found to be suitable to monitor the effect of various design parameters, soil properties, and solution techniques on wetting pattern shape.

Mohammad Phull and Mohammad M. B (2012) observed the performance of drip system by developing a model to simulate soil wetting pattern. The model characterized the geometric properties of the soil wetting pattern, which depends on saturated hydraulic conductivity of the soil, depth of lateral placement, water application rate per unit length of the pipe and the time elapsed. This model was a useful tool in predicting the components of wetting fronts throughout soil profile under subsurface drip irrigation, which can be used in design to check the percolation losses.

2.4 EFFECT OF DEPTH OF INSTALLATION OF SUBSURFACE DRIP ON CROP PERFORMANCE

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

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

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

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

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

Howell *et al.* (1997) evaluated surface and subsurface micro irrigation on corn yields. Here subsurface drip laterals were placed 0.3 m below the surface with emitters spaced 0.45 m apart and drip lines were placed 1.5 m apart. Corn yield exceeding 1.4 kg/m^2 were achieved in 1994, and yields exceeding 1.3 kg /m^2 were achieved in 1993.

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

Reddy *et al.* (2005) conducted a study on effect of subsurface and surface drip irrigation on soil moisture distribution and growth of mango varieties. Four treatments via, subsurface irrigation with dripper at 20 cm, 30 cm depth, drip line at 30 cm depth with emitter in surface and subsurface drip line were arranged. Results indicated that plants height, stem growth, number of branches and plant spread were not influenced by the system of irrigation whereas soil moisture content at 50 cm away from the emitter was higher with subsurface drip irrigation than with surface drip irrigation at 60 cm depth. Moisture content 100 cm away from the dripper with subsurface dripper at 30 cm depth was high at 60 cm soil depth directly vertical to the dripper than surface drip irrigation. Relative water content of leaf was higher with surface irrigation than subsurface drip irrigation.

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

2.5 MANAGING CHALLENGES IN SDI

According to Marais *et al.* (2000) crop roots that grow around the driplines also can plug emitters, especially when the soil around the dripline is dry. The phenomenon is known as root intrusion. By keeping the soil around the dripline sufficiently wet and injecting chemical products to kill those roots are used to alleviate this problem.

Some rodents like field mice can cause severe damage to driplines. Evidence of leak can be detected by periodic inspection and by measuring pressure drops and high flow rates in the system. Since locating and fixing leaks created by rodents is a difficult task, the potential for rodent attack in the area should be evaluated prior to installation. Rodent control and prevention program can be implemented, if needed (Marais *et al.*, 2000).

Lamm (2002) reported that if water is applied at a rate greater than infiltration rate of soil, a saturated zone will develop around the dripline. Water under pressure may take the path of least resistance. If the dripline is sufficiently close to the surface, water and soil particles could pop up to the surface, creating a wetted area above each emitter. This is known as surfacing or chimney effect. It can sometimes be avoided by deeply placed driplines. The choice of emitter discharge must be considered to avoid surfacing.

Sinobas and Rodríguez (2012) revealed that the major cause of failure of SDI systems is clogging of the emitters. Proper maintenance is necessary for an efficient SDI system. Emitters can be easily clogged by small particles, since they have very small diameter. If the emitters are clogged, it may difficult to unclog them. Therefore it is necessary to avoid those particles that cause clogging. Clogging by soil particles can be prevented by proper filtration and flushing. Chemical precipitates are removed by injecting acids to the irrigation water.

Vyrlas *et al.* (2014) conducted a study to evaluate the effect of continuous application of air in the moisture distribution pattern under SDI. They reported that subsurface drip irrigation system provides water directly to the crop root zone. Long duration irrigation events result in root development concentrated around the emitters resulting in lack of air, which prevents the proper root functioning and it directly influences the crop growth. This can be minimized by applying air in the root zone. Continuous application of air can improve the distribution of soil moisture in the root zone that provides high crop yield.

2.6 SOIL WATER BALANCE STUDIES UNDER SDI

Thompson and Maki (1995) carried out a research to estimate a season long water balance under one subsurface trickle irrigated plot each of lettuce and broccoli and water stored in the root zone was found to be constant at 12-14 cm water/50 cm soil except after rainfall.

Kendy *et al.* (2003) conducted a study on a soil-water-balance approach to quantify groundwater recharge from irrigated cropland in the North China Plain. They introduce a one-dimensional soil-water-balance model to estimate precipitation- and irrigation generated areal recharge from commonly available crop and soil characteristics and climate data. For calibration, model-calculated water contents of 11 soil depth intervals from 0 to 200 cm were compared with measured water contents of loam soil. Average root mean-squared error between measured and model-calculated water content of the top 180 cm was 4.2 cm, or 9.3 percent of average total water content.

Westenbroek. S.M *et al.* (2010) developed a soil water balance computer code to calculate spatial and temporal variations in groundwater recharge based on a modified Thornthwaite-Mather soil-water-balance approach. Recharge calculations were made on a rectangular grid of computational elements that might be easily imported into a regional groundwater- flow model. Output determined from the model might be as daily, monthly, or annual values.

Jadavi *et al.* (2014) reported that water extraction variability in the banana root zone affects the reliability of water balance. The range of variability of soil water extraction affects the reliability of the crop evapotranspiration. To prevent the overestimation of banana evapo transpiration, water extraction in the soil profile must be monitored with at least 16 TDR probes installed at a minimum distance of 0.9 m and to a minimum depth of 0.7 m, spaced horizontally at length intervals of 0.2 m.

2.7 STUDIES ON DEEP PERCOLATION

Bethune *et al.* (2008) conducted a lysimeter experiment to quantify deep percolation (DP) response under irrigated pasture to soil type, water table depth, and ponding time during surface irrigation. A simple conceptual model was developed and tested to describe DP response. For most of the soils, steady-state percolation was found to be the dominant process contributing to DP. Non steady-state percolation (redistribution) was as important as steady-state percolation for the sandy soil type.

According to Punitha and Vanitha (2015) the traditional method of rice cultivation under water logged situations needs a paradigm shift towards an irrigation scheduled aerobic environment that can facilitate total elimination or minimization of the irrecoverable deep percolation losses. They reported that micro irrigation system preferably a subsurface drip irrigation system embedded with fertigation components has been construed as the right choice to meet these criteria.

Upreti *et al.* (2015) estimated the deep percolation in sandy loam soil using water balance approach. They concluded that, deep percolation computed by using water balance approach was less expensive and less time consuming than that obtained from lysimeter. Also, both data were comparable.

2.8 COMPARISON WITH OTHER IRRIGATION SYSTEMS

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

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

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

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

Comparison between surface and subsurface irrigation system made by Lal (1998) is as shown in Table 2.1.

Table 2.1 Comparison between surface and subsurface irrigation system

Particulars	Surface	Subsurface
Wetted soil volume	Small	large
Wetted change of soil water content	Large	Small
Surface evaporation	Large	Small
Total transpiration	Small	Large
Irrigation efficiency	Low	High

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

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

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

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

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

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

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

Abou Kheira (2009) reported that the surface drip system resulted in a good distribution of the soil profile up to 60 cm depth for treatments such as 100%, 80% and 60% of ET_p. Moisture distribution was found to be more uniform at 48 hr after irrigation. This may be due to high value of uniformity distribution in the surface drip irrigation system. Under subsurface drip, the water available in root zone was enough for plant growth. This is because under subsurface drip, the soil profile below effective soil depth became wetter due to minimum evaporation loss.

The soil moisture distribution and its uniformity within the soil profile under surface drip were affected by the distance between drippers rather than distance between laterals. Lesser the dripper spacing, more will be moisture distribution. Under SDI, the allocation of irrigation system plays an important role in soil moisture trend. Depth of lateral below soil surface, emitter spacing and system pressure are important for delivering the required amount of water to plant (Badr *et al*, 2011).

Mokh *et al.* (2014) evaluated the effect of two drip irrigation systems; surface and subsurface system. For that, three levels of irrigation were applied viz. full irrigation (FI_{100}) and deficit irrigation (DI_{30}, DI_{60}). Water with an EC_i of 7.0 dS/m was used for irrigation. Average soil moisture content values under different irrigation treatments for surface drip irrigation (DI) and subsurface drip irrigation (SDI) methods at planting, development, mid-season and harvest period of spring and autumn potato crop were measured. Moisture was directly related to the amount of water applied at full or deficit-irrigated treatments. Moisture content in soil profile initially showed higher value in all the treatments due to the irrigation amount applied before planting to replenish the soil profile to field capacity. Initial soil moisture content in root zone area was about 17.37 and 18.04 percent in spring season and 17.03 and 18.11 percent in autumn season, respectively, for DI and SDI. They concluded that for all irrigation treatments significant differences were observed between the soil moisture content of the subsurface irrigated plots and those irrigated with the surface drip system. SDI had higher value of soil moisture content than DI's.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter describes the materials used and the methods employed for the study entitled "Soil water balance studies in subsurface drip irrigation for Amaranthus" conducted at the Institutional Farm, Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Malappuram, Kerala during the period of 2015-2016.

3.1 LOCATION AND CLIMATE

The experiment was conducted in the Instructional Farm, KCAET, Tavanur, in Malappuram district, Kerala. The place is situated at 10^0 85' 67.10" North Latitude and 76^0 98' 62.23" East longitude. Location map of KCAET, Tavanur is given in Plate 3.1. The total area of KCAET is 40.99 ha, out of which total cropped area are 29.65 ha. Agro climatically, the area falls within the border line of Northern zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon. Average annual rainfall of the region varies from 2500 to 2900 mm. Climatological data of the experimental area is shown below.

Mean maximum temperature : 30.7° C

Mean minimum temperature: 23.5° C

Average relative humidity : 70%

Average annual rainfall : 2700 mm

Monthly evapotranspiration : 6.35 mm/day

Mean solar radiation : 24.9 $MJ/m^2/day$

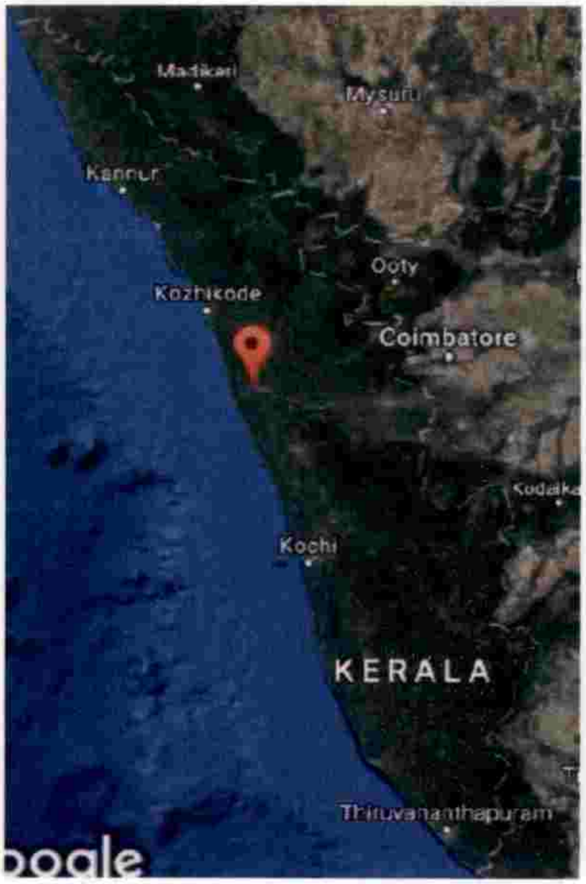


Plate 3.1 Location map of Tavanur

3.2 EVALUATION OF SOIL PHYSICAL PROPERTIES

Soil properties determine the availability of oxygen in the soil, the mobility of water through the soil, availability of water to the crop and ease of root penetration. Physical properties include texture, moisture content, field capacity, bulk density, hydraulic conductivity etc in the experimental area were studied. The properties are determined by using standard procedures as explained below.

3.2.1 Soil Texture

Texture is an important soil characteristic since it affects the infiltration rate, water storage in the soil, ease of tilling the soil, the amount of aeration and influence of soil fertility. Particle size analysis for finding out the percentage of various sizes of particles in a dry soil can be performed by sieve analysis and sedimentation analysis.

3.2.1.1 Sieve Analysis

Soil was collected from the experimental field at a depth of 60 cm from the soil surface by using an auger. Soil sample was oven dried and passed through a set of IS sieves of size 4.75 mm, 2 mm, 1 mm, 600 micron, 425 micron, 300 micron, 212 micron, 150 micron and 75 micron for sieve analysis. Percentage finer was calculated on the basis of percentage of soil retained in each sieve.

3.2.1.2 Sedimentation Analysis – Hydrometer Method

Soil fraction finer than 75 micron size was kept in suspension in liquid (water). Calibration of hydrometer was done. Sodium hexametaphosphate solution of 100 ml was added to the dry soil sample passing through 2 mm IS sieve. It was then warmed for 10 minutes and was mixed thoroughly for 15 minutes. Soil suspension was then transferred to 75 micron IS sieve placed on a receiver and washed the soil on the sieve using a jet of distilled water. Distilled water was added to the soil suspension to make the volume exactly to 1000 ml. A rubber bung was inserted on the top of 1000 ml measuring jar containing soil suspension and shakes it vigorously. Suspension was allowed to stand for some time. Cover of the cylinder was removed and stop watch was started immediately. Hydrometer reading was taken after ½ minute by inserting the hydrometer in the solution. Similarly the readings were taken at 30 sec, 1 min, 5 min, 10 min, 20 min, 1 hr, 2 hr, 4 hr, 8 hr, 12 hr and 24 hr. Particle size was obtained for each hydrometer reading by using the formula.

$$D = 10^{-5} F \sqrt{\frac{H_e}{t}} \qquad \ldots\ldots \qquad 3.1$$

Where

D = Particle size in mm

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

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

t = Elapsed time in min

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

3.2.2 Moisture Content

Moisture content was found out by oven drying method. It is the most accurate method of determining moisture content of soil. Soil sample was collected from the field and kept in a clean moisture can. After taking the weight of the specimen, moisture cans were placed in an oven at 110°C for 24 hr. The container was removed and took weight of the dried soil sample. Moisture content in per cent (W) can be calculated by the following formula.

$$w = \frac{M_2 - M_3}{M_3 - M_1} * 100 \qquad \ldots\ldots \qquad 3.2$$

where,

M_1 = mass of the container (g)

M_2 = mass of the container and wet soil (g)

M_3 = mass of the container with dry soil (g)

3.2.3 Field Capacity

Field capacity of soil is the moisture content after the drainage of gravitational water has become very slow and the moisture content has become relatively stable.

Field capacity was determined by ponding water on the soil surface to saturation in an area of 2 to 5 sq m and permitting it to drain for one to three days. The surface was covered with PVC sheet to prevent the evaporation. Soil samples were collected with an auger from different depths of 10 cm, 15 cm and 20 cm. Moisture content was determined by gravimetric method. The values of moisture content of two successive samples which are nearly equal to this constant value of moisture content was considered as the field capacity of the soil.

3.2.4 Infiltration Rate

Infiltration process influences run off, and determines the water content of the soil. Infiltration rate was measured using double ring infiltrometer. It consists of two cylinders of 25 cm deep and was made of 2 mm rolled steel. The outer cylinder of 60 cm in diameter is provided 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. Test was replicated at different locations in the field. The average values of accumulated infiltration (y) and infiltration rate were found. Using these data an equation of following form was developed to find functional relationship

$$y = a\, t^{\alpha} + b \qquad \ldots\ldots \qquad 3.3$$

where

y = accumulated infiltration in cm

t = elapsed time in hour

a, b, α = constants

3.2.5 Bulk Density

Bulk density helps 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.

Core cutter method was adopted to determine the bulk density. Soil samples were collected by using core sampler. Weight in gram (W_1) and volume in cm^3 (V_1) of the core cutter were noted. Sample was then over dried and weighed again (W_2) in gram. Bulk density was calculated using the relation

$$Bulk\ density = \frac{W_2 - W_1}{V_1} \qquad \ldots\ldots \qquad 3.4$$

3.2.6 Hydraulic Conductivity

Permeability (hydraulic conductivity) is the capacity of a porous medium to transmit water and is proportional to the square of average particle size of the medium. Hydraulic conductivity was determined by constant head permeameter method.

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

$$K = \frac{Q.L}{t.h.a} \quad \ldots\ldots \quad 3.5$$

where

K = hydraulic conductivity (cm/sec)

Q = discharge collected (cm^3)

L = Soil column length (cm)

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

t = time (sec)

a = area of soil column (cm^2)

3.3 DETAILS OF THE FIELD SELECTED FOR THE STUDY

Selected plot for the study was located in the Northern side of the KCAET farm which has Bharathapuzha River as its northern boundary. Soil type in the selected plot was studied and it was sandy clay loam in nature. Total area selected for the study was 113.4 m^2. Here subsurface drip method was practiced. Proper land preparation was done using harrows and cultivator before the installation of the system in the field. Field experiment was conducted during December 2015 to June 2016.

Plate 3.2 A view of selected field prior to installation of laterals

Plate 3.3 Land preparation

3.4 COMPONENTS OF SUBSURFACE DRIP SYSTEM

Components of the unit are:

1. Main and sub-main pipes
2. Laterals
3. Inline emitters

1. Main and sub-main pipes

A pipe of 1.5 inches was used for main and sub-main. Length of sub-main was about 32 m. A valve of 1.5 inches was provided in the sub-main to distribute water to the entire crop field. PVC pipes were used for the mains and sub-mains.

2. Laterals

The main component of the subsurface drip irrigation system is the lateral which is placed in the crop root zone and delivers water to the field. Inline drippers manufactured with Linear Low Density Poly Ethylene (LLDPE) having nominal diameter 16 mm were used. End caps were provided at the end of each lateral which helps to check the proper functioning of the system and also helps for periodic flushing of the laterals.

2. Inline emitters

Inline emitters are fixed within the lateral line. It makes a continuous flow after fixing the dripper. It is usually necessary to shut off flow to the lateral and cut the pipe to replace a malfunctioning in inline emitters. A 16 mm lateral with inline emitter is shown in Plate 3.4.

Plate 3.4 mm lateral with inline emitter

3.4.1 Installation Procedure

In order to install the system in the field, proper land preparation was done. Then 27 beds were made with 70 cm width and 6 m length and spacing between laterals varied as 95 cm, and 100 cm, 105 cm. The sub main pipes were placed and connected to main lines. Laterals were installed through the center of each bed at 3 different depths of 10 cm, 15 cm, and 20 cm. End caps were provided at the end of each lateral for flushing and checking proper functioning of the system.

Plate 3.5 A view of a bed after installation

3.4.2 Crop and Variety

Amaranth crop is the most popular leafy vegetable in Kerala. It is a short duration perennial plant. Hence this particular crop was selected for the study. The variety used was '*A. tricolor*, red stripe leaf' (Karnataka local), since it is easy to grow and tolerate hot weather. Crop to crop spacing is 30 cm with a root depth of 30 cm. Double row planting was done for the experiment with a row to row spacing of 50 cm and the total crop duration was 3 to 4 months.

Plate 3.6 Karnataka local variety of Amaranth in the field

3.4.3 Sowing and Transplanting

The selected crop variety was *A. tricolor* (Karnataka local or Tampala). Sowing was done on 8th December 2015 in a part of the experimental plot. After 15 days from germination, seedlings were transplanted in the prepared beds. The plants were irrigated with watering cans immediately after transplanting.

Plate 3.7 A view of the plot after transplanting

Plate 3.8 A close view of the crop at the time of first harvest

3.5 ESTIMATION OF CROP WATER REQUIREMENT

Water requirement of crops (WR) is a function of plants, surface area covered by plants and evapotranspiration rate. Irrigation water requirement need to be calculated for different seasons. Maximum water requirement among the three seasons is adopted for design. Daily water requirement for fully-grown plants was calculated as under

$$V = E_p * K_c * K_p * W_p * S_p \quad \ldots\ldots \quad 3.6$$

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

$$V_n = V - (R_e * S_p) \quad \ldots\ldots \quad 3.7$$

Total water requirement of the farm plot = $V_n * no. of\ plants$

Values of the various parameters used for estimating the water requirement of amaranth in the present case is shown in bracket against each parameter explained

V - Water requirement in litre/day/ plant

E_p - maximum pan evaporation in mm / day

K_c - crop factor.

The value of crop factor depends on foliage characteristics, stage of growth, environment and geography ($K_c = 0.8$)

K_p - pan coefficient (0.7)

W_p - wetted area, which is shaded due to canopy.

Canopy cover when the sun is over head, which depends on the stage of crop growth. This is otherwise known as canopy factor ($W_p = 1$) for a matured amaranth plant.

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

R_e - effective rainfall in mm (Nil)

The monthly water requirement was calculated by using the software "CROPWAT".

3.6 SOIL MOISTURE DISTRIBUTION PATTERN UNDER SUBSURFACE DRIP IRRIGATION SYSTEM IN BARE SOIL

In order to study the soil moisture distribution under subsurface, an experiment was conducted in the bare soil in the field. Since the subsurface drip laterals were placed at different depths, soil moisture distribution patterns were studied separately for different depths. Emitters were located at 10, 15, 20 cm depths from the surface and they are spaced at 30 cm interval along the laterals.

Moisture distribution pattern was studied with 4.0 lph discharge emitters at different depth of installation. Total quantity of water applied was 2.0 liters for 30 minutes which remain same for all depths of installation.

Profiles were exposed by cutting the soil of subsurface drip at 10, 15, 20 cm of the depth of laterals. Dimensions of the wetted profile in horizontal and vertical directions were measured and recorded by measurements. Soil samples at 5, 15, 30 cm depth were collected before irrigation, 1 hr after irrigation and 24 hr after irrigation and moisture contents were determined gravimetrically. Moisture data were analyzed for distribution pattern by plotting moisture contour using the computer software package "SURFER".

3.7 EFFECT OF DEPTH OF INSTALLATION AND SPACING BETWEEN LATERALS OF AMARANTH UNDER SUBSURFACE DRIP IRRIGATION

A field experiment was conducted to evaluate the effect of depth of installation of laterals and spacing between laterals.

Table 3.1 Details of treatments

Treatment	Name	Depth of installation (cm)	Spacing between laterals (cm)
T_1	D_1S_1	10	95
T_2	D_1S_2	10	100
T_3	D_1S_3	10	105
T_4	D_2S_1	15	95
T_5	D_2S_2	15	100
T_6	D_2S_3	15	105
T_7	D_3S_1	20	95
T_8	D_3S_2	20	100
T_9	D_3S_3	20	105

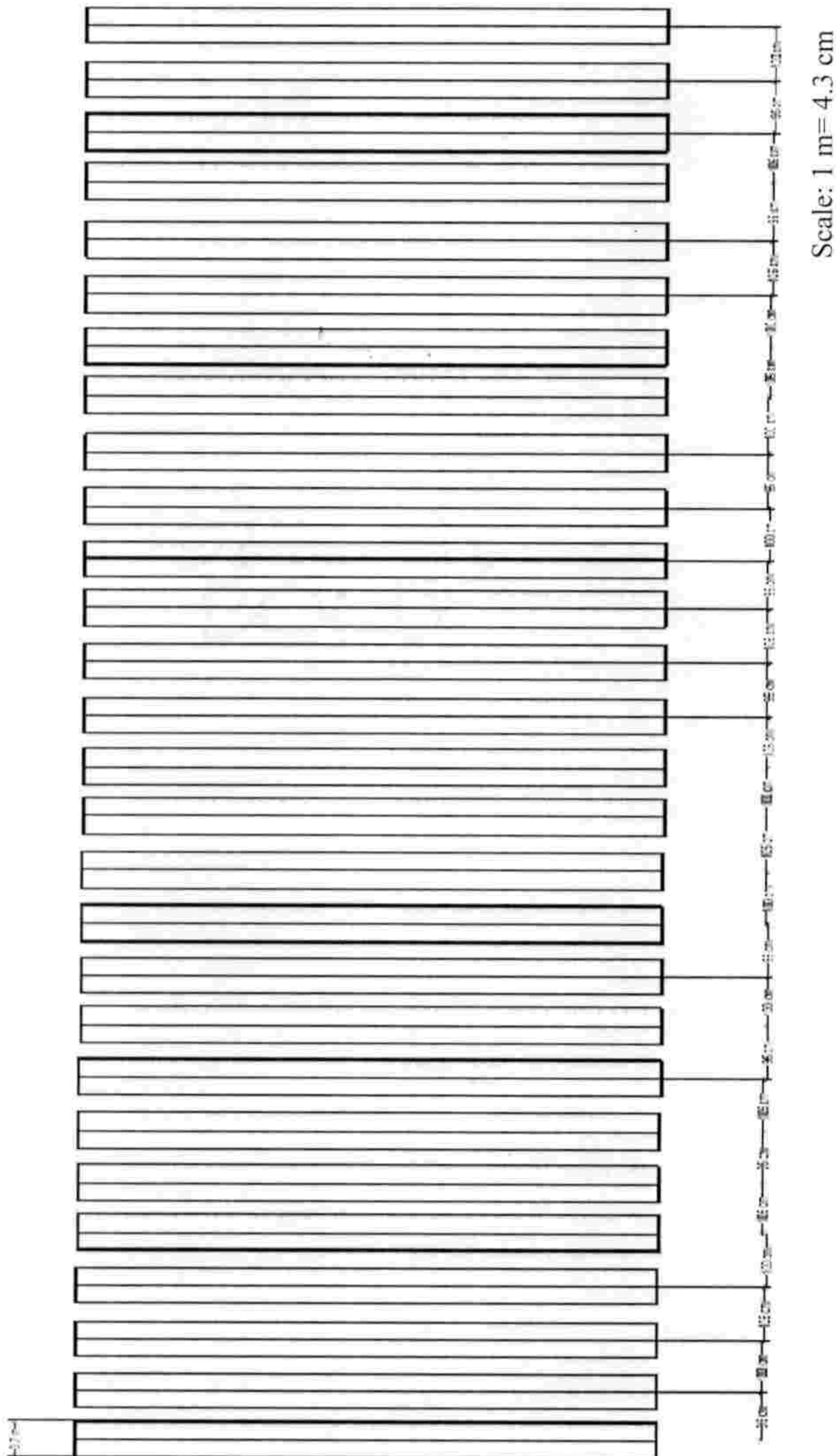
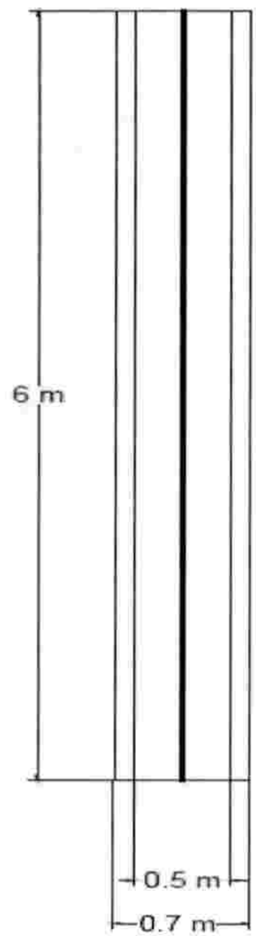


Figure 3.1 Layout of the experimental plot



Scale: 1 m= 4.3 cm

Figure 3.2 Plan of a single bed

3.8 OBSERVATIONS

3.8.1 Moisture Content

Performance of the system was evaluated on the basis of the following observations

1. Moisture content at different depths and horizontal distance from emitter before irrigation without crop
2. Moisture content at different depths and horizontal distance from emitter 1 hr after irrigation without crop

3. Moisture content at different depths and horizontal distance from emitter 24 hr after irrigation without crop
4. Moisture content at different depths and horizontal distance from emitter before irrigation with crop
5. Moisture content at different depths and horizontal distance from emitter 1 hr after irrigation with crop
6. Moisture content at different depths and horizontal distance from emitter 24 hr after irrigation with crop

The depths taken and corresponding horizontal distance for the measurement of moisture content is shown below

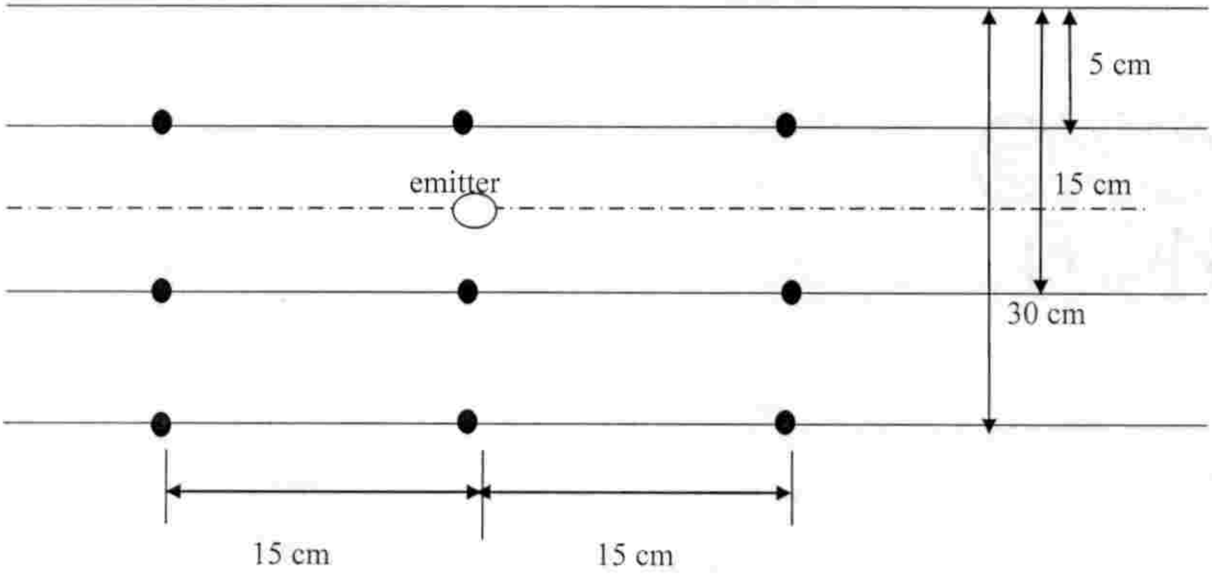


Figure 3.3 Schematic diagram representing depths and corresponding horizontal distance from which soil samples were taken

Measurements were taken at a distance of 15 cm from either side of the emitter and at the point of emitter and also, at three depths viz. 5 cm, 15 cm, and 30 cm from the surface. The measured moisture content was used to plot the moisture distribution pattern using software package "SURFER".

3.8.2 Growth parameters

Growth parameters such as plant height, stem girth and number of leaves were taken at one month interval from the date of planting. Observations on height, stem girth and number of leaves were recorded from randomly selected plants for each plot.

3.8.2.1 Height of the Plant

Average height of the randomly selected plants grown under each treatment was taken. The measurement was taken from the ground surface to the shoot tip for the selected plants at one month interval from the date of planting.

3.8.2.2 Girth of the Plant

Girth of the plant was measured at 2.5 cm above ground level at one month interval from the date of planting. It was taken for each treatment from randomly selected plants.

3.8.2.3 Number of Leaves

Total number of leaves was counted for the randomly selected crops in each treatment at one month interval from the date of planting.

3.8.3 Yield Measurements

First harvesting was done on January 26, 2016. Harvesting was continued at an interval of two weeks. Yield was recorded and evaluated to know how evenly the water and nutrients were being distributed in the plot. Statistical analysis was done to analyze the significance of lateral spacing and lateral depth on crop yield.

3.8.3.1 Water Use Efficiency

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

$$E_w = \frac{Y}{W_u} \quad \ldots\ldots \quad 3.8$$

where,

E_w = Water use efficiency (kg/ha mm)

Y = Yield of the crop in kg/ha

W_u = Total water applied, mm

3.8.4 Statistical Analysis for Yield and Biometric Observations

Results obtained from the experiment were statistically analyzed by analysis of variance using computer software OP STAT. The experimental design was a randomized block design (RBD) with three replications. ANOVA test was performed to find out the significant difference in the treatments. The level of significance used was p=0.05. Statistical analysis was done for growth parameters and yield and compared them for getting the suitable treatment.

3.9 SOIL MOISTURE DISTRIBUTION PATTERN UNDER SUBSURFACE DRIP IRRIGATION SYSTEM WITH CROP

An experiment was conducted to study the moisture distribution pattern under subsurface drip irrigation with crop. Since the subsurface drip laterals were placed at different depths, soil moisture distribution patterns were studied separately for different depths. Emitters were located at 10 cm, 15 cm and 20 cm depths from the surface and they are spaced at 30 cm interval along the laterals with three different lateral spacing of 95 cm, 100 cm and 105 cm.

Moisture distribution pattern was studied with 4.0 lph discharge emitter for 30 minutes at different depth of installation. Total quantity of water applied was 2 liters which remain same for all depths of installation.

Profiles were exposed by cutting the soil of subsurface drip at 10 cm, 15 cm and 20 cm of the depth of laterals. Dimensions of the wetted profile in horizontal and vertical directions were measured and recorded. Soil samples at 5 cm, 15 cm and 30 cm depth were collected before irrigation, 1 hr after irrigation and 24 hr after irrigation and moisture contents were determined gravimetrically. Moisture data were analyzed for distribution pattern by plotting moisture contour using the computer software package "SURFER".

3.10 SOIL WATER BALANCE

An understanding of water balance is essential to understand the role of various water management strategies. It helps to minimize the losses and optimize the utilization of water, which is the most limiting factor of crop production in semi-arid tropics.

In this study, water balance equation was used for determining the deep percolation. Deep percolation is the movement of water by gravity downward through the soil profile; that is not used by plants. It is the percolation of water through the ground and beyond the lower limit of the root zone of plants into a ground water aquifer.

In order to find out the deep percolation from each layer, the following equation was used:

$$L = \theta D_i - \theta D_{i+1} + I + P - ET_a \quad \ldots\ldots \quad 3.9$$

where,

L = Leaching losses from the root zone (i.e., deep percolation) (mm)

θD_i = Amount of water in the root zone at the beginning of the period (mm)

θD_{i+1} = Amount of water in the root zone at the end of the period (mm)

I = Amount of irrigation water applied (mm)

P = Precipitation (mm)

ET_a = Actual evapotranspiration (mm/day)

Here, precipitation was negligible during the growing season. Therefore the equation becomes;

$$L = \theta D_i - \theta D_{i+1} + I - ET_a \quad \ldots\ldots \quad 3.10$$

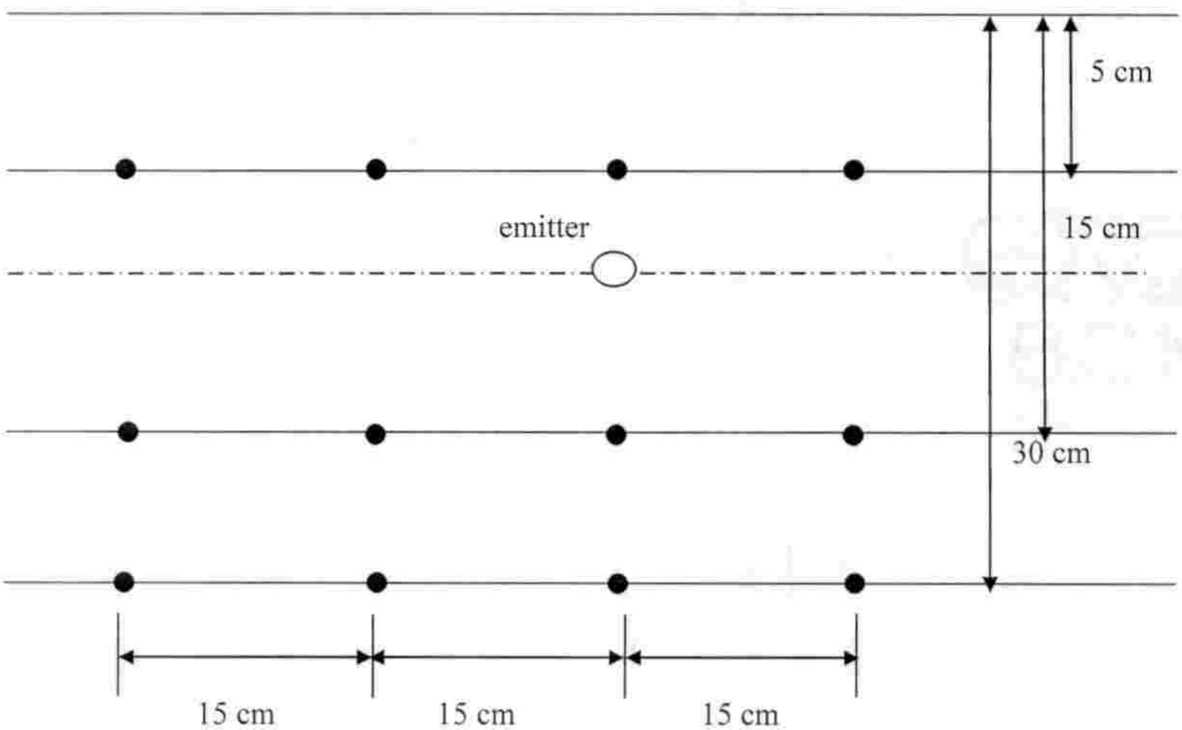


Figure 3.4 Schematic diagram representing depths and corresponding horizontal distance from which soil sample were taken

3.10.1 Regression Analysis

Regression analysis is a common method to correlate two or more variables. Plotting soil depth against deep percolation and drawing best fit line can be done for rough estimate. The equation for quadratic regression between soil depth and deep percolation is given by:

$$y = ax^2 + bx + c \qquad \ldots\ldots \qquad 3.11$$

where,

x = Soil depth (cm)

y = Deep percolation (mm)

a, b, c = coefficients of quadratic equation

x - coordinate of vertex of the parabola = -b/2a

The regression equation represents how much y changes with any given change of x.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This study was conducted to optimize the depth of installation of laterals and spacing between laterals under subsurface drip irrigation system for Amaranthus. Additionally, deep percolation from different soil layers for different depth of installation of laterals was computed. Results obtained from this study were analyzed to provide basic information of soil moisture movement under subsurface drip irrigation and its performance on growth and yield of crop.

4.1 EVALUATION OF SOIL PHYSICAL PROPERTIES

The following physical properties of soil were evaluated for the study.

4.1.1 Soil Texture

Soil samples were collected at 60 cm depth from different representative locations. They were analyzed for grain size distribution and texture. Results of textural analysis are given in APPENDIX I. Particle size distribution curves were plotted as shown in Figure 4.1.

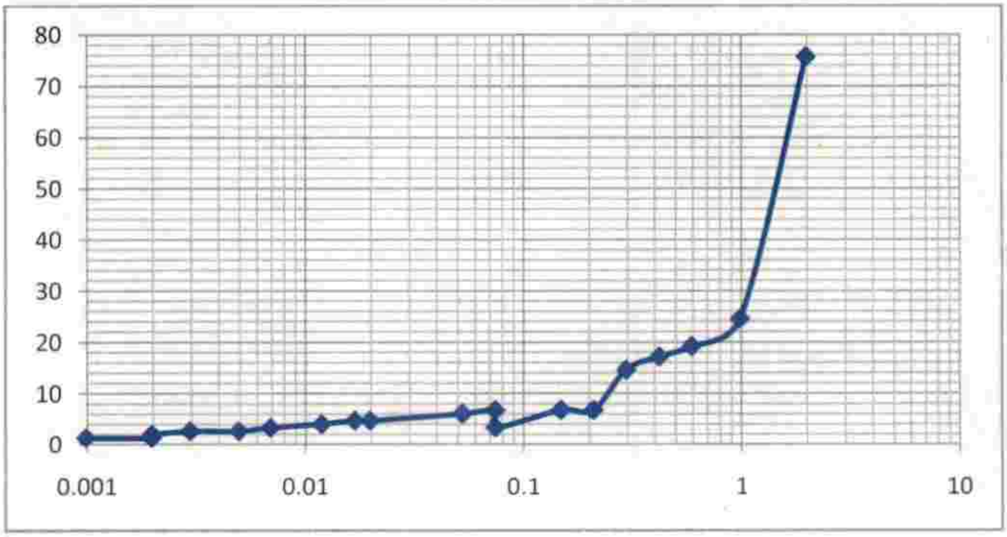


Figure 4.1 Particle size distribution curve

In this curve, percentage finer "N' was taken as ordinate and particle diameter (mm) as the abscissa on logarithmic scale. Result showed that the soil sample consisted of 73.066 per cent sand having size range 2 to 0.05 mm, 1.357 per cent silt (0.05 to 0.002 mm) and the remaining part 25.577 per cent clay. According to USDA classification chart, textural class of the soil was identified as sandy clay loam.

4.1.2 Moisture Content

Average moisture content of the experimental field prior to land preparation was determined by oven drying method. It was about 15.52 per cent.

4.1.3 Field Capacity

Soil samples from various locations of the experimental site were taken from different depths of 10 cm, 15 cm and 20 cm for determining the field capacity. It was found to be 38 per cent of the soil and the value is within the range of 35 to 45 per cent for sandy clay loam (Linn and Doran, 1984).

4.1.4 Infiltration Rate

A double ring cylinder infiltrometer test was conducted to determine the infiltration rate of soil as the performance of the system was influenced by infiltration properties of soil and results are shown in APPENDIX II.

Basic infiltration rate of sandy clay loam soil ranges between 0.20 to 0.79 cm/hr (Lowery *et al.*, 1996). Average basic infiltration rate of soil was found to be 0.635 cm/hr.

4.1.5 Bulk Density

Bulk density of soil in the experimental field was determined by core cutter method. Weight and volume of core cutter and weight of soil samples are given in

APPENDIX III. Mean bulk density of soil was found to be 1.57 g/cm^3 which lie within the range of 1.55 to 1.65 g/cm^3 for sandy clay loam soil (Linn and Doran, 1984).

4.1.6 Saturated Hydraulic Conductivity

Subsurface movement of water is greatly influenced by the hydraulic conductivity of soil. Value obtained as 2.63×10^{-4} cm/sec. Generally, the hydraulic conductivity of sandy clay loam lies within the range of 1.41×10^{-4} to 4.23×10^{-4} cm/sec (Lowery *et al.*, 1996).

4.2 CROP WATER REQUIREMENT

Crop water requirement as per theoretical calculation based on evaporation data of Tavanur region was estimated as 2 L/ day/ plant. It is in close agreement with the results reported by CWRDM Kozhikode, Kerala and PFDC centre of KCAET. Also it coincides with the water requirement computed from CROPWAT 8.0.

4.3 SOIL MOISTURE DISTRIBUTION UNDER SUBSURFACE DRIP IRRIGATION SYSTEM IN BARE SOIL

An experiment was conducted to evaluate soil moisture distribution pattern of inline drippers in the bare field. Emitters were located at 10 cm, 15 cm and 20 cm depth from the surface and they were spaced at 30 cm interval along the laterals. System was operated for 30 minutes to get the quantity of water applied as 2 L for laterals installed at 10 cm, 15 cm and 20 cm depth from the surface.

Profiles were exposed by cutting the soil at the point of application of emitter. A close view of the exposed profile with lateral installed at 10 cm is shown in Plate 4.1. This vertical profile exposed had a total horizontal length of 30 cm and a vertical length of 30 cm downwards. Vertical spread and horizontal spread were found to follow the same trend in all the depth of installation of laterals. Soil samples were collected from this vertical profile at grid points and moisture content was determined gravimetrically. Calculated value of moisture content is shown in APPENDIX V. Moisture data were analyzed for distribution pattern by plotting the soil moisture contour as shown in Figure 4.2 to Figure 4.4. Contours were drawn for before irrigation, 1 hr after irrigation and 24 hr after irrigation for all the lateral depths selected for the study.

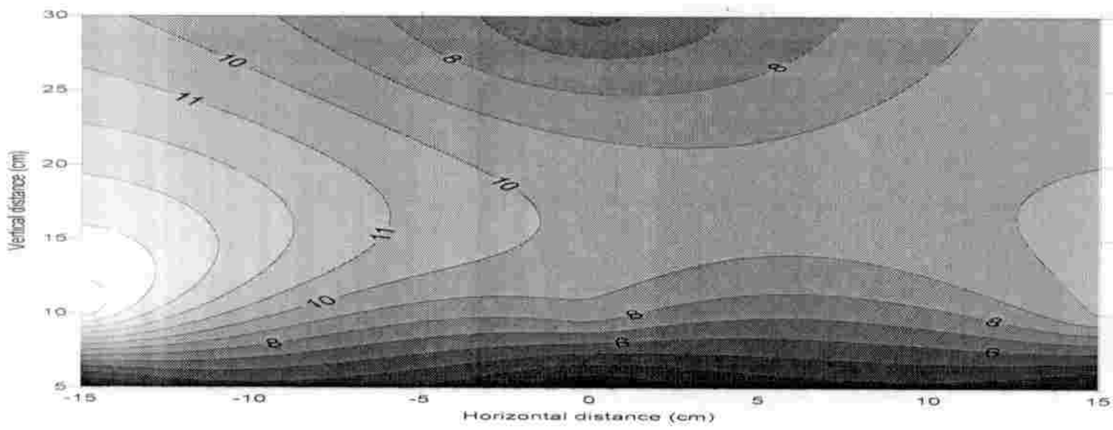
When emitter was placed below the soil surface and water was allowed to flow, a saturated sphere of small diameter was found to develop first, which keeps on growing till the unsaturated water flow rate from the surface of saturated sphere becomes equal to the emitter discharge rate i.e. the wetting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

Plate 4.1 A view of vertical profile with lateral at 10 cm depth without crop

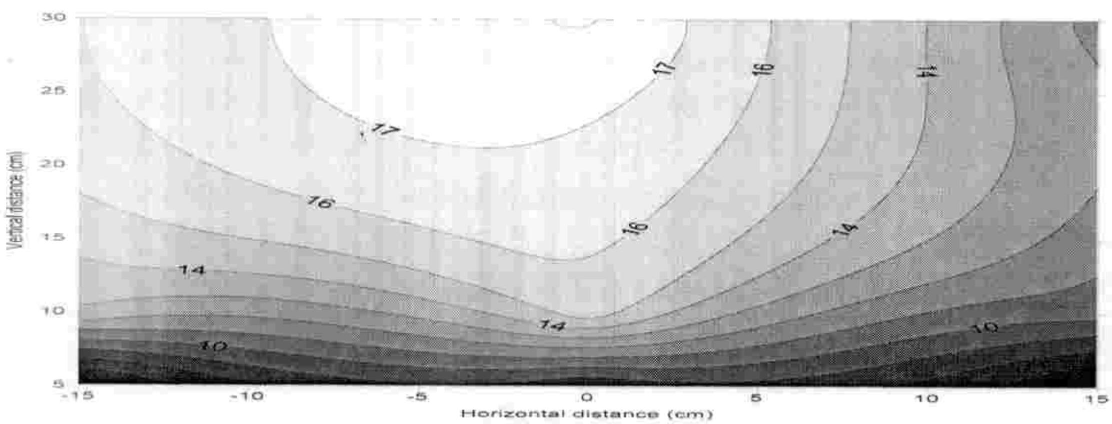
Surface soil appears to be almost dry in higher depth of installation say 15 and 20 cm as seen from the data obtained from field due to less capillary rise as these cases, the lateral was placed more distance away from soil surface. The maximum moisture content was observed around the emitter position and decreased as the distance from the emitter increased. Maximum moisture content observed at 10 cm, 15 cm and 20 cm depth of installation were 14 per cent, 13.06 per cent and 15.42 per cent respectively for one hour after irrigation. Corresponding values for 24 hours after irrigation were 9.69 per cent, 9.83 per cent and 12.3 per cent respectively for 10 cm, 15 cm and 20 cm lateral depths and the data obtained are shown in the Table 4.1.

Table 4.1 Maximum moisture content at the emitter position

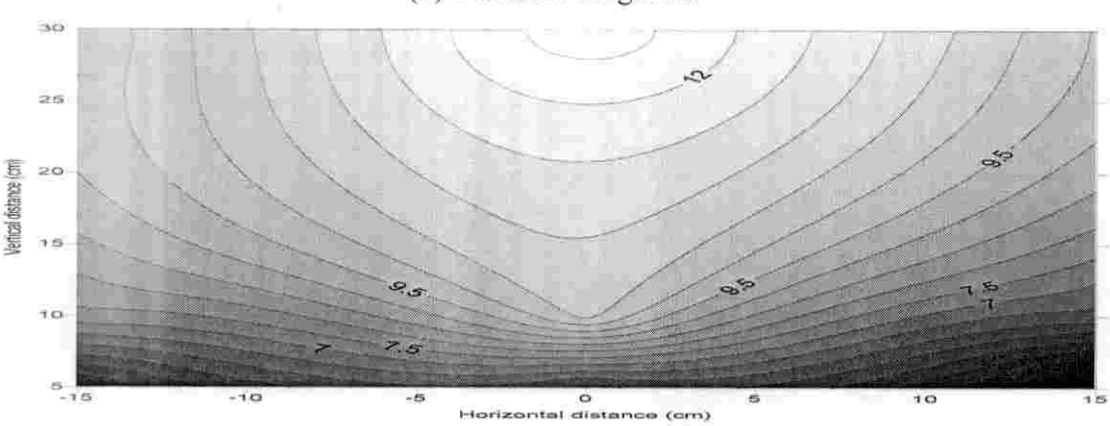
Depth of installation (cm)	**Maximum moisture content (%) at the emitter position**		
	Before irrigation	**1 hr after irrigation**	**24 hr after irrigation**
10	8.79	14.00	9.69
15	8.84	13.06	9.83
20	9.95	15.42	12.3



(a) Before irrigation

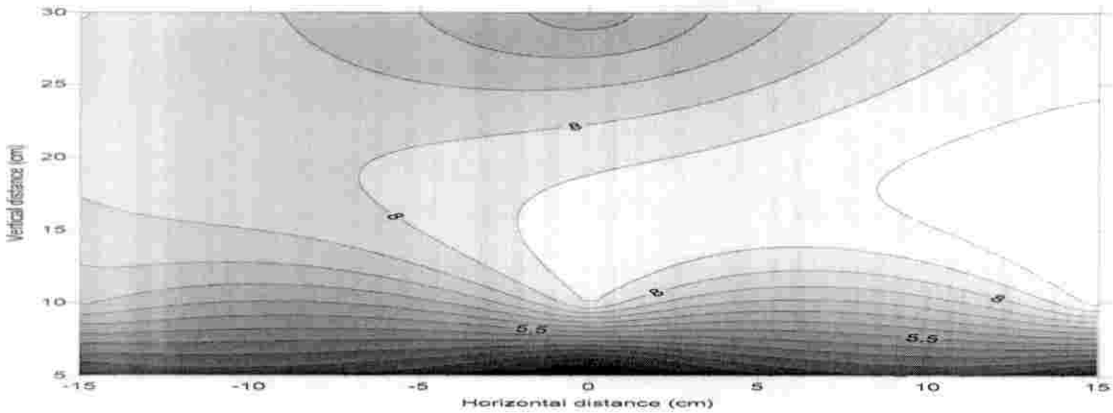


(b) 1 hr after irrigation

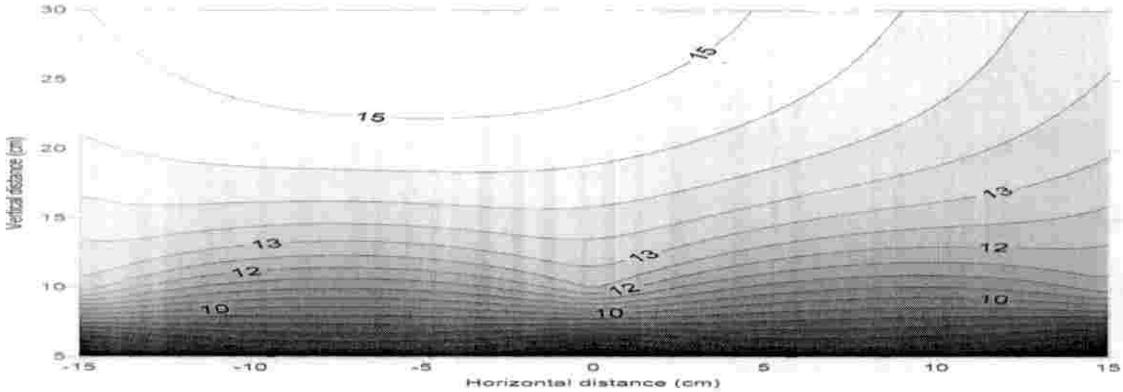


(c) 24 hr after irrigation

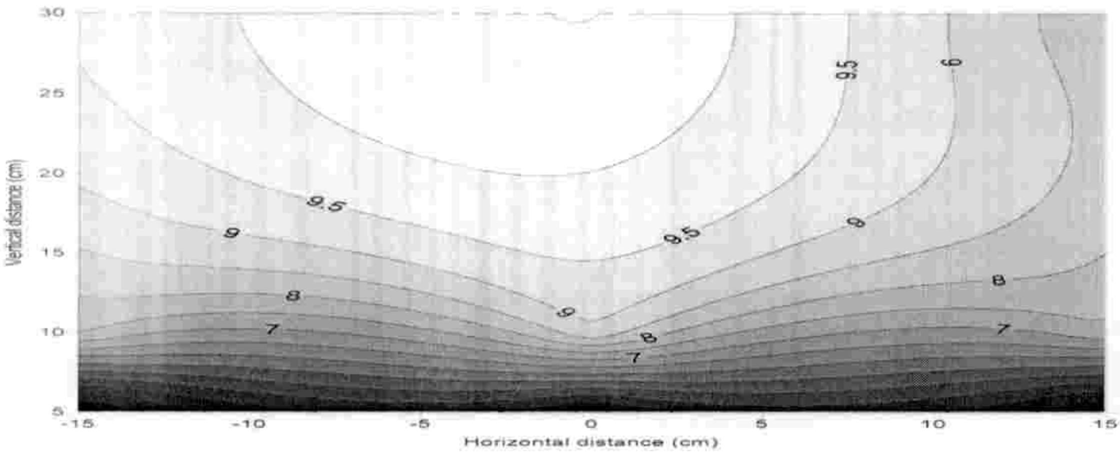
Figure 4.2 Moisture distribution pattern in bare soil at 10 cm depth of installation a) before irrigation, b) 1 hr after irrigation, c) 24 hr after irrigation



(a) Before irrigation

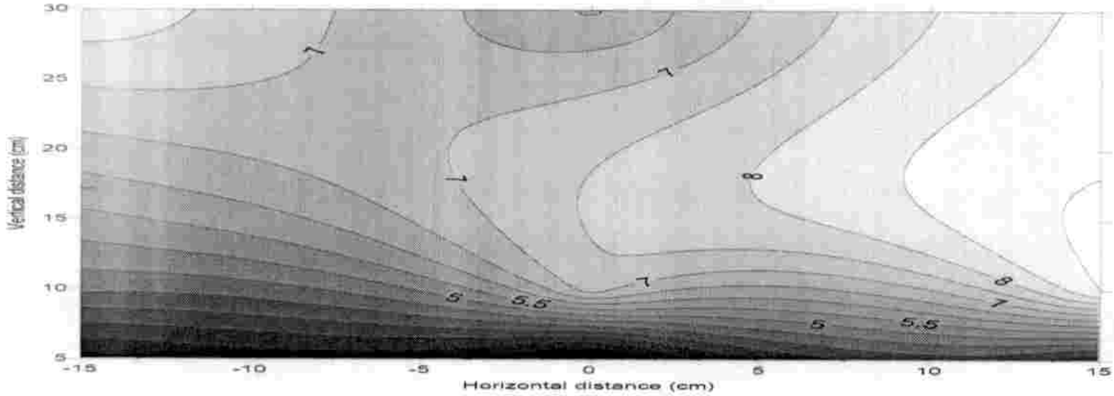


(b) 1 hr after irrigation

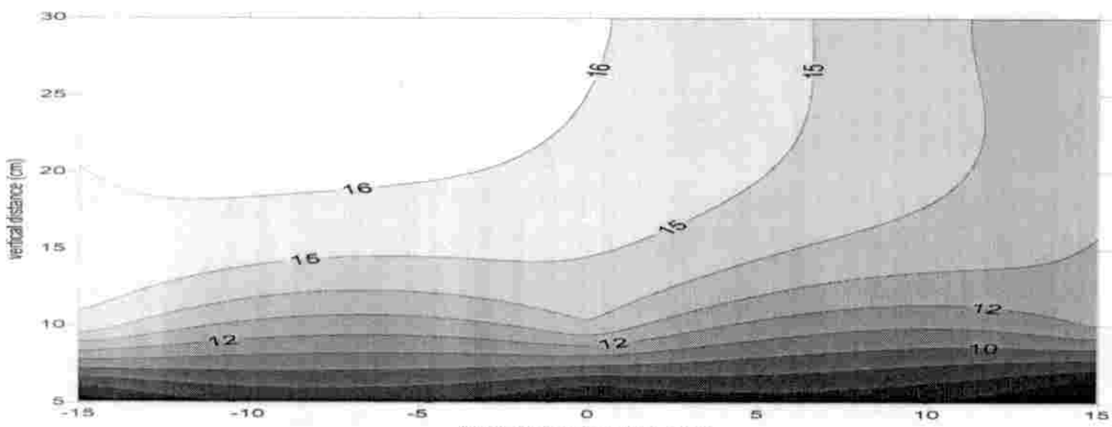


(c) 24 hr after irrigation

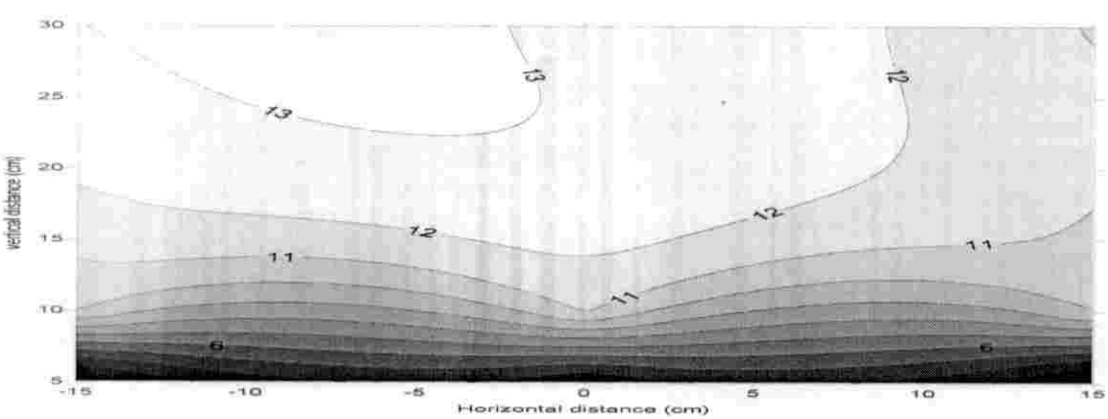
Figure 4.3 Moisture distribution pattern in bare soil at 15 cm depth of installation a) before irrigation, b) 1 hr after irrigation, c) 24 hr after irrigation



(a) Before irrigation



(b) 1 hr after irrigation



(c) 24 hr after irrigation

Figure 4.4 Moisture distribution pattern in bare soil at 20 cm depth of installation a) before irrigation, b) 1 hr after irrigation, c) 24 hr after irrigation

Moisture distribution pattern in bare soil at three lateral depths (10 cm, 15 cm and 20 cm) are shown in Figure 4.2 to Figure 4.4. Emitters were located at coordinate points (0, 10), (0, 15) and (0, 20) for 10 cm, 15 cm and 20 cm laterals respectively.

At 10 cm depth of installation of lateral, moisture content was found to be 14 per cent (1 hr after irrigation) at the emitter position (0, 10) and decreased with decrease in depth from the surface. Moisture content at the surface layer at 5 cm depth was 9 per cent measured at 1 hr after irrigation. The same for 24 hr after irrigation was 6.5 per cent with a variation of 2.5 per cent. It may be due to more evaporation loss near to the soil surface. Maximum moisture content observed was 17 per cent in 30 cm depth. There is a 3 per cent variation of moisture content between 10 and 30 cm depth. This may possibly be due to infiltration of water to deeper layers in 1 hour after irrigation. Horizontally the moisture content variation 1 hour after irrigation between 0 and 15 cm at emitter position was 4 per cent and in 30 cm depth variation was 5 per cent. This may perhaps be due to lateral movement of water immediately after irrigation in deeper layers.

Water content at the emitter position (0, 10) measured after 24 hr was 9.69 per cent and 30 cm depth it was 12.5 per cent. There is a variation of 2.81 per cent moisture content between 10 and 30 cm depth. Horizontal variation in moisture content between 0 and 15 cm was about 2.5 per cent at emitter position and 30 cm depth it was 12.5 per cent and 9.5 per cent between 0 and 15 cm horizontal distance with a variation of 3 per cent. In both cases, moisture content was more at the emitter position and showed a gradual reduction while moving away from the emitter. Variation in moisture content in both vertical and horizontal direction was almost similar. This characteristic and bulb shape of moisture contour map indicates the sandy clay loam soil. A reduction of 4.31 per cent and 4.5 per cent moisture content was observed in 10 cm and 30 cm depth 24 hour after irrigation.

At 1 hr after irrigation where laterals are located at 15 cm depth, moisture content at the emitter position (0, 15) was 13.06 per cent and at 30 cm depth it was about 15 per cent. A variation of 1.94 per cent was observed between 15 cm and 30 cm depth 1 hr after irrigation. Horizontal variation in moisture content between 0 and 15 cm was 13.06 per cent and 12.6 per cent in emitter position with a variation of only 0.46 per cent and 30 cm depth it was 15 per cent and 13.5 per cent between 0 and 15 cm horizontal distance, a variation of 1.5 per cent observed.

Soil moisture at 5 cm depth was 8 per cent and 5.3 per cent for 1hr and 24 hr after irrigation respectively with a variation of 2.7 per cent. At 24 hr after irrigation at 15 cm depth it was 9.4 per cent and 30 cm 10.5 per cent, a variation of 1.1 per cent was only observed among different depths. A reduction of 3.66 per cent moisture content was observed in 15 cm depth between 1 hr and 24 hour after irrigation. Also, at 15 cm lateral depth, the moisture was uniformly distributed within the layer. Amount of water in soil was found to be decreased with time. Horizontal variation in moisture content between 0 and 15 cm was 1.4 per cent in emitter position and 30 cm depth in between 0 and 15 cm horizontal distance, a variation of 2 per cent observed.

Regarding the lateral of 20 cm depth, the moisture content at the emitter position (0, 20) was 15.4 per cent measured at 1 hr after irrigation and was reduced to 12.3 per cent which was measured 24 hr after irrigation. A reduction of 3.1 per cent moisture content was observed in 20 cm depth 24 hour after irrigation. At 30 cm depth, in line with the emitter position, moisture content was 18 per cent 1 hour after irrigation and was reduced to 12.8 per cent at 24 hour after irrigation. A reduction of 5.2 per cent was observed in 30 cm depth. The variation of moisture content horizontal in direction between 0 and 15 cm was 2.4 per cent in emitter position 20 cm depth and 30 cm depth in between 0 and 15 cm horizontal distance, a variation of 3 per cent was observed. Amount of water at the soil surface was found to be less as compared to other lateral depths. Also, soil moisture was decreased with time due to percolation loss and evaporation loss.

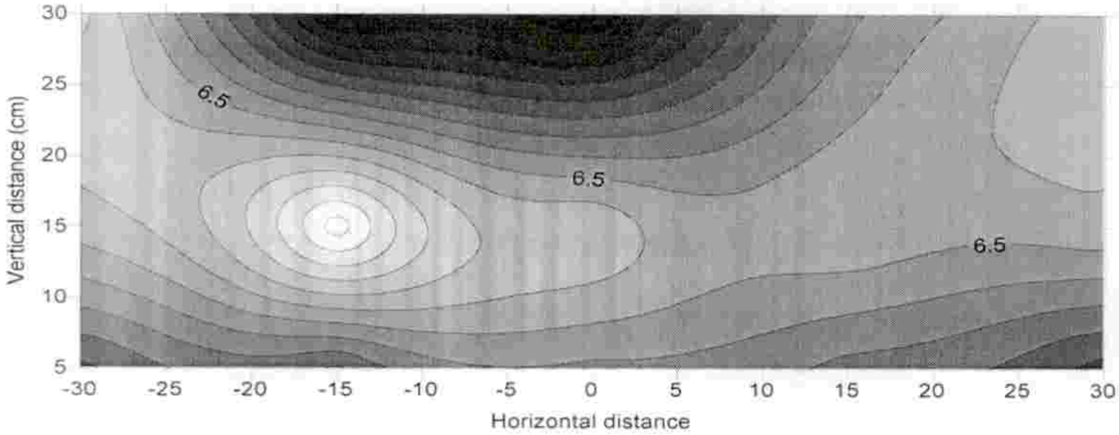
To summarize, uniformity in moisture distribution varied with lateral location from the soil surface. Moisture content was found to decrease with time in all lateral depths. At 24 hr after irrigation, emitter position at 10 cm depth, there is a variation of 2.81 per cent moisture content between 10 and 30 cm depth. Horizontal variation in moisture content between 0 and 15 cm was 2.5 per cent in emitter position and 30 cm depth, a variation of 3 per cent was observed. A variation of 4.31 percent was observed between 1 hr and 24 hr after irrigation at emitter position. More moisture content in 20 cm depth was due to less evaporation loss from deeper layers. Moisture movement from one point to another followed the same trend for all the depth selected and also that measured 1 hr after irrigation and 24 hr after irrigation. 24 hr after irrigation at 15 cm depth, a variation of 1.1 per cent was only observed among different depths.

Horizontal variation in moisture content between 0 and 15 cm was 1.4 per cent in emitter position and 30 cm depth in between 0 and 15 cm horizontal distance, a variation of 2 per cent observed (24 hr after irrigation). At 15 cm depth, a reduction of 3.23 per cent moisture content was observed in 15 cm depth between 1 hr and 24 hr after irrigation. Regarding the lateral of 20 cm depth, a reduction of 4.34 per cent moisture content was observed in 20 cm depth (emitter position) 24 hour after irrigation and a reduction of 3 per cent was observed in 30 cm depth. Variation of moisture content horizontal in direction between 0 and 15 cm was 3 per cent in emitter position and 30 cm depth in between 0 and 15 cm horizontal distance, a variation of 3 per cent observed. Depletion in moisture content in both horizontal and vertical direction shows almost similar trend in all depths and corresponding horizontal distances. Moisture depletion was within the range of 2.5 to 4.5 percent except 1 in case of 20 cm depth. Moisture contour maps showed uniform distribution of moisture 24 hr after irrigation also.

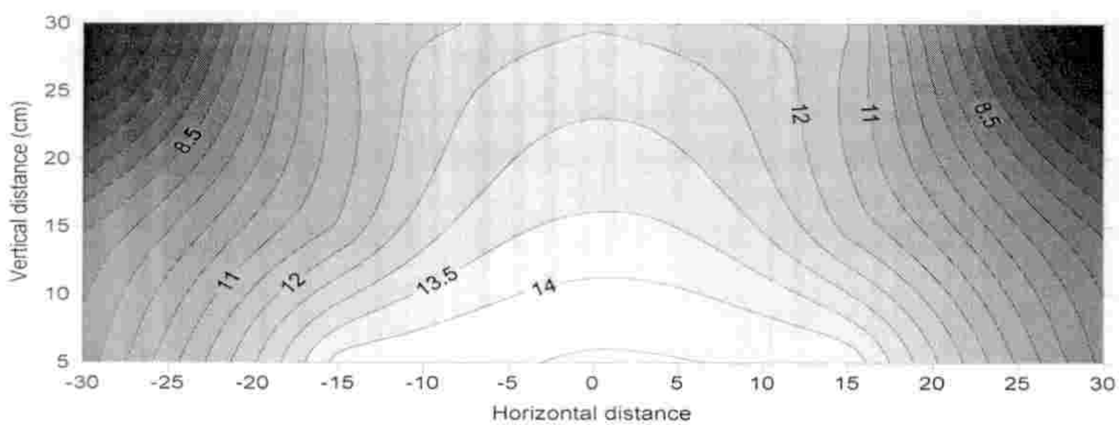
4.4 SOIL MOISTURE DISTRIBUTION PATTERN UNDER SUBSURFACE DRIP IRRIGATION SYSTEM WITH CROP

In order to study soil moisture distribution under subsurface, an experiment was conducted. Since the subsurface drip laterals were placed at different depths, soil moisture distribution patterns were studied separately for different depths. Emitters were located at 10 cm, 15 cm and 20 cm depths from the surface and they were spaced at 30 cm interval along the laterals with three lateral spacing viz. 95 cm, 100 cm and 105 cm. The system was operated for 30 minutes to get the emitter discharge of 2 lph for all depths of installation.

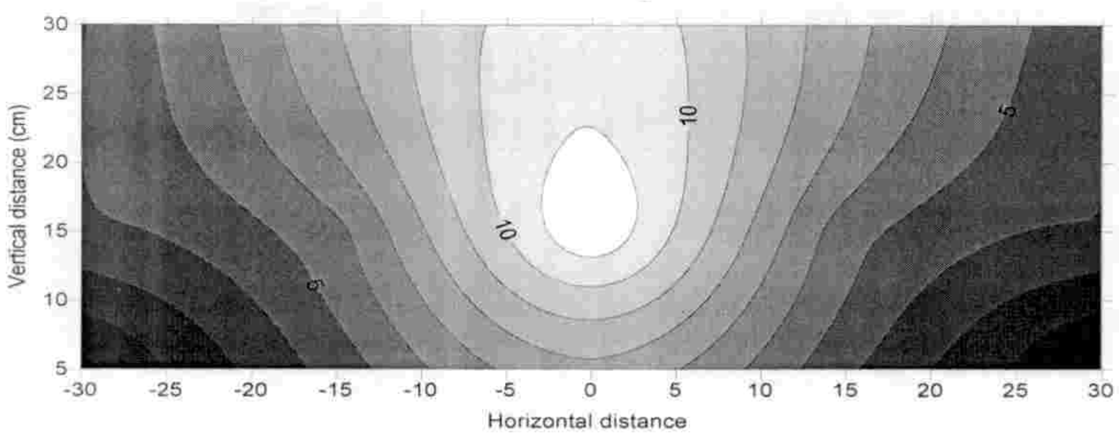
Profiles were exposed by cutting soil of subsurface drip at 10 cm, 15 cm and 20 cm of depth of laterals. Soil samples at 5, 15 and 30 cm depth were collected before irrigation, 1 hr after irrigation and 24 hr after irrigation and moisture contents were determined gravimetrically. Moisture data were analyzed for distribution pattern by plotting moisture contour using the computer software package "SURFER". Moisture distribution pattern with crop at different depths before irrigation, 1 hr after irrigation, 24 hr after irrigation were shown in Figure 4.5 to Figure 4.7. Emitter is located at coordinate points (0, 10), (0, 15) and (0, 20) respectively for 10 cm, 15 cm and 20 cm laterals.



(a) Before irrigation

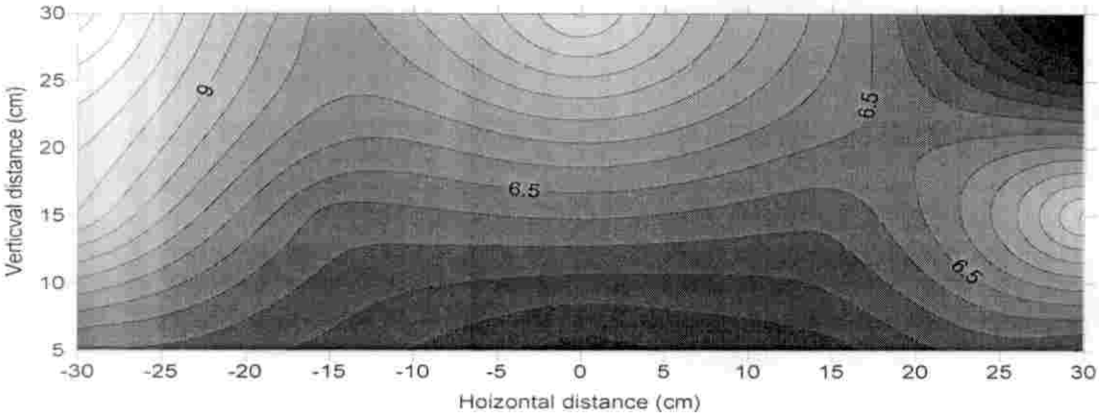


(b) 1 hr after irrigation

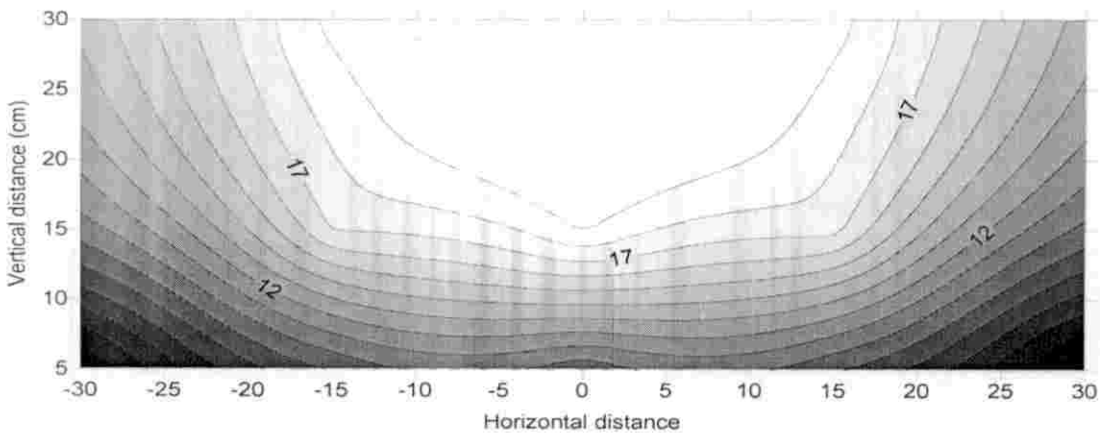


(c) 24 hr after irrigation

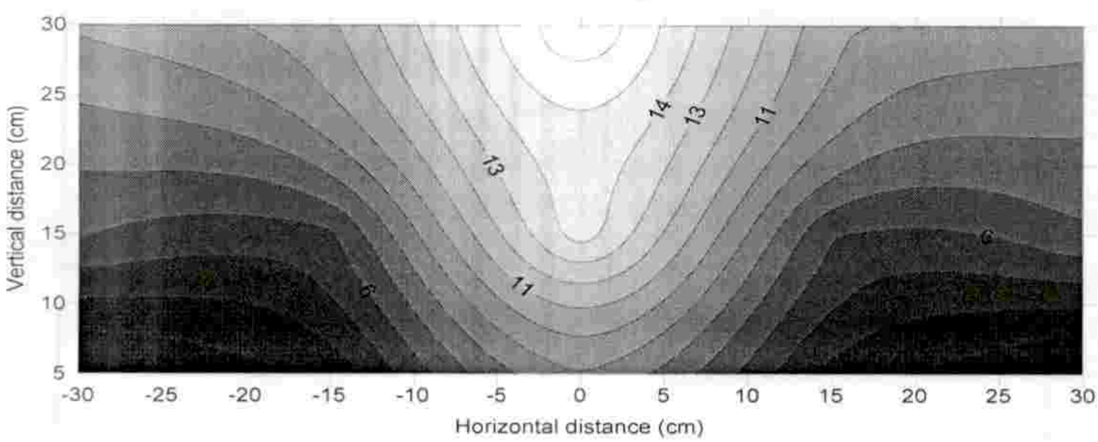
Figure 4.5 Moisture distribution pattern with crop at 10 cm depth of installation a) before irrigation, b) 1 hr after irrigation, c) 24 hr after irrigation



(a) Before irrigation

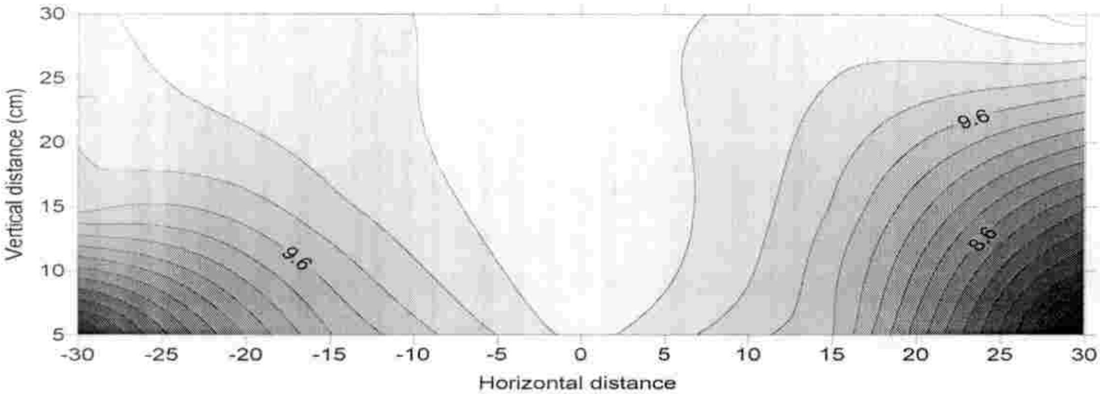


(b) 1 hr after irrigation

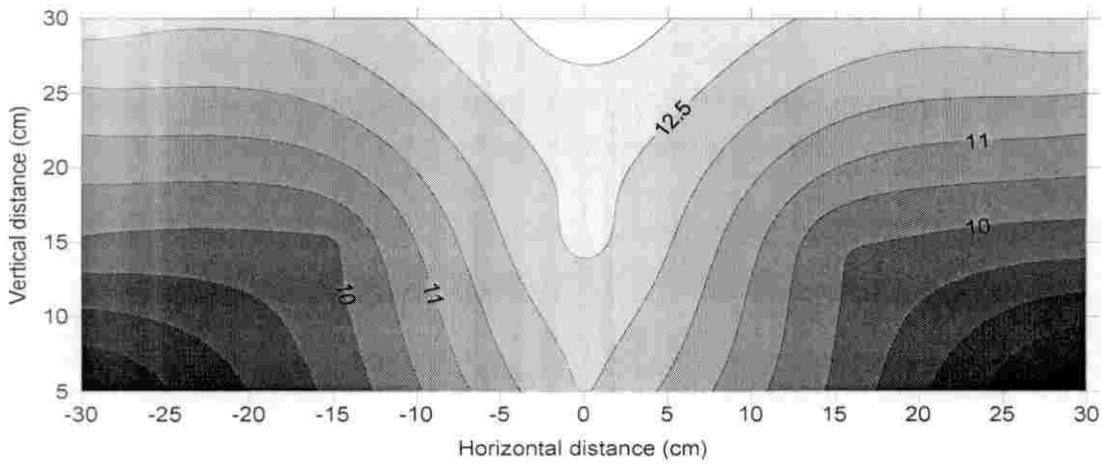


(c) 24 hr after irrigation

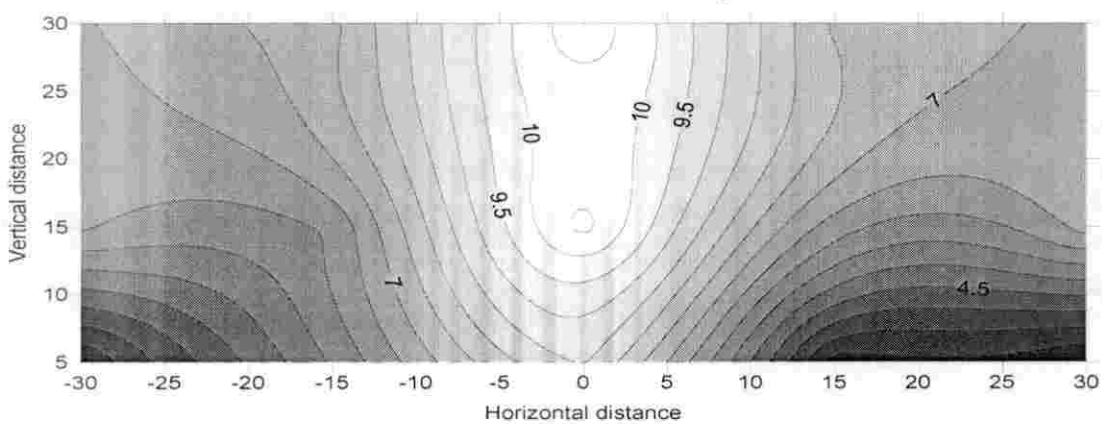
Figure 4.6 Moisture distribution pattern with crop at 15 cm depth of installation a) before irrigation, b) 1 hr after irrigation, c) 24 hr after irrigation



(a) Before irrigation



(b) 1 hr after irrigation



(c) 24 hr after irrigation

Figure 4.7 Moisture distribution pattern with crop at 20 cm depth of installation

a) before irrigation, b) 1 hr after irrigation, c) 24 hr after irrigation

At 10 cm depth of installation of lateral, moisture content at the emitter position was 14 per cent measured 1 hr after irrigation whereas that measured 24 hr after irrigation was 11 per cent. Moisture content variation of 3 per cent was observed between 1 hr and 24 hr after irrigation. Moisture content at soil surface was 14.4 per cent and it declined as the depth increased. Soil moisture at the surface was found to be more as compared to other lateral depths. At 30 cm depth, 1 hr after irrigation moisture content was 12.5 per cent and 24 hr after irrigation 9.5 per cent. A variation of 3 per cent was observed. Horizontal variation in moisture content between 0 and 15 cm was 3 per cent in emitter position (0, 10) and 30 cm depth it was 0.4 per cent (1 hr after irrigation). Also, the variation in moisture content between 0 and 15 cm horizontal distance was 5 per cent at 24 hr after irrigation. Moisture content was found to be decreased with distance from the emitter. i.e., moisture content at emitter position was 14 per cent and at 15 cm horizontal distance was 11 per cent with a variation of 3 per cent. Likewise, moisture content at 30 cm depth above emitter position (0, 30) was 12.5 per cent and that at (15, 30) was 11.8 per cent with a variation of 0.4 per cent. By analyzing the results, it was found that more moisture variation is observed between horizontal distance of 0 and 15 cm 24 hr after irrigation in all depths. This may be due to extraction of moisture by crop roots, as crop is also in line with emitter position.

For 15 cm depth of installation of lateral, water content at the emitter position (0, 15) was 18.3 per cent and 14 per cent measured at 1 hr and 24 hr after irrigation respectively with a variation of 4.3 per cent. Moisture content was found to be almost uniform for the layer 15cm. It was reduced with depth and time. At 30 cm depth, moisture content was 19 per cent and 16 per cent for 1 hr after irrigation 24 hr after irrigation respectively. A variation of 3 per cent was observed. Horizontal variation in moisture content between 0 and 30 cm was 1.2 per cent at emitter position and 30 cm depth it was 1.7 per cent (1 hr after irrigation). The same for 24 hr after irrigation was 5.7 per cent between 0 and 15 cm horizontal distance. There was a variation of 0.7 per cent in moisture content between 15 cm and 30 cm depth at 0 cm horizontal distance. Also, about 1.2 per cent variation was found between 15 cm and 30 cm at 30 cm horizontal distance (1 hr after irrigation). In the case of 24 hr after irrigation, a variation of 2 per cent was shown between 30 cm and 15 cm depth for 0 cm horizontal distance whereas for 30 cm horizontal distance it was 2.5 per cent. By analyzing the moisture content of different depths and horizontal distance, variation in moisture content was observed more in between 0 and 15 cm horizontal distance at all depths 24 hr after irrigation and regarding the depths more variation was observed at 15 cm depth. This may be due to more extraction of moisture by the crop, as the effective root zone of crop is at 15 cm depth from the surface and 0 to 15 cm horizontal distance (i.e, at 15 cm from emitter position).

Regarding 20 cm depth of installation of lateral, amount of moisture at the surface layer was comparatively less as compared to treatments with lateral depth 10 cm and 15 cm due to the fact that water could not pop up much to the soil surface at higher depths. At the emitter position (0, 20), it was about 12.5 per cent and 10.3 per cent for 1 hr and 24 hr after irrigation respectively. Moisture content variation of 2.2 per cent was observed between 1 hr and 24 hr after irrigation. Here, moisture was distributed uniformly at lower depths. At 30 cm depth, moisture content measured at 1 hr and 24 hr after irrigation was 13.8 per cent 11 per cent respectively. A variation of 2.8 per cent was observed. Horizontal variation in moisture content between 0 and 15 cm was 1.0 per cent at emitter position and 30 cm depth it was 1.4 per cent.

To further summarize, moisture content near to the emitter was found to be high and decreased as distance from the emitter decreased. Moisture content increased with depth from the surface due to less evaporation loss. Also, amount of moisture was found to be decreased as time increased. Moisture content at the surface layer (5 cm) for 10 cm lateral was 14.5 per cent whereas the same for 20 cm lateral was 11.6 per cent for 1 hr after irrigation. A variation of 2.9 per cent was observed. For 24 hr after irrigation it was 8 per cent and 6.5 per cent respectively for 10 cm and 20 cm lateral. Variation in moisture content at 5 cm soil depth for 15 cm depth of installation of lateral, between 1 hr and 24 hr after irrigation was observed as 3 per cent. Relatively high moisture content at the surface layer for 10 cm lateral was due to the surfacing effect. It is the process of creating a wetted area above each emitter. This will occur when the application rate becomes more than the infiltration rate of soil. Moisture distribution pattern obtained from the software was uniform at a lateral depth of 15 cm. Also higher moisture content was observed at 15 cm below the soil surface where the emitter was placed (Joseph *et al.*, 2006). By analyzing the moisture content of different depths and horizontal distance, variation in moisture content was observed more in between 0 and 15 cm horizontal distance at all depths 24 hr after irrigation and regarding the depths more variation was observed in 15 cm depth. This may be due to the more extraction of moisture by the crop as the effective root zone of the crop is laying at 15 cm depth from the surface and 0 to 15 cm horizontal distance (i.e, at 15 cm from emitter position). Radial movement of water was observed mostly at 24 hr after irrigation which is in agreement with the result revealed from the study done by Powar *et al.*, (2001).

Variation in moisture content between 1 hr and 24 hr after irrigation at emitter position (0, 10) in bare soil was 4.31 per cent whereas that in soil with crop was 2.5 per cent. Also, the variation at 30 cm horizontal distance (30, 10) between 1 hr and 24 hr after irrigation was 6.1 per cent and 4.3 per cent in bare soil and soil with crop respectively. It is clear that the variation followed the same trend for all lateral depths and almost all points. On comparing depletion in moisture content in both bare soil and soil with crop, it is evident that it was more in soil with crop than bare soil with a value ranging from 1-5 per cent. Since, most of soil moisture was extracted by crop roots and rest of the moisture was percolated down to next layers. Also, moisture depletion in surface soil layers was high due to high rate of infiltration at the top layers and atmospheric interactions. In the case of deeper soil layers, variation was less in both cases. The best moisture distributions were observed at 10 and 15 cm depth of installations after 24 hrs of irrigation. Moisture content observed 24 hours after irrigation was found high in deeper installations (Nisha *et al.*, 2007). Obviously, amount of soil moisture at the crop root zone was sufficient for the growth. Since, about 80 per cent of the roots of a crop were in the surface soil layers and most of water needs of plants are met from this zone (Majumdar. 2000).

4.5 GROWTH AND YIELD PARAMETERS

4.5.1 Yield of Crop

A close view of the standing crop is shown in Plate 4.2. Yields under different treatments were compared to find out the effect of lateral depth and the spacing between laterals in subsurface drip irrigation system. Three replications were done for all the treatments. Results of the yield obtained from the field for various treatments were tabulated in Table 4.2 and the same are presented in Figure 4.8.

Plate 4.2 A crop in the plot

Table 4.2 Yield obtained from 9 treatments

Treatment	Name	Spacing between laterals (cm)	Depth of installation (cm)	Yield / m^2 (kg/m^2)	Yield (t/ha)
T_1	D_1S_1	95	10	2.113	21.127
T_2	D_1S_2	100	10	1.560	15.599
T_3	D_1S_3	105	10	1.575	15.748
T_4	**D_2S_1**	**95**	**15**	**2.384**	**23.844**
T_5	D_2S_2	100	15	1.401	14.009
T_6	D_2S_3	105	15	1.412	14.124
T_7	D_3S_1	95	20	1.902	19.020
T_8	D_3S_2	100	20	1.564	15.643
T_9	D_3S_3	105	20	1.762	17.620

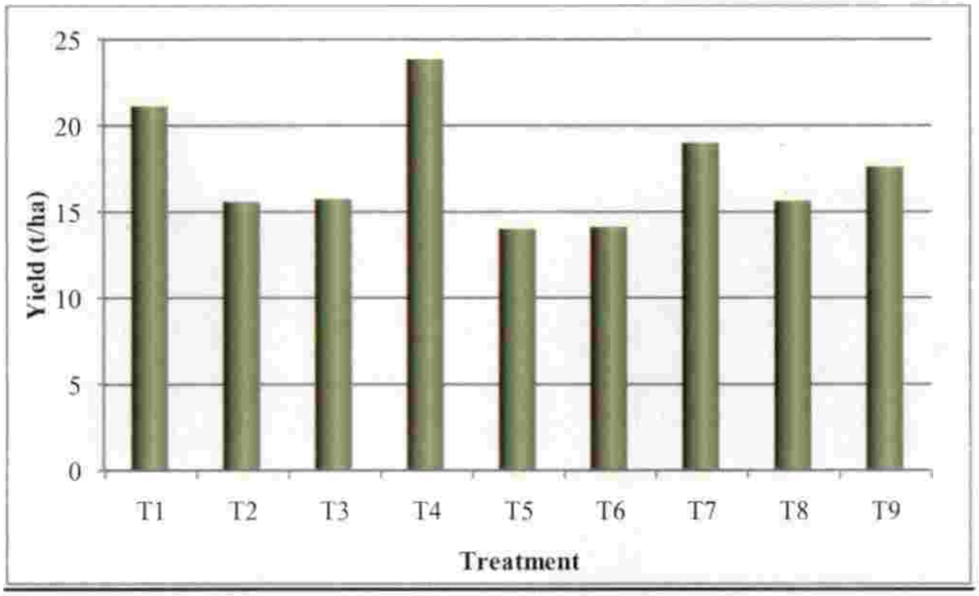


Figure 4.8 Yield obtained from 9 treatments

Table 4.3 ANOVA table for yield

Source of Variation	SS	df	MS	F	P-value	F crit
Lateral spacing (S)	1.035797	3	0.345266	28.55618	0.000126	4.066181
Lateral depth (D)	0.08151	1	0.08151	6.741538	0.031793	5.317655
Interaction (S*D)	0.460355	3	0.153452	12.69165	0.002075	4.066181
Within	0.096726	8	0.012091			
Total	1.674388	15				

Table 4.3 represents the effect of lateral spacing and lateral depth on yield obtained from 1 m^2 area of each treatment. From the table it is evident that;

1. There is significant difference among treatments for yield at 5 per cent significance level
2. It is also seen that there is significant difference among three depths of placement of laterals for the yield parameter at 5 per cent level of significance
3. There is significant difference among three lateral spacing for yield at 5 per cent level of significance
4. Analytical results also showed that there is interaction between lateral spacing, depth of installation for yield at 5 per cent level of significance.

From the data in Table 4.2, it is clear that maximum yield obtained is 23.8 t/ha for the treatment T_4 (i.e., lateral depth= 15 cm, spacing between laterals= 95 cm). It was due to availability of enough water at the crop root zone. Harvest was done once in two weeks. Crop yield from each harvest and its statistical analysis are given in the following charts. A close view of the crop before 1st harvest is shown in the Plate 4.3.

Plate 4.3 View of crop in the experimental plot

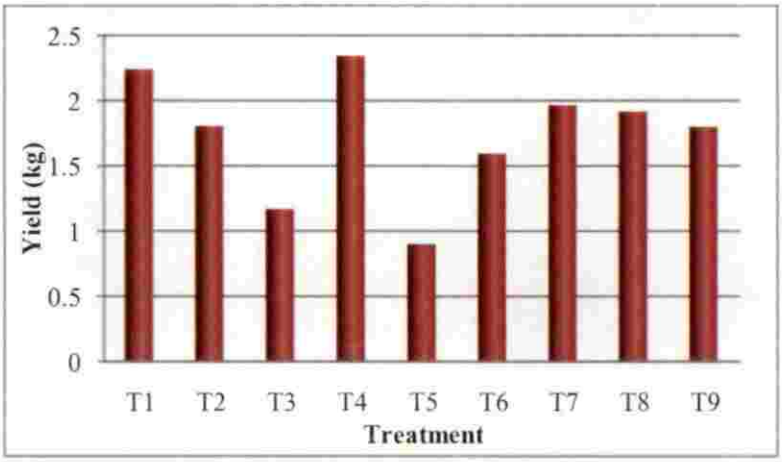


Figure 4.9 Crop yield from 1st harvest

Table 4.4 ANOVA Table for yield obtained from 1st harvest

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**6.903**	**3.229**	**2.283**
Factor(B)	**6.903**	**3.229**	**2.283**
Factor(A X B)	N/A	5.592	3.954

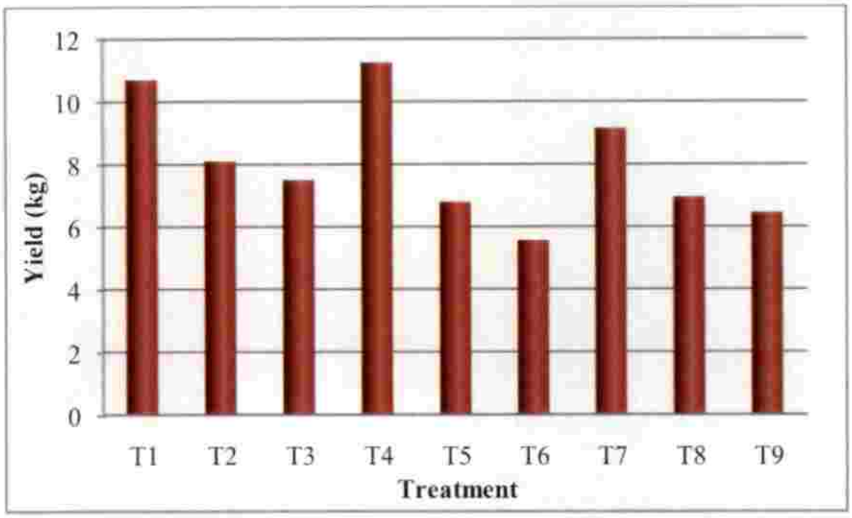


Figure 4.10 Crop yield from 2nd harvest

Table 4.5 ANOVA Table for yield from 2nd harvest

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**9.724**	**4.548**	**3.216**
Factor(B)	**9.724**	**4.548**	**3.216**
Factor(A X B)	N/A	7.877	5.57

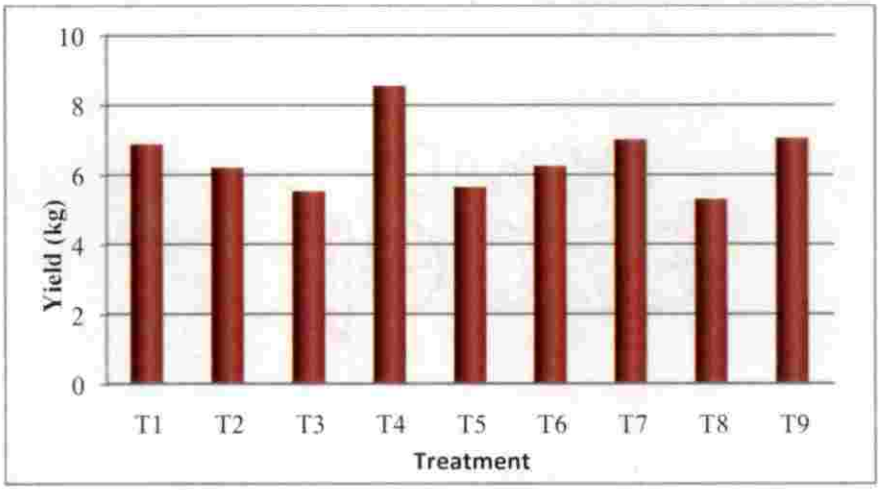


Figure 4.11 Crop yield from 3rd harvest

Table 4.6 ANOVA Table for yield from 3rd harvest

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**7.816**	**3.655**	**2.585**
Factor(B)	**7.816**	**3.655**	**2.585**
Factor(A X B)	N/A	6.331	4.477

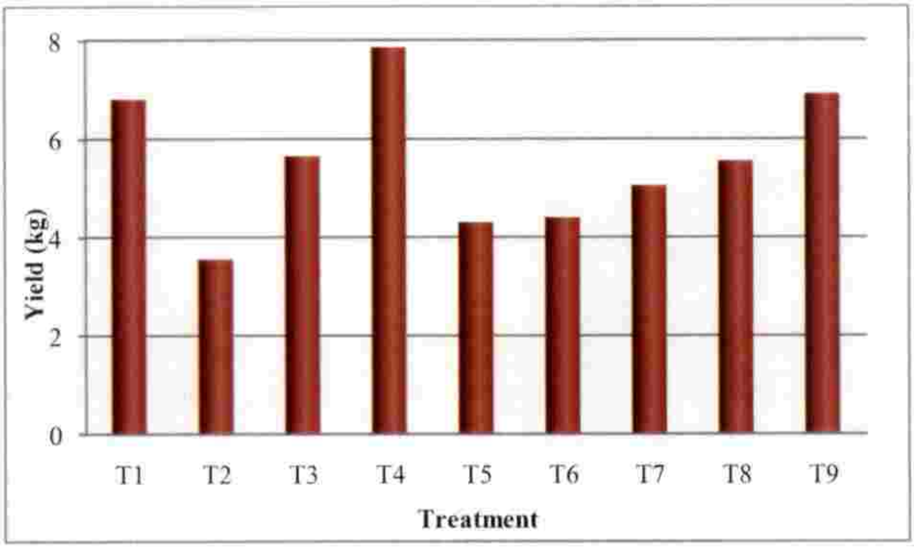


Figure 4.12 Crop yield from 4th harvest

Table 4.7 ANOVA Table for yield from 4th harvest

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**13.639**	**6.379**	**4.51**
Factor(B)	**13.639**	**6.379**	**4.51**
Factor(A X B)	N/A	11.048	7.812

From Figure 4.9 to Figure 4.12 and Table 4.4 to Table 4.7, it can be seen that

1. Factor A is the spacing between laterals and Factor B is the lateral depth.
2. Lateral spacing (factor A) has significant effect on crop yield from first, second, third and fourth harvest.
3. Lateral depth also has an effect on yield in the particular period.
4. Combination of lateral spacing and lateral depth has no significant effect on yield

From the first harvest, maximum yield obtained was about 2.3 kg from the treatment T_4 and then T_1 (2.24 kg). i.e., spacing between laterals = 95 cm and lateral depth 15 cm, 10 cm respectively. About 11.250 kg were obtained from treatment T_4 from the 2nd harvest. From 3rd and 4th harvest, maximum yield obtained was 8.6 kg and 7.8 kg respectively from T_4. Treatments with less lateral spacing contributed more yield due to increase in number of plants per unit area.

Maximum water was extracted from the upper layer of root zone which is in agreement with Rama Kant *et al.,* (1998). The effect was same for all harvest operations. The yield was comparatively less in T_5 (lateral depth = 15 cm, spacing between laterals = 100 cm) due to the more spacing between laterals. Poor yield from T_5 also may be because of the deficiency of moisture and disease affected to crop. Maximum yield was obtained from the second harvest (72 kg).

Plate 4.4 Crop in the treatment T_4

Total yield from four harvest operations are shown in the Figure 4.13. About 200 kg was obtained from all the treatments. Maximum yield obtained was 30.04 kg that harvested from treatment T_4 and then T_1 (26.620 kg). In both the treatments, the lateral spacing was 95 cm where the number of plants was more. Lateral depth was 15 cm and 10 cm respectively for T_4 and T_1. Thus, root could extract more water. Therefore, lateral depth of 15 cm and spacing between laterals of 95 cm are preferred for amaranth cultivation in sandy clay loam soil while considering the crop yield from the experimental plot. This is in agreement with Nisha *et al*. (2007), reported that the optimum depth of installation of lateral for Okra in sandy loam soil was 10 cm and 15 cm. Crop stand in the treatment T_4 is in Plate 4.4 and crop 15 days after transplanting is in Plate 4.5.

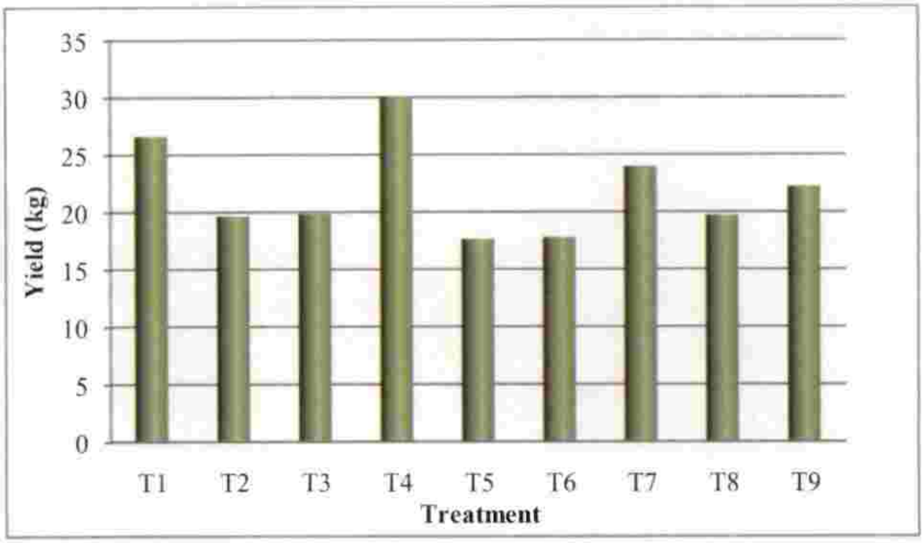


Figure 4.13 Total weight of harvested crop in each treatment

Plate 4.5 Crop 15 days after transplanting

4.5.1.1 Water Use Efficiency (WUE)

Water use efficiency for different treatment is given in Table 4.8 and the same is shown in Figure 4.14. The highest water use efficiency was for treatment T_4 with a value of 28.48 kg/ha-mm followed by treatment T_1 with 37.96 kg/ha-mm.

Table 4.8 Water use efficiency for each treatment

Treatment	Yield (kg/ha)	Water use efficiency (kg/ha-mm)
T_1	21126.98	34.63
T_2	15599.21	24.84
T_3	15748.21	25.07
T_4	**23844.44**	**37.96**
T_5	14008.73	22.31
T_6	14123.81	22.49
T_7	19019.84	30.28
T_8	15642.86	24.91
T_9	17619.84	28.06

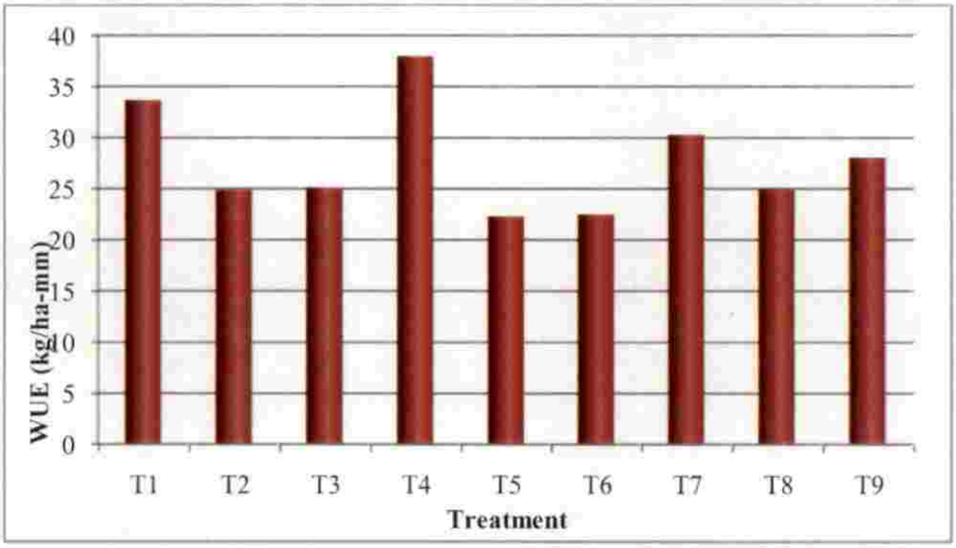


Figure 4.14 Water use efficiency for each treatment

Treatments with lateral spacing 95 cm showed the highest water use efficiency (T_1, T_4 and T_7) because of increased yield. Also, a lateral depth of 10 cm and 15 cm with 95 cm lateral spacing showed comparatively more water use efficiency. This may be due to sufficient quantity of moisture in the root zone because of less lateral spacing. It coincide with the results by Nisha *et al.* (2007), reported that the optimum depth of installation of lateral for Okra in sandy loam soil was 10 cm and 15 cm while considering water use efficiency.

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

The low water use efficiency may be due to yield reduction caused by less water availability during the growth period and crop disease.

4.5.2 Growth Parameters

Growth Parameters (biometric properties) such as height of the crop, number of leaves and girth of plant were taken one month, two months, three months and four months after planting. It is shown in Table 4.9. The growth parameters of crop during the growth period are shown in Figure 4.15 to Figure 4.17.

It is evident that maximum response was obtained for the treatments T_4 (depth of installation of lateral - 15 cm, spacing between laterals - 95 cm), and then T_1 (depth of installation of lateral - 10 cm, spacing between laterals - 95 cm). It may be due to enough soil moisture applied at the root zone of the crop. Treatments having more spacing between laterals and more lateral depth showed less yield and poor biometric properties. This may be due to the lack of enough water at the root zone. It can be avoided by selecting proper lateral depth and spacing between adjacent laterals.

From this study, it is clear that treatment T_4 (depth of installation of lateral - 15 cm and spacing between adjacent laterals - 95 cm) is suited for the experimental crop in sandy clay loam soil while considering the biometric properties of the crop since it shows the maximum response during the particular crop period.

Table 4.9 Growth parameters (one, two, three and four months after planting)

Treatments	1 Month			2 Months			3 Months			4 Months		
	Height of crop (cm)	No. of leaves	Girth of crop (cm)	Height of crop (cm)	No. of leaves	Girth of crop (cm)	Height of crop (cm)	No. of leaves	Girth of crop (cm)	Height of crop (cm)	No. of leaves	Girth of crop (cm)
T_1	50	30	2.01	57	38	2.04	48	40	2.04	53	39	2.06
T_2	41	31	1.82	46	33	1.85	47	37	1.85	47	36	1.91
T_3	40	25	1.94	44	30	1.94	46	32	1.98	46	33	2.03
T_4	48	31	2.25	52	36	2.25	54	37	2.26	54	38	2.28
T_5	40	32	1.83	45	33	1.92	44	34	1.92	43	31	1.98
T_6	30	27	1.86	37	32	1.86	39	32	1.92	40	32	1.96
T7	44	31	1.98	48	37	2.01	48	35	2.01	47	37	2.04
T_8	43	30	1.72	42	34	1.72	45	34	1.75	42	35	1.79
T_9	42	28	1.75	49	32	1.82	47	33	1.86	47	32	1.94

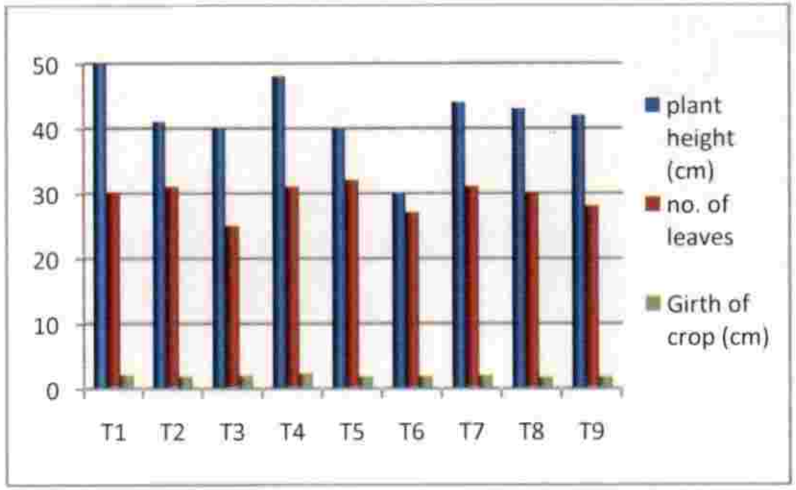


Figure 4.15 Growth parameters (1 month after planting)

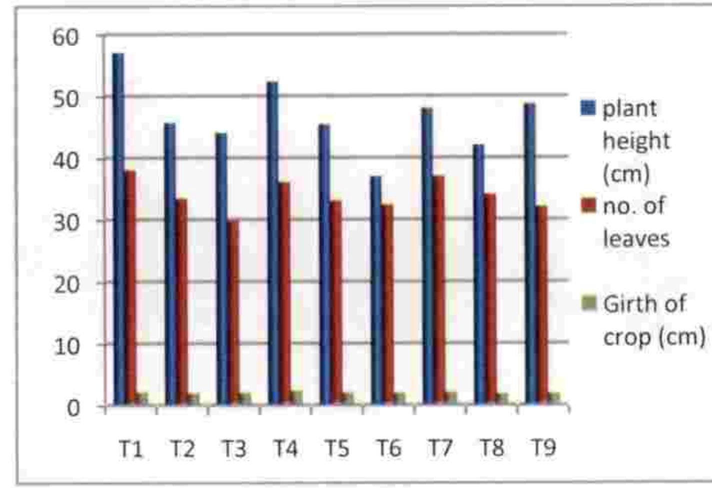


Figure 4.16 Growth parameters (2 months after planting)

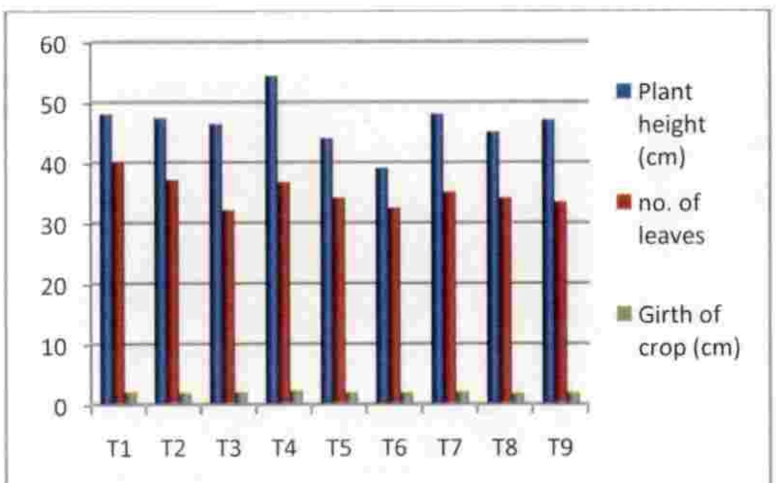


Figure 4.17 Growth parameters (3 months after planting)

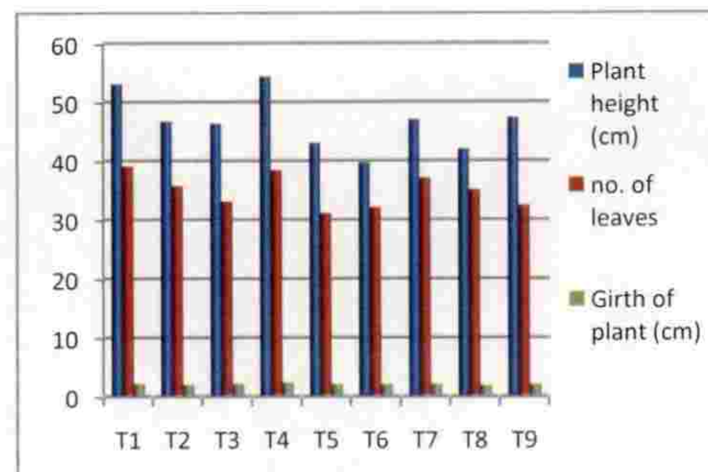


Figure 4.18 Growth parameters (4 months after planting)

4.5.3.1 Plant Height

The height of plants under different treatments were analysed using ANOVA with two way interaction between depth of installation and spacing between laterals. Plant height in each treatment at various stages of growth (one month, two months, three months and four months after planting) was found to be highly remarkable under various treatments and is shown below.

Table 4.10 ANOVA Table for plant height 1 month after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	24.073	11.259	7.961
Factor(B)	24.073	11.259	7.961
Factor(A X B)	41.696	19.501	13.789

Table 4.11 ANOVA Table for plant height 2 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	20.026	9.366	6.623
Factor(B)	20.026	9.366	6.623
Factor(A X B)	34.686	16.222	11.471

Table 4.12 ANOVA Table for plant height 3 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	9.022	4.22	2.984
Factor(B)	9.022	4.22	2.984
Factor(A X B)	15.627	7.309	5.168

Table 4.13 ANOVA Table for plant height 4 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	12.749	5.962	4.216
Factor(B)	12.749	5.962	4.216
Factor(A X B)	22.081	10.327	7.303

From Table 4.10 to Table 4.13, it is found that both factors (spacing between laterals and depth of installation) either independently or together have remarkable effect on plant height. Plant height was comparatively more in treatment T_1. Because maximum quantity of water could be extracted by the upper layer of roots (Rama Kant *et al.*, 1998).

4.5.3.2 Number of Leaves

Number of leaves of the plants were also noted and it was found maximum in T_4 and T_1 (depth of installtion-15 cm and 10 cm respectively and spacing between laterals - 95 cm).

Table 4.14 ANOVA Table for no. of leaves 1 month after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	N/A	5.062	3.579
Factor(B)	N/A	5.062	3.579
Factor(A X B)	**18.745**	**8.767**	**6.199**

Table 4.15 ANOVA Table for no. of leaves 2 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	N/A	4.497	3.18
Factor(B)	N/A	4.497	3.18
Factor(A X B)	**16.655**	**7.79**	**5.508**

Table 4.16 ANOVA Table for no. of leaves 3 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	9.022	4.22	2.984
Factor(B)	9.022	4.22	2.984
Factor(A X B)	**15.627**	**7.309**	**5.168**

Table 4.17 ANOVA Table for no. of leaves 4 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor (A)	N/A	10.761	7.609
Factor (B)	N/A	10.761	7.609
Factor (A X B)	**39.853**	**18.639**	**13.18**

Both spacing between laterals and lateral depth together have effect on number of leaves. But both factors independently have no significant effect on number of leaves.

4.5.3.3 Stem Girth of Plant

Stem girth of plants under each treatment were measured at one month, two months and three months and four months after transplanting. The highest stem girth was obtained for the treatment T_4 (spacing between laterals - 95 cm, lateral depth - 15 cm).

Table 4.18 ANOVA Table for stem girth of plant 1 month after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**0.145**	**0.068**	**0.048**
Factor(B)	N/A	0.068	0.048
Factor(A X B)	N/A	0.117	0.083

Table 4.19 ANOVA Table for stem girth of the plant 2 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**10.663**	**4.987**	**3.526**
Factor(B)	N/A	4.987	3.526
Factor(A X B)	N/A	8.638	6.108

Table 4.20 ANOVA Table for stem girth of the plant 3 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**0.442**	**0.207**	**0.146**
Factor(B)	N/A	0.207	0.146
Factor(A X B)	N/A	0.358	0.253

Table 4.21 ANOVA Table for stem girth of the plant 4 months after planting

Factors	C.D.	SE(d)	SE(m)
Factor(A)	**0.476**	**0.223**	**0.158**
Factor(B)	N/A	0.223	0.158
Factor(A X B)	N/A	0.386	0.273

Analysis of variance for spacing between laterals (A) and lateral depth (B) was conducted to find the differential response of Amaranth towards subsurface drip irrigation effected at three depths, accommodating three spacing among the laterals accordingly. Parameters that were analyzed were crop yield and biometric properties. Differential response was noticed at higher order level at 20 per cent. Some diseases were noticed during the growth stages of crop. Also water shortage was experienced during the growth period. This might have retarded the growth of plant at different stages. However, with these conditions, efficiency of the method of SDI has been assessed based on the above mentioned parameters from which a certain amount of differential response was noticed. From the Table 4.10 to Table

4.21, it is quite evident that maximum response was noticed with the combination of spacing between laterals - 95 cm and depth of installation of lateral - 15 cm, and 10 cm.

To further summarize, spacing between laterals of 95 cm and depth of installation of lateral of 15 cm was found to be most efficient combination while considering crop yield, plant characters, and moisture distribution in the soil.

4.6 SOIL WATER BALANCE

Soil water balance analysis helps to determine the amount of water held in the root zone at a given time. It reduces the risk of applying excessive water resulting in deep percolation and runoff.

The following equation was used for finding out the deep percolation from each layer;

$$L = \theta D_i - \theta D_{i+1} + I + P - ET_a \qquad \ldots\ldots \qquad 4.1$$

Where,

L = Leaching losses from the root zone (i.e., deep percolation) (mm)

θD_i = Amount of water in the root zone at the beginning of the period (mm)

θD_{i+1} = Amount of water in the root zone at the end of the period (mm)

I = Amount of irrigation water applied (mm)

P = Precipitation (mm)

ET_a = Actual evapotranspiration (mm/day)

Here, precipitation was negligible during the growing season. Therefore, the equation becomes;

$$L = \theta D_i - \theta D_{i+1} + I - ET_a \qquad \ldots\ldots \qquad 4.2$$

Here, moisture content data are given in Appendix VI. Amount of water applied and actual evapotranspiration was 628 mm was 5.619 mm/day respectively.

The deep percolation losses for three lateral depths at 1 hr after irrigation with crop are given in Table 4.22 to Table 4.24

Table 4.22 Deep percolation (mm) from each layer (depth of lateral = 10 cm)

Vertical distance (cm)	Horizontal distance (cm)				
		0	15	30	45
	5	19.98	26.98	26.04	26.62
	15	15.049	18.189	22.0	20.042
	30	14.421	26.698	28.92	21.28

Table 4.23 Deep percolation (mm) from each layer (depth of lateral = 15 cm)

Vertical distance (cm)	Horizontal distance (cm)				
		0	15	30	45
	5	20.34	18.99	21.015	19.916
	15	13.526	30.074	33.434	30.702
	30	14.657	30.51	25.898	31.44

Table 4.24 Deep percolation (mm) from each layer (depth of lateral = 20 cm)

Vertical distance (cm)	Horizontal distance (cm)				
		0	15	30	45
	5	15.431	17.45	19.853	12.85
	15	14.2	13.746	16.022	12.804
	30	17.489	18.66	22.91	18.007

Deep percolation was relatively less from the surface layers than from the deeper layers in higher lateral depths (i.e., 20 cm lateral depth). Deep percolation at the surface layer from lateral with depth 10 cm, 15 cm and 20 cm was found to be 24.905 mm, 20.06 mm and 14.11 mm respectively.

Deep percolation from 5 cm layer was more in almost all horizontal distances. As this layer is close to the 10 cm depth of installation of lateral, due to capillary rise there cause sudden increase in moisture content. This may be the reason for more percolation from 5 cm layer. Average deep percolation from 5 cm, 15 cm and 30 cm depth layer is 24.905 mm, 18.82 mm and 22.77 mm respectively. Less percolation was observed in 15 cm depth layer.

At 15 cm depth of installation of lateral, due to capillary rise, more moisture observed in just above the emitter position (30, 15). Percolation was also more here, when compared to other layers because of the availability of more moisture. Average deep percolation from 5 cm, 15 cm and 30 cm depth layer is 20.07 mm, 26.93 mm and 25.63 mm respectively.

At 20 cm depth of installation of lateral, due to capillary rise, more moisture observed in the layer just above the emitter position (30, 20). Percolation was comparatively more than other layers because of the availability of more moisture. Average deep percolation from 5 cm, 15 cm and 30 cm depth layer is 14.12 mm, 14.35 mm and 21.41 mm respectively.

In deeper layers, deep percolation was more for lateral with 15 cm and 20 cm lateral depth. Obviously, the deep percolation was more from the emitter position because of the high moisture content at that position.

4.6.1 Regression Equations for Deep Percolation

The relation between soil depth and deep percolation is represented by regression equation. Regression equations for deep percolation from each layer for three lateral depths were determined to compare observed and predicted deep percolation.

The equation for quadratic regression between soil depth and deep percolation is given in CHAPTER III.

4.6.1.1 Regression Equation for 10 cm Lateral

The regression equation for deep percolation for 10 cm lateral is:

$$y = 0.003x^2 - 0.130x + 3.057 \quad \ldots\ldots \quad 4.4$$

Figure 4.19 shows a quadratic regression curve. It is a convex parabola since it's 'a' value is positive where 'a' is the magnitude of the parabola. Steepness of parabola increases with increase in 'a' value. The data are decreasing and opens up. That means, there was a decline in deep percolation with soil depth. At a lateral depth of 10 cm, moisture content was more in surface layers and declined towards the deeper layers. Deep percolation from a layer depends on moisture content of that soil layer. This may be the reason for negative variation in deep percolation.

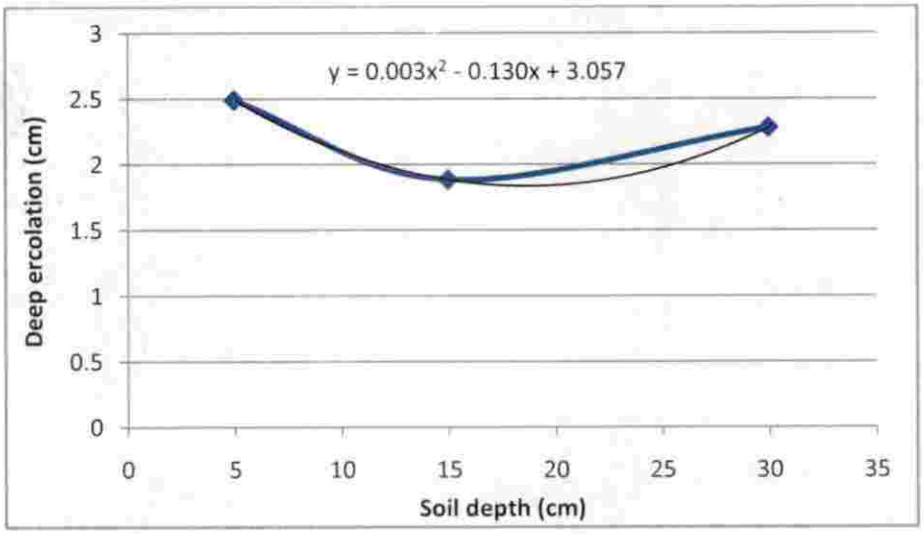


Figure 4.19 Regression curve for deep percolation (10 cm lateral)

4.6.1.2 Regression Equation for 15 cm Lateral

The equation for deep percolation at any depth for 15 cm lateral is given below.

$$y = -0.002x^2 + 0.120x + 1.536 \quad \ldots\ldots \quad 4.5$$

It is a concave regression curve since its 'a' value is negative. The variable y varies positively with variable x. Here, the data are increasing and curve opens down. That means any change in soil depth causes a same effect in deep percolation. In the case of 15 cm lateral, amount of moisture was increasing with soil depth. Therefore, more water might percolate downward from deeper layers. Maximum value of deep percolation within 0-35 cm soil depth is 2.690 cm and corresponding soil depth is 15 cm.

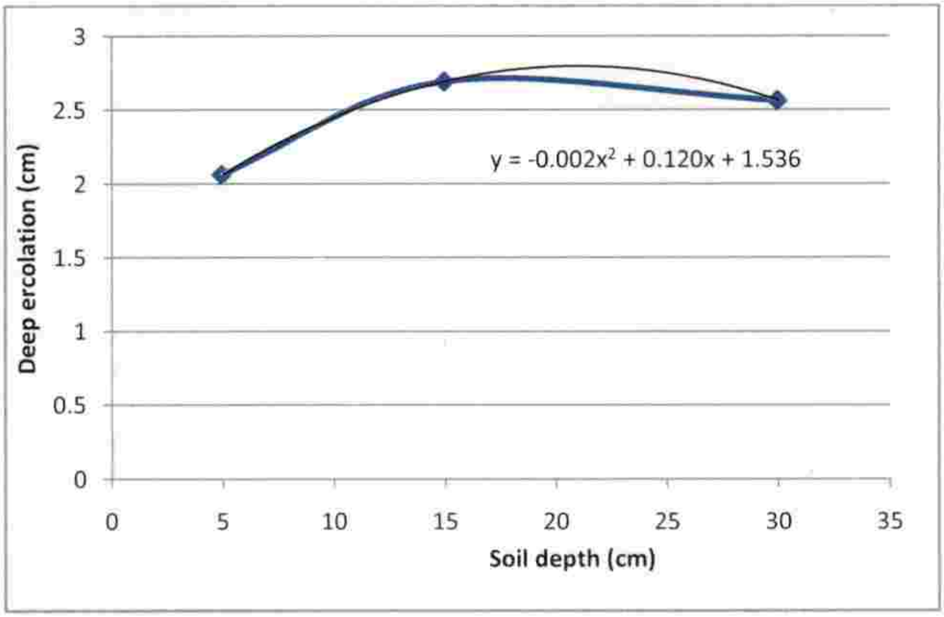


Figure 4.20 Regression curve for deep percolation (15 cm lateral)

4.6.1.3 Regression Equation for 20 cm Lateral

The equation for deep percolation (20 cm lateral) is:

$$y = 0.002x^2 - 0.066x + 1.917 \quad \ldots\ldots \quad 4.6$$

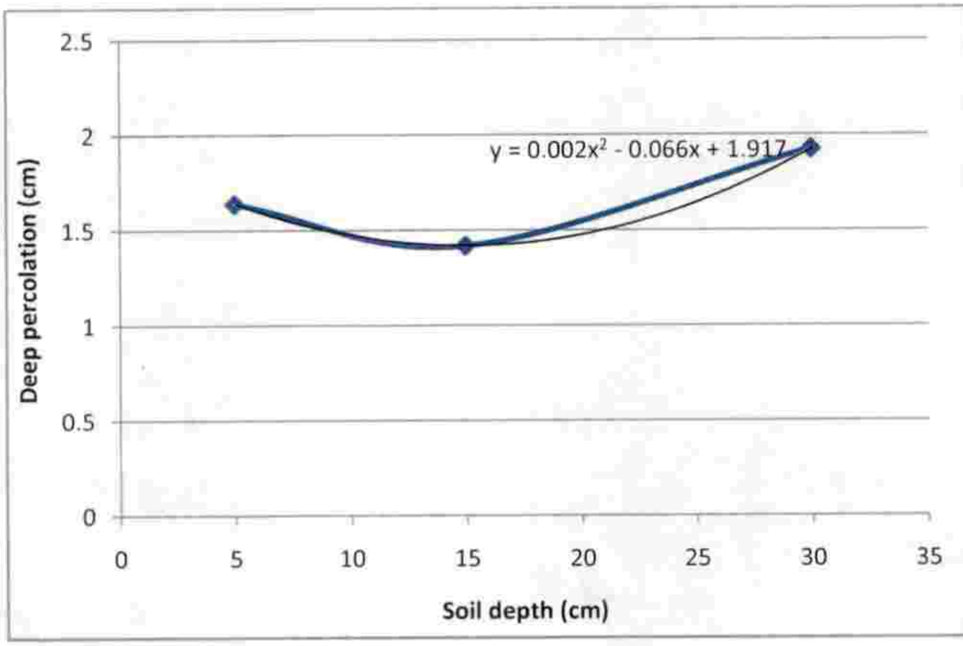


Figure 4.21 Regression curve for deep percolation (20 cm lateral)

Figure 4.21 represents quadratic regression curve of deep percolation for 20 cm lateral. In this equation, 'b' value is negative which determines vertical and horizontal placement of the parabola. Deep percolation will increase with the soil depth. Moisture content was more in deeper layers than in surface layers in lateral that installed at more depth. Therefore, deep percolation might be more from those layers. Table 4.25 to Table 4.27 shows the observed and predicted deep percolation for three lateral depths.

Table 4.25 Observed and predicted value of deep percolation (10 cm lateral)

Soil depth (cm)	**Observed DP (cm)**	**Predicted DP (cm)**
5	2.4905	3.067
15	1.882	1.782
30	2.282	1.857

Table 4.26 Observed and predicted value of deep percolation (15 cm lateral)

Soil depth (cm)	**Observed DP (cm)**	**Predicted DP (cm)**
5	2.06525	2.086
15	2.6934	2.886
30	2.562625	3.336

Table 4.27 Observed and predicted value of deep percolation (20 cm lateral)

Soil depth (cm)	**Observed DP (cm)**	**Predicted DP (cm)**
5	1.43544	1.637
15	1.41168	1.378
30	2.14132	1.737

From the Table 4.25 to Table 4.27, it is clear that observed deep percolation from 5 cm depth (10 cm lateral depth) was 2.4905 cm while predicted value from regression equation was 3.067 cm with an error of 0.5 cm. In the case of 15 cm depth, observed and predicted deep percolations were 1.882 cm and 1.782 cm respectively. An error of 0.1 cm was observed. For 30 cm soil depth, error observed was 0.4 cm between predicted and observed deep percolation. All laterals follow the same trend. Maximum variation between predicted and observed deep percolation was 0.5 cm for 10 cm lateral at 5 cm depth.

In subsurface drip irrigation system, root growth is more rapid and more number of fibrous roots can be seen near to lateral to absorb water and nutrients effectively. Thereby it saves water up to 55 percent than other conventional type of irrigation methods. From this study, it is evident that optimum lateral depth for this particular crop in sandy clay loam soil is 15 cm. Also, 95 cm can be considered as the optimum spacing of lateral.

On comparing the variation between moisture content in both bare soil and soil with crop, it is evident that variation in moisture content was more in soil with crop than bare soil due to the extraction of water by the crop roots. Moreover, in deeper layers, deep percolation was more for lateral with 15 cm and 20 cm lateral depth. Obviously, deep percolation was more from the emitter position because of the high moisture content at that position.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The study entitled "Soil water balance studies in subsurface drip irrigation for Amaranthus" was aimed to optimize the depth of installation of laterals and spacing between laterals under subsurface drip irrigation system for Amaranthus. This study also computed the deep percolation from different layers with different depth of installation of laterals.

In order to study the soil moisture distribution under subsurface, an experiment was conducted in the bare soil of the field. Emitters were located at 10, 15, 20 cm depths from the surface and they are spaced at 30 cm interval along the lateral.

A plot of size 113.4 m^2 was selected for the study. Field was ploughed and 27 beds of 0.70 m wide and 6 m length were made. Three different spacing between laterals of 95, 100, and 105 cm were made for this study. Laterals were laid at three depths viz. 10, 15 and 20 cm from the ground surface. Variation in soil moisture distribution was studied. Results showed that moisture distribution pattern was uniform at a lateral depth of 15 cm. Also higher moisture content was observed at 15 cm below the soil surface where the emitter was placed (Joseph *et al.* 2006). Radial movement of water was observed mostly at 24 hr after irrigation which is in agreement with Powar *et al.*, (2001). Moisture content near to the emitter was found to be high and decreased as distance from the emitter increased. Moisture content increased with depth from the surface due to less evaporation loss. Also, amount of moisture was found to be decrease with time. Moisture content at the surface layer for 10 cm lateral was 13.5 percent whereas the same for 20 cm lateral was 12.4 percent. Relatively high moisture content at the surface layer for 10 cm lateral was due to the surfacing effect. Obviously, variation in soil moisture in soil with crop was found to be more when compared to that of bare soil. Also, moisture content determined at 24 hr after irrigation was uniformly distributed over soil layers. It was more uniform at 15 cm lateral depth (10-15 cm soil layer).

The maximum values of yield were observed for the treatment T_4, then T_1 and T_7 (which have 15 cm, 10 cm, and 20 cm lateral depth with a lateral to lateral spacing of 95 cm). Among these three treatments T_4 (23.884 t/ha) shows high yield. In treatments T_1, and T_7 i.e., laterals at 10 cm and 20 cm depth, yield varies between 21.127 t/ha and 19.020 t/ha. Minimum yield was harvested from the treatments T_5 and T_6 (spacing between laterals of 100 cm and 105 cm respectively, lateral depth of 15 cm) due to more lateral spacing.

The highest water use efficiency was obtained for the treatment T_4 with a value of 37.96 kg/ha-mm followed by treatment T_1 with 34.63 kg/ha-mm. Variation of water use efficiency may be due to influence of pest and disease control, choice of crop and genetic improvement (by selection and breeding) of its productivity and adaptation to the particular environment as well as by improvement of the water, air and nutrient supply to the roots, and of light and carbon dioxide supply to foliage.

Growth parameters (number of leaves, stem girth of plant and crop height) were taken 1 month 2 months, 3 months and 4 months after transplanting. Maximum response was noticed with the combination of spacing between laterals - 95 cm and depth of installation of lateral - 15 cm (T_4), and also spacing between laterals - 95 cm and depth of installation of lateral - 10 cm (T_1). To further summarize, spacing between laterals of 95 cm and depth of installation of lateral of 15 cm was found to be most efficient combination while considering crop yield, plant characters and moisture distribution.

In statistical analysis, it was observed that, there were significant variations among treatments. Number of leaves was influenced by both spacing between laterals and depth of laterals. From that T_4 and T_1 were showed significant difference as compared to other treatments. Maximum value obtained in the case of stem girth was observed for the treatment T_4. Stem girth was varied significantly by spacing between laterals. Maximum height was observed for treatment T_4. Both spacing between laterals and lateral depth had remarkable effect on crop height.

Deep percolation was relatively less from surface layers than from deeper layers in higher lateral depths (i.e., 20 cm lateral depth). Deep percolation at the surface layer from lateral with depth 10 cm, 15 cm and 20 cm was found to be 24.905 mm, 20.06 mm and 14.11 mm respectively.

Deep percolation from 5 cm layer was more in almost all horizontal distances. As this layer is close to 10 cm depth of installation of lateral, capillary rise caused sudden increase in moisture content. This may be the reason for more percolation from 5 cm layer. Average deep percolation from 5 cm, 15 cm and 30 cm depth layer is 2.4905 cm, 1.882 cm and 2.277 cm respectively. Less percolation was observed in 15 cm depth layer. At 15 cm depth of installation of lateral, due to capillary rise, more moisture observed in just above the emitter position (30, 15). Percolation also more here compared to other layers because of the availability of more moisture. Average deep percolation from 5 cm, 15 cm and 30 cm depth layer is 2.007 cm, 2.693 cm and 2.563 cm respectively. At 20 cm depth of installation of lateral, due to capillary rise, more moisture content was observed in just above the emitter position (30, 20). Percolation was comparatively better than other layers because of the availability of more moisture. Average deep percolation from 5 cm, 15 cm and 30 cm depth layer is 1.412 cm, 1.435 cm and 2.141 cm respectively. In deeper layers, deep percolation was more for lateral with 15 cm and 20 cm lateral depth. Obviously, the deep percolation was more from the emitter position because of the high moisture content at that position. Regression equations were developed for predicting deep percolation and those equations could compute approximate value for deep percolation from any layer with 10 cm, 15 cm and 20 cm depth laterals.

In subsurface drip irrigation system, the root growth is more rapid and more number of fibrous roots can be seen near to the lateral to absorb water and nutrients effectively. Thereby it saves water up to 55 percent than other conventional type of irrigation methods. From this study, it is evident that the treatment T_4 (lateral spacing - 95 cm, lateral depth - 15 cm) has showed maximum response while considering moisture distribution, crop yield, biometric properties and deep percolation. Therefore T_4 has been selected as the best treatment in sandy clay loam soil for amaranthus.

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Appendices

APPENDIX I

1.1 Determination of Soil texture :–

a) Sieve analysis

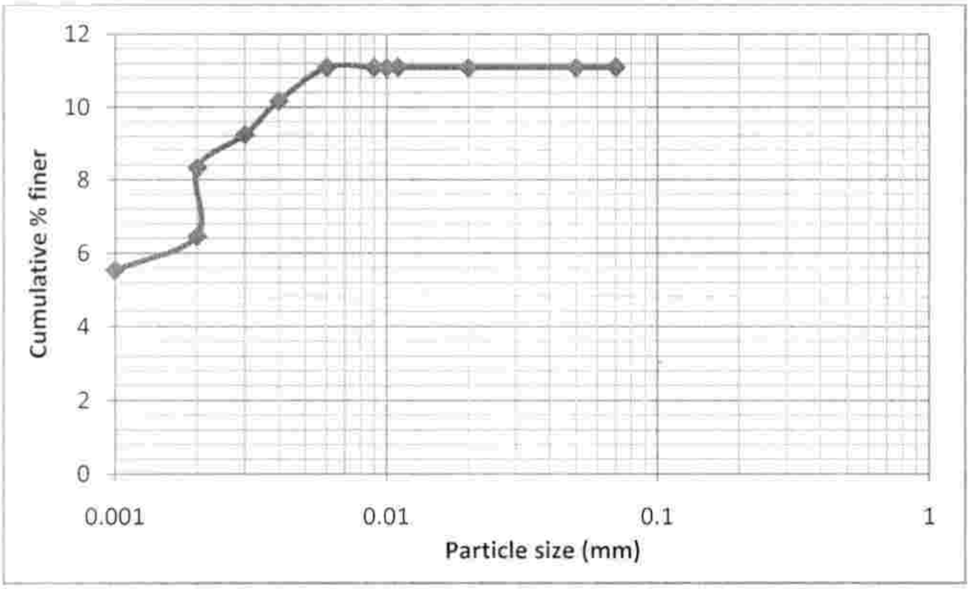
Sl.No	IS sieve	Particle Size D(mm)	Mass retained (g)	% retained	Cumulative % retained	Cumulative % finer
1	2	2	242.17	24.217	24.217	75.783
2	1	1	511.83	51.183	75.4	24.6
3	0.6	0.6	58	5.35	80.75	19.25
4	0.425	0.425	20.5	2.05	82.8	17.2
5	0.3	0.3	28.25	2.825	85.625	14.675
6	0.212	0.212	78.25	3.9125	93.15	6.85
7	0.15	0.15	0	0	93.15	6.85
8	0.075	0.075	0.57	0.057	93.207	6.793
9	pan	pan	33.75	3.375	96.582	3.418

b) Hydrometer method

Time	Density	Rh	He	D	M_D	N'	N
30 sec	1.012	12	15.7	0.07	0.0200	29.6296	11.09207437
1 min	1.012	12	15.7	0.05	0.0200	29.6296	11.09207437
5	1.012	12	15.7	0.02	0.0200	29.6296	11.09207437
10	1.012	12	15.7	0.01	0.0200	29.6296	11.09207437
20	1.012	12	15.7	0.011	0.0200	29.6296	11.09207437
30	1.012	12	15.7	0.009	0.0200	29.6296	11.09207437
1 hr	1.012	12	15.7	0.006	0.0200	29.6296	11.09207437
2	1.011	11	16	0.004	0.0183	27.1605	10.16773484
4	1.010	10	16.3	0.003	0.0167	24.6914	9.243395309
8	1.009	9	16.6	0.002	0.0150	22.2222	8.319055778
12	1.007	7	17.2	0.002	0.0117	17.2840	6.470376716
24 hr	1.006	6	17.5	0.001	0.0100	14.8148	5.546037185

Specific gravity - Pycnometer

Dry wt. of pycnometer(g), w_1	627.5
wt. of dry soil sample(g), w_d	250
wt. of pycnometer + soil(g), w_2	743
pycnometer + soil + water, w_3	1600
pycnometer + water, w_4	1450
specific gravity=wd/[(w_4-w_3)+w_d]	**2.5**



APPENDIX II

Determination of Infiltration rate

Elapsed time	Interval	Distance of water surface from reference point			Infiltration during period	
(min)	(min)					
		Initial depth (cm)	Final depth (cm)	Decrease in water level (cm)	Average rate (cm/hr)	Accumulated infiltration (cm)
-	-	10	-	-	-	-
5	5	10	7.8	2.2	26.4	2.2
10	5	10	7.6	2.4	28.8	4.6
15	5	10	7	3	36	7.6
20	5	10	8.32	1.68	20.16	9.28
35	15	10	8.11	1.89	7.56	11.17
50	15	10	9	1	4	12.17
65	15	10	9.4	0.6	2.4	12.77
80	15	10	9.52	0.48	1.92	13.25
100	20	10	9.78	0.22	0.635	13.47
120	20	10	9.78	0.22	0.635	13.69

APPENDIX III

Determination of bulk density using core cutter method

Description	Value
Mass of core cutter + wet soil (W_1), g	2409.68
Mass of core cutter (W_2), g	930
Mass of wet soil (W_3), g	1479.68
Volume of core cutter (V_1), g	942.47
Bulk density (W_3/V_1), g/cc	**1.57**

APPEMDIX IV

Determination of hydraulic conductivity by constant head permeameter

Details	Value
Hydraulic head (cm)	100
Length of soil sample (cm)	12
Hydraulic Gradient	10
Cross sectional area of sample (cm^2)	78.5
Time interval (sec)	900
Quantity of water (cm^3)	155
Permeability coefficient (cm/sec)	**2.63×10^{-4}**

APPENDIX V

5.1 Soil moisture content at different lateral depth without crop

a) Depth of lateral = 10 cm

Grid point	Moisture content (%)		
	Before irrigation	1 hr after irrigation	24 hr after irrigation
(0,5)	0.64	5.23	2.399
(0,15)	13.33	8.621	5.633
(0,30)	8.85	10.17	8.65
(15,5)	2.201	5.204	3.88
(15,15)	15.63	12.824	7.34
(15,30)	10.22	15.98	9.05
(30,5)	1.68	8.06	5.279
(30,15)	8.65	15.57	10.66
(30,30)	5.68	18.07	12.88
(45,5)	2.37	5.632	2.35
(45,15)	10.09	10.301	6.278
(45,30)	9.74	11.64	9.456

b) Depth of lateral = 15 cm

Grid point	Moisture content (%)		
	Before irrigation	1 hr after irrigation	24 hr after irrigation
(0,5)	0.534	5.23	2.632
(0,15)	5.813	8.621	5.16
(0,30)	5.925	10.17	7.053
(15,5)	2.821	5.204	2.237
(15,15)	6.603	12.824	7.521
(15,30)	8.022	14.98	9.57
(30,5)	0.62	5.63	3.31
(30,15)	8.54	12.57	8.894
(30,30)	6.168	15.39	10.52
(45,5)	2.571	5.632	2.824
(45,15)	9.207	11.301	7.365
(45,30)	8.715	13.64	8.108

c) Depth of lateral = 20 cm

Grid point	Moisture content (%)		
	Before irrigation	1 hr after irrigation	24 hr after irrigation
(0,5)	0.746	0.92	0.74
(0,15)	4.025	12.825	9.024
(0,30)	6.84	15.012	11.72
(15,5)	1.802	6.223	1.029
(15,15)	4.121	14.82	10.028
(15,30)	7.89	16.041	12.985
(30,5)	0.92	6.36	2.93
(30,15)	7.235	13.89	11.059
(30,30)	5.921	16.087	12.824
(45,5)	3.082	5.028	1.285
(45,15)	9.01	12.105	9.95
(45,30)	8.62	13.08	10.92

APPENDIX VI

6.1 Soil moisture content at different depths with crop

a) Depth of lateral = 10 cm

Grid point	Moisture content (%)		
	Before irrigation	1 hr after irrigation	24 hr after irrigation
(0,5)	4.36	9.22	0.69
(0,15)	6.73	8.43	3.84
(0,30)	4.39	3.69	3.68
(15,5)	4.91	14.21	4.4
(15,15)	9.84	11.54	5.69
(15,30)	2.31	11.43	7.97
(30,5)	5.87	9.37	7.76
(30,15)	7.46	13.59	11.97
(30,30)	1.9	12.44	11.02
(45,5)	5.32	14.39	4.21
(45,15)	6.94	11.82	5.39
(45,30)	5.89	11.56	7.35

b) Depth of lateral = 15 cm

Grid point	Moisture content (%)		
	Before irrigation	1 hr after irrigation	24 hr after irrigation
(0,5)	5.38	2.9	1.79
(0,15)	9.47	9.5	6.12
(0,30)	11.76	13.21	9.17
(15,5)	4.86	9.07	3.25
(15,15)	5.79	17.06	5.83
(15,30)	7.74	19.29	10.84
(30,5)	3.76	9.26	8.93
(30,15)	6.07	19.08	14.48
(30,30)	10.62	19.23	16.94
(45,5)	4.32	9.12	3.59
(45,15)	5.61	17.28	6.07
(45,30)	7.23	19.37	10.24

c) **Depth of lateral = 20 cm**

Grid point	Moisture content (%)		
	Before irrigation	1 hr after irrigation	24 hr after irrigation
(0,5)	7.3	7.88	2.51
(0,15)	9.69	10.82	6.09
(0,30)	10.23	15.48	6.45
(15,5)	9.39	9.62	2.79
(15,15)	9.95	9.94	6.08
(15,30)	10.12	12.21	7.38
(30,5)	10.28	12.04	8.56
(30,15)	10.32	12.64	10.65
(30,30)	10.87	13.3	10.84
(45,5)	9.62	9.92	2.92
(45,15)	9.79	10.06	6.27
(45,30)	10.06	12.37	7.41

APPENDIX VII

Yield (kg) obtained from each bed from four harvest operations

Treatment	1st harvest	2nd harvest	3rd harvest	4th harvest
T_1	2.240	10.700	6.880	6.800
T_2	1.805	8.100	6.200	3.550
T_3	1.168	7.500	5.525	5.650
T_4	2.344	11.250	8.600	7.850
T_5	0.901	6.800	5.650	4.300
T_6	1.596	5.550	6.250	4.400
T_7	1.965	9.150	7.800	5.050
T_8	1.915	6.950	5.295	5.550
T_9	1.801	6.450	7.050	6.900

SOIL WATER BALANCE STUDIES IN SUBSURFACE DRIP IRRIGATION FOR AMARANTHUS

by

NEETHA SHAJU
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ABSTRACT

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Kerala Agricultural University

Department of Land and Water Resources and Conservation Engineering

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ABSTRACT

Subsurface drip irrigation (SDI) is advanced drip irrigation where the tubing and emitters are buried beneath the soil surface. Field experiment was done at the instructional farm, KCAET, Tavanur. Experiment was aimed to optimize the depth of installation of laterals and spacing between laterals under subsurface drip system. This study also computed deep percolation from different layers with different lateral depths. Soil moisture was taken from different depths and horizontal distance and soil moisture contour maps were plotted. Results showed that moisture content increased with depth from the surface due to less evaporation loss. Also, amount of moisture was found to be decreased with time. Moisture content at the surface layer for 10 cm lateral was 14.5 per cent whereas the same for 20 cm lateral was 11.6 per cent due to surfacing. Moisture distribution pattern was uniform for lateral with 15 cm depth.

Maximum values of yield were observed for the treatment T_4, and then T1 (which have 15 cm and 10 cm lateral depth respectively). Highest water use efficiency was for treatment T_4 with a value of 37.96 kg/ha-mm followed by treatment T_1 with 34.6 kg/ha-mm. In statistical analysis, it was observed that, there were significant variations between treatments. Number of leaves was influenced by both spacing between laterals and depth of laterals. Stem girth was varied significantly by spacing between laterals. Both spacing between laterals and lateral depth had remarkable effect on crop height. Deep percolation was relatively less from the surface layers than from the deeper layers in higher lateral depths (i.e., 20 cm lateral depth). From this study, it is evident that treatment T_4 (lateral spacing = 95 cm, lateral depth= 15 cm) has showed maximum response while considering moisture distribution, crop yield, biometric properties and deep percolation.