OPTIMIZATION OF FERTIGATION LEVEL AND DEPTH OF LATERAL UNDER SUBSURFACE DRIP IRRIGATION FOR AMARANTHUS

By

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PROJECT REPORT

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2013

DECLARATION

We hereby declare that, this project entitled **"Optimization of fertigation level and depth of lateral under subsurface drip irrigation for amaranthus"** is a bonafide record of project work done by us during the course of study, and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project entitled **“Optimization of fertigation level and depth of lateral under subsurface drip irrigation for amaranthus”** is a record of project work done jointly by Jeena Joseph and Sariga, S under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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Jeena Joseph

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Dedicated to

GOD, Almighty,

Our Parents

and

Teachers

CONTENTS

Chapter	Title	Page No.
	LIST OF TABLES	i
	LIST OF FIGURES	ii
	LIST OF PLATES	iii
	SYMBOLS AND ABBREVIATIONS	iv
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	7
III	MATERIALS AND METHODS	29
IV	RESULTS AND DISCUSSION	45
V	SUMMARY AND CONCLUSION	62
	REFERENCES	65
	APPENDICES	viii
	ABSTRACT	x

LIST OF TABLES

Table No.	Title	Page No.
1	Treatment details	35
2	Fertilizer requirements for amaranthus per bed	42
3	Vertical and horizontal advance of water	46
4	Analysis of variance for stem girth	48
5	Analysis of variance for number of leaves	50
6	Analysis of variance for yield	57
7	Fertilizer use efficiency for amaranthus crop	58
8	Cost of materials used for the subsurface drip fertigation system for an area of one hectare	59
9	Cost of inputs used for the subsurface drip fertigation systems for an area of one hectare	59
10	Cost of labour charges for 3 season crop	60
11	Benefit Cost Ratio for different treatments	61

LIST OF FIGURES

Fig No.	Title	Page No.
1	Experimental layout	31
2	Plan lay out of the field	36
3	Horizontal advance of water front with elapsed time	46
4	Vertical advance of water front with elapsed time	47
5	Variation of stem girth with days in different treatments	48
6	Variation of number of leaves with days in different treatments	50
7	Variation of yield in different treatments after first harvest	53
8	Variation of yield in different treatments after second harvest	54
9	Variation of yield in different treatments after third harvest	54
10	Variation of yield in different treatments after fourth harvest	55
11	Variation of yield in different treatments after fifth harvest	55
12	Variation of yield in different treatments after sixth harvest	56
13	Variations in total harvesting yield of amaranthus in different treatments	56

LIST OF PLATES

Plate No.	Title	Page No.
1	**Pumping unit**	32
2	**16 mm lateral with inline emitter**	32
3	**Tap to control the irrigation**	33
4	**Dosmatic fertigation unit**	33
5	**Bed preparation and mulch sheet fixing**	39
6	**Mulch sheet hole making**	39
7	**Prepared beds for transplanting**	40
8	**Seedlings for transplanting in the field**	40
9	**Transplanting of amaranth seedling**	41
10	**Harvesting of amaranth**	44
11	**Roots of amaranthus of three lateral depths and control**	51

SYMBOLS AND ABBREVIATIONS

A	Ampere
ANOVA	Analysis of variance
B/C	Benefit/Cost
bales/ha	Bales per hectare
BMP	Best Management Practice
Cm	Centimeters
C_V	Coefficient of manufacturing variation
° C	Degree celsius
Dept.	Department
DI	Drip irrigation
DMAPR	Directorate of Medicinal and Aromatic Plants Research
E	Evaporation
ET	Potential evapotranspiration
et al	And others
EU	Excellent uniformity
Fig.	Figure
gm	Gram (s)
gm/m^2	Gram (s) per square meter(s)

ha	hectare
hp	horse power
hrs	Hours
i.e.	That is
inch	inches
j.	Journal
IWUE	Irrigation water use efficiency
K	potassium
KAU	Kerala Agricultural University
KCAE T	Kelappaji College of Agricultural Engineering and Technology
kg(f)/cm^2	Kilogram force per centimeter square
kg/cm^2	Kilogram per centimeter square
kg/ha	Kilogram per hectare
kg /m^2	Kilogram per meter (s)
KPa	Kilo Pascal
LDPE	Low Density Poly Ethylene
lph	Litres per minute
lps	Litres per second
Ltd.	Limited
L W R C E	Land and Water Resources Conservation Engineering

m	Meter (s)
m^2	Square meter (s)
Mg/ha	Milligram per hectare
M ha	Million hectare
M ha m	Million hectare meter
ml	milli litre
mm	millimeter
N	Nitrogen
NS	Not significant
PVC	Poly Vinyl Chloride
rpm	revolution per minute
SDI	Subsurface drip irrigation
sec	Second
SSDF	Subsurface drip fertigation
ton/acre	Tone(s) per acre (s)
V	Volt
viz	Which are
Vs.	Versus
W	Watts
&	and
°	Degree (s)

/	Per
%	percentage
′	Minute (s)
″	second (s)

INTRODUCTION

Water is most precious and prime element in the socio economic development of the nation and can be described as “eco currency”. Many countries in the world are experiencing big water scarcity. The volume of available water more or less remains the same and the increasing demand is due to the increase in population, industrialization and growth in agricultural sector. Water, mankind’s most vital and versatile resource is a basic human need and a precious national asset. It is essential for broad based agricultural and rural development in order to improve food security and poverty alleviation. Water, a life sustaining resource, closely linked to the quality of life, a renewable resource is getting deteriorated in terms of quality as well as quantity.

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

The pressure for survival and the need for additional food supplies are causing the rapid expansion of irrigation throughout the world. The area of land irrigated in the world is more than 248million hectares. 9 countries- China, India, The United States of America, Pakistan, Indonesia, Mexico, Iran, Thailand and Uzbekistan have the largest irrigated areas amounting to almost 70% of the world’s irrigated area.

As far as the Indian agriculture is concerned, irrigation plays a crucial role in the various development projects of the country. The existing methods of surface irrigation are less efficient and we are confronted with many problems regarding soil and water. A major challenge is to develop systems for greater precision in water and plant nutrient control, so as to increase the use efficiencies of soil, water and energy resources and to improve the environment for mankind. Expansion of irrigation is also essential for increasing food production for the alarming Indian population. With present potential of 114 M ha m of water, only 57 M ha (40 per cent) is under irrigation in India against the total cultivated area of 145 M ha. Therefore the effective management of water resources is essential to meet the increasing competition for water between agricultural and non-agricultural sectors.

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

The micro irrigation system is one of the most efficient methods of water application directly into soil at the root zone of plants. About 4, 00,000 ha of cultivated lands in India utilize this system of irrigation. Among the states, Maharashtra is the leading state covering 1, 42,347 ha under micro irrigation followed by Karnataka with 64,680 ha and Tamil Nadu with 43,292 ha. It is also expected that the projected area of 1 M ha (i.e. 1 per cent of irrigated area) will be brought under micro irrigation in the next 5 years and about 10 M ha by the year 2020 / 2025 AD. About 55 per cent of the total area of Kerala State with a humid tropical climate is under agriculture. The irrigated area in Kerala is estimated to be 1, 55,130 ha and the irrigated area in the plantation crops constitute only about 2.8 per cent of the total irrigated area in the State. The area under micro irrigation in Kerala is as low as 6000 ha. (Horticultural mission, 2010)

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

It has been found that the micro irrigation saves fertilizer up to 30 per cent, increases the yield up to 100 per cent with saving of water up to 70 per cent. It also prevents weed growth, saves energy and improves the quality of the produce. Thus the micro irrigation system has to be seen as a holistic approach to address poverty alleviation, horticulture-led diversification of agriculture, enhanced productivity, environmental protection and ecological security, and reduced biotic and abiotic stresses. But there are constraints in the development of micro irrigation systems. Micro irrigation is generally perceived as a technology-driven movement, hence receives resistance from certain quarters. The initial cost of establishing micro irrigation system is high, generally out of reach of resource poor farmers. Micro irrigation is not integrated with total water management system, hence generally viewed in isolation. Lack of information on temporal and spatial variation in soil moisture and on the optimal fraction of soil to be wetted, lack of availability of low cost soluble fertilizers and other agro chemicals and poor institutional support system are also the constraints.

Now these constraints are being solved to some extent. There are lot of schemes that provides financial assistance to the farmers up to the extent of 90 per cent of the capital cost of the system for a hectare, for small or marginal and women farmers, and 70 per cent of the cost for other categories of farmers. The cost of incentive is shared in the ratio of 90 per cent by Central and 10 per cent by the State Governments. Moreover even with all these constraints and high initial investment it has also been observed that the payback period of micro irrigation project is about one year only for most of the crops and benefit cost ratio varies from 2 to 5.

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

Vegetable production in Indian agriculture has wider scope for increasing the income of the marginal and small farmers. Vegetables have vast potential in gaining foreign exchange through the export. The vegetable growers are looking for new ways to achieve superior quality produce with higher yields. Among the vegetables grown, amaranthus is a vegetable crop of commercial importance. Amaranthus [*Amaranthus hypochondriacus, A. cruentus* (Grain type) & *A. tricolor* (Vegetable type)] is an herbaceous annual with upright growth habit, cultivated for both its seeds which are used as a grain and its leaves which are used as a vegetable or green. Both leaves and seeds contain protein of an unusually high quality

Kerala, which lies in the humid subtropics, gets a rain of an average of 300 cm per year out of which almost 70 per cent is received from the Southwest monsoon. Throughout Kerala, especially in northern regions, it is relatively dry during the periods from December to May. The amount and distribution of rainfall in many parts are not adequate to meet the total water requirement of crops. Kerala being dominated by plantation crops in two-third of the cropped area and due to uneven topography, drip irrigation is expected to have high demand. According to the latest data available 86.75 per cent of total cropped area is covered by plantation and horticultural crops. The contribution being 50.9 per cent by plantation crops, 12.16 per cent by spices, 13.55 per cent by fruits and 10.14 per cent by vegetables. The average size of land holding in the state is 0.33 ha and the man to land ratio is declining fast. The per capita net zone area is 0.09 ha and gross cropped area is 0.11 ha. It is also reported that 85 per cent of the coconut, 79 per cent of arecanut, 76 per cent of pepper, 60 per cent of cashew, 55 per cent of rubber, 45 per cent of coffee and 86 per cent of banana are grown in holdings less than 2 ha. The nature of farming therefore is homestead with a mixture of crops in each tiny holding except for crops like rubber, cardamom and tea. The irrigation system suitable for these crops in homestead condition is minor irrigation with emphasis on drip or micro sprinkler irrigation (CTCRI, Annual report, 2009-10)

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

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

Fertigation and drip irrigation is an effective method that can be resorted to improve the vegetable production. Fertigation was first started in the late 1960's in Israel with the development of drip irrigation. Fertigation is the application of fertilizers, soil amendments, or other water-soluble products through an irrigation system. Benefits of fertigation over traditional broadcast or drop-fertilizing methods include: increased nutrient absorption by plants, reduction in fertilizer and chemicals needed, reduced leaching to the water table, reduction in water usage due to the plant's resulting increased root mass's ability to trap and hold water, application of nutrients at the precise time they are needed and at the rate they are utilized. The important components of a fertigation system include drip irrigation system of suitable layout and fertigation equipment. Crops are raised under fertigation system with the application of suitable mulch materials in order to reduce the water loss and weed infestation. The performance of crop may vary with the application rates and schedule of irrigation. The cost of the system will vary with the layout of the drip irrigation system as the use of laterals in each system of layout may vary.

During summer season, the available water has to be used effectively and the soil moisture has to be conserved. Mulching is a relevant practice for soil moisture conservation under this context. Fertigation along with mulching helps to achieve both the objectives of efficient utilization of available water and the conservation of soil moisture. Plastic mulch can reduce the loss of soil moisture. Effective control of weed growth is also attained under this system.

In view of all the above facts this study has undertaken to evaluate the performance of subsurface drip fertigation for amaranthus in sandy loam soil with the following specific objectives:

1. To optimize the fertigation level under subsurface drip irrigation for amaranthus.
2. To optimize the depth of laterals under subsurface drip irrigation for amaranthus.
3. Workout the cost economics.

REVIEW OF LITERATURE

Subsurface Drip Irrigation (SDI) is one of several types of Micro irrigation. It is a planned irrigation system in which water is applied directly to the root zone of plants by means of applicators (E.g. orifices, emitters, and porous tubing) placed below the ground surface. It is one of the more advanced irrigation methods in use today. It is potentially more efficient than flood or sprinkler irrigation, due to large part to reduced evaporation. Micro irrigation conserves irrigation water easily, doubling the command area of a water resource with yield increase up to 50 per cent. Micro irrigation coupled fertigation methods ensures the congruence of sustainability, productivity and profitability. The productivity of crops is based on effective utilization of water and fertilizer, along with other agricultural inputs. Fertigation provides flexibility of fertilizer application, which enables three specific nutritional requirements of the crop to be met at different stages of its growth. In comparison with the conventional methods, it appears that fertigation gives higher crop yields with substantial saving in fertilizer usage. Since micro irrigation greatly enhances water, fertilizer and energy use efficiency, the sustainability in agriculture could be achieved without the burden of environmental degradation.

2.1 Comparison between surface and subsurface drip irrigation

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

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

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

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

Hutmacher *et al.* (1996) compared the subsurface drip and furrow irrigation with Alfalfa in the Imperial Valley. The study was conducted in silt clay loam soil. He found that by using subsurface drip irrigation the water use efficiency was increased 20 % higher than with furrow irrigation method. Because of this higher water use efficiency the yield was also increased.

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

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

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

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

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

2.2 Hydraulics of micro irrigation system

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Cheng XianJun *et al.* (2010) conducted a study on Model application of water flow and solute transport during non-steady diffusion from subsurface emitter source. The flow of soil water and transport of solute during subsurface irrigation and fertigation are described using a simulation model which illustrates the impact of water flow and solute transport on soil texture and structure, discharge rate of emitters, depth of laterals, and time consumed during single irrigation.

2.3 Field performance of subsurface drip

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

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

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

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

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

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

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

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

2.4 Moisture distribution under subsurface drip

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

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

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

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

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

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

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

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

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

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

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

2.5 Subsurface drip fertigation

Beyaert *et al.* (2001) was conducted an experiment to evaluate the response of processing cucumber *(Cucumis sativus* L.) to irrigation and fertilization strategies on a loamy sand. This study indicates that processing cucumbers in Ontario benefit from irrigation, with drip irrigation/fertigation being more beneficial than overhead sprinkler irrigation. Subsurface drip irrigation systems increase irrigation water use efficiency over sprinkler and surface drip systems when higher than average temperatures coupled with lower than average rainfall are experienced on coarse-textured soils.

Hebbar *et al.* (2001) was conducted a field experiment in rabi-summer seasons in red sandy loam soil of Main Research Station, University of Agricultural Sciences, Bangalore, Karnataka, India, to study the effect of drip fertigation on soil water, soil fertility and yield of field- grown tomato *(Lycopersicon esculentum* cv. Arka Abhijit) in the semiarid tropics. Fertigation with 100% water soluble fertilizers increased the marketable fruit yield and water use efficiency compared to soil application of fertilizer directly either with furrow ordrip irrigation. Subsurface drip fertigation was on par with surface drip fertigation in maintaining favourable soil moisture and enhancing the yield. Fruit quality parameters were not altered either by drip irrigation or fertigation except the ascorbic acid content and titratable acidity. Drip fertigation could maintain soil fertility but there was no change in soil pH and electrical conductivity.

Kaniszewski *et al. (2002)* was conducted a study on effect of drip irrigation and fertigation on growth and yield of celeriac. The effects of drip irrigation and traditional broadcast N fertilizer application were compared with those of drip fertigation in Polish field experiments. The yield of celeriac was highest with one-third of the N applied before planting and two-thirds applied through the drip irrigation system, and lowest with broadcast N application without drip irrigation. Fertigated plants had greater leaf area, dry matter production, nitrate-N and total N contents than those given broadcast N, with or without drip irrigation. There were no significant differences in yield, dry matter production and contents of nitrate-N and total N between surface and subsurface fertigation treatments.

Lamm et al. (2009) was conducted a four-year study on western Kansas on a deep, well-drained, loessial Keith silt loam to develop a Best Management Practice for nitrogen fertigation for corn using subsurface drip irrigation (SDI). Results emphasize that high-yielding com production also can be efficient in nutrient and water use. The BMP can be used for managing SDI fertigation of com on the deep silt loam soils of western Kansas.

Li JiuSheng *et al.*(2009) was conducted a study on water and nitrogen distribution under subsurface drip fertigation as affected by layered-textural soils. Laboratory experiments were conducted using a plexiglass box to investigate the effects of soil texture, layered structure and emitter discharge rates on the distribution of water nitrate nitrogen and ammonium nitrogen from a buried source. The results indicated that the sandy-loam interface existing in the SL soil limited the downward movement of water while increased the horizontal water movement, resulting in an accumulation of water and nitrate nitrogen in the sublayer soil underneath the interface. The distribution of nitrate nitrogen concentration was also controlled by input concentration and initial concentration of soil nitrate nitrogen. A nitrate nitrogen concentration approximating the input nitrate nitrogen concentration was found in the proximity of the buried source and the concentration decreased as the distance from the source increased under the tested conditions that input nitrate nitrogen concentration was substantially higher than the initial nitrate nitrogen concentration.

Thompson *et al*. (2009) fertigation frequency for drip-irrigated broccoli. A 3 year field experiment was conducted on a sandy loam soil with subsurface drip irrigated broccoli to (i) to determine the effects of N rate and fertigation frequency on crop yield, quality, and crop N status, and (ii) estimate N balance. Broccoli marketable yield and quality were responsive to N rate, but not to increased fertigation frequency. They conclude that foe broccoli production with subsurface drip-irrigation on sandy loam or finer soils, fertigation can be applied as infrequently as monthly, without compromising crop yield and quality, or causing excessive N losses.

Tan *et al.* (2010) was conducted on a study on Farm-scale processing tomato production using surface and subsurface drip irrigation and fertigation. The result was no significant difference in average marketable tomato yield among drip or fertigated treatments. Drip irrigated and/or fertigated tomatoes increased water use efficiency by 25 and 17% relative to non-irrigated tomatoes for the light and the heavy soils, respectively. Drip fertigation increased P and N use.

Barbosa *et al*. (2012) was conducted an experiment to evaluate the effect of subsurface drip irrigation and the application of stillage and nutrients in some agronomic parameters, stem yield, technological characteristics of sugarcane and yield of theoretical recoverable sugar.. The treatments were: mineral fertilizers without irrigation; irrigation and fertigation with NPK using mineral fertilizers; irrigation and fertigation with stillage supplying the K and complementation of N and P with mineral fertilizers; and irrigation and fertigation with stillage supplying the NK and complementation of P with mineral fertilizer. The system of irrigation adopted was the subsurface drip irrigation. The fertigation with stillage supplying the K promoted higher Brixand stem yield when compared to non-irrigated cultivation. The irrigation and fertigation with stillage supplying the NK promoted higher yield of theoretical recoverable sugar, when compared the cultivation without irrigation.

Kong QingHua *et al.* (2012) was conducted an experiment to investigate different bell paper response to subsurface drip irrigation and surface drip irrigation under four nitrogen levels. The result was soil N residue under SDI was lesser than that under DI.

Nadiya Nesthad (2012) was conducted a study on impact of fertigation and drip system layout on performance of Chilli. She reported that maximum yield was obtained in 85% of the daily irrigation requirement, with one lateral in between two rows of crop in a bed.

2.6 Effect of depth of lateral on subsurface drip irrigation

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

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

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

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

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

Howell *et al.* (1997) conducted a study to evaluate surface and subsurface micro irrigation on Corn Yields. Here subsurface drip laterals were placed 0.3 m below the surface with emitters spaced 0.45 m apart and drip lines were placed 1.5 m apart. Corn yield exceeding 1.4

kg/m^2 were achieved in 1994, and yields exceeding 1.3 kg /m^2 were even achieved with the late planting date and the insect problems in 1993.

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

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

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

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

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

Nisha. T.V. (2007) conducted a study on subsurface drip irrigation of ladies finger in sandy loam soil. She reported that the subsurface drip irrigation with 10 cm depth of placement of laterals and 1.5 lit/day/plant of irrigation was considered as the best treatment for okra in sandy loam soil.

Li JiuSheng et al. (2010) was conducted an experiment to evaluate the effects of injector types and lateral depths on fertigation uniformity of subsurface drip irrigation (SDI) systems by simultaneously measuring the distributions of water application, solution concentration, and fertilizer application. The results indicate that injector type and lateral depth had an insignificant effect on emitter discharge and the uniformity of water applied, but the uniformity for fertilizer applied is mainly dependent on injector type. The uniformity for fertilizer applied of the differential pressure tank is lower than that of the Venturi device and the water-driven piston proportional pump. For a given lateral depth, the differential pressure tank generally produced a higher coefficient of variation (C_v) for fertilizer application than that of the Venturi injector and the proportional pump.

2.7 Effect of mulch on plant growth and yield

Clough *et al.* (1990) have been well documented that the advantages of mulching in vegetable crop production. Various mulching materials are utilized and these include weed or grass clippings, paddy straw, bark, sawdust and plastic. Mulches can effectively minimize water loss as vapour, soil erosion, weed problems and nutrient loss.

Raina *et al.* (1999) was studied the advantages of drip irrigation coupled with black polyethylene mulch. It has been reported to improve the yield, quality and water use-efficiency of high value crop like tomato.

Rajbir *et al.* (2003) was conducted a field experiment on sandy loam soil to investigate the effect of drip irrigation and black polyethylene mulch compared with surface irrigation on growth, yield and water use efficiency and economics of tomato. Drip irrigation at 80 per cent pan evapo transpiration applied gave significantly higher fruit yield compared with the surface irrigation. Use of black polyethylene mulch plus the drip irrigation further raised the fruit yield to 57.89 t/ha.

Tiwari *et al.* (2005) conducted experiments on pineapple crop grown in the lateritic sandy loam soil to study yield response and to evaluate the economic feasibility of its cultivation with drip irrigation and plastic mulch. The yield of pineapple was highest and recorded 81 t/ha in case of 100 per cent irrigation requirement met by drip plus plastic mulch. The net income was highest for the 100 per cent irrigation requirement met with drip plastic mulch.

Singh *et al.* (2009) reported the effect of drip irrigation and polyethylene mulch influence on growth, yield and water use efficiency of tomato in India. Among different irrigation levels, drip irrigation at 80 per cent ET resulted in higher fruit yield of 45.57 t/ha compared with surface irrigation.

2.8 Yield of crops under subsurface drip

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

Camp *et al.* (1989) conducted an experiment to evaluate three micro irrigation lateral placements and two irrigation application modes for corn in a coarse textured Southeastern

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

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

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

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

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

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

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

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

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

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

MATERIALS AND METHODS

This chapter describes the materials used and the methods employed for the study entitled "Optimization of fertigation level and depth of lateral under subsurface drip irrigation for amaranthus" conducted at the Instructional Farm, Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Malappuram, Kerala during the period of October 2012 to January2013. The materials used and methodology adopted during the study are described in this chapter.

3.1 Location and climate

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

The selected plot for the study was located in the western side of the farm which was nearer to the Bharathapuzha river basin. The soil in the selected plot was sandy loam. The total area selected for the study was 32x13 m^2. The land preparation was done before the installation of the system in the field. The field experiment was conducted during October to January 2013.

3.2 Components of the experimental setup

3.2.1 Pumping unit

An electric motor of 12 hp, volt 380/415V, cycle 50, phases 3 and current 12A connected with a pump of 4 hp, size of 60 × 65mm, 2900 rpm and capacity of 23.5 litres per second was used for the present study shown in plate 1. A portion of water was by passed to the tank by means of a ball valve arrangement to control the inlet pressure. The water source for drip system was a filter point well located near the experimental site.

3.2.2 Pressure gauges

Two pressure gauges with pressure range of 0-7 kg (f)/cm^2 were located before and after the fertigation unit for indicating the pressure in the system.

3.2.3 Mainline and Laterals

PVC pipes of 90 mm and 75 mm diameter with pressure rating of 6 kg (f)/cm^2 was used as the main and sub main respectively. Low density polyethylene pipe of 16 mm diameter was used as the laterals shown in plate 2. End caps were provided at the end of laterals. Each lateral was provided with individual tap to control the flow rate as shown in plate 3. The inline drippers of 4 liters per hour discharge with a spacing of 40 cm were used for the study. The total length taken for one row was about a length of 12 m.

3.2.4 Fertigation equipment

Dosmatic fertigation unit was used for this study. These are piston or diaphragm pumps which are driven by the water pressure of the irrigation system. The injection rate is proportional to the flow rate of water in the system. A high degree of control of the fertilizer injection rate is possible. Dosmatic fertigation unit was a self-priming unit and operated on hydraulic pressure. Operating pressure for this fertigation unit is 0.3 – 5 kg (f)/cm^2. The experimental set up for dosmatic fertigation unit is shown in plate 4.

Dosmatic fertigation unit was connected as a by-passassembly to the main line. A suction pipe with a screen filter was provided in the center of fertigation unit and suction pipe with its filter was dipped into the container having the solution. Suction was created by the piston arrangement maintaining a pressure difference.

The required quantity of fertilizers were taken in the container and mixed thoroughly with water proportionately. The water pressure forces the solution downstream to main line. The water in the main line on its way through, due to its pressure activates the dosmatic unit which in turn takes up the required quantity of solution directly from the container.

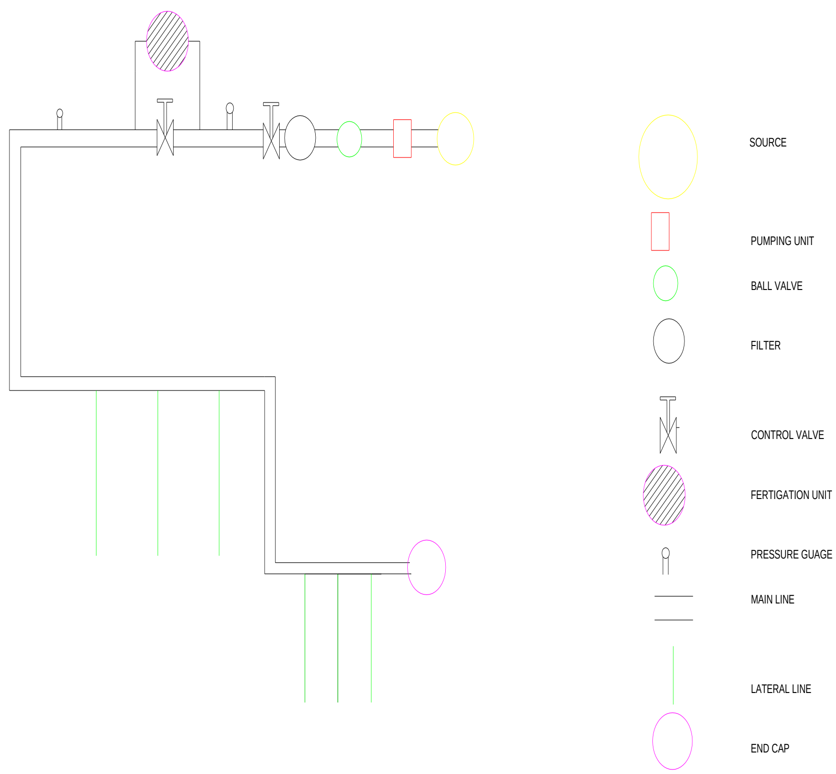

Fig.1 Experimental layout

Plate1. Pumping unit

Plate 2. 16 mm lateral with 4 lph inline emitter

Plate 3. Tap to control the irrigation

Plate 4. Dosmatic fertigation unit

3.3 FIELD EXPERIMENT

3.3.1 Treatment details

The experiment was laid out with ten treatments, from which nine treatments are the combination consisting of three fertigation levels and three depths of laterals and one treatment as control were shown in Table 1.

Fertigation levels

1. F_1 : 120% of the fertigation level.
2. F_2 : 100% of the fertigation level.
3. F_3 : 80% of the fertigation level.

Depths of laterals

1. D_1 : 16mm lateral of 4 lph lateral at 10 cm depth
2. D_2 : 16mm lateral of 4 lph lateral at 20 cm depth
3. D_3 : 16mm lateral of 4 lph lateral at 30 cm depth

3.3.2 Design and Layout

The experiment was laid out in Randomised Block Design having ten treatment combinations and was replicated thrice shown in Fig 2.

Table 1.Treatment details

Sl. No.	Treatments	Name	Description
1	T1	F1D1	120% of fertigation level, lateral of 4 lph at 10 cm depth
2	T2	F2D1	100% of fertigation level, lateral of 4 lph at 10 cm depth
3	T3	F3D1	80% of fertigation level, lateral of 4 lph at 10 cm depth
4	T4	F1D2	120% of fertigation level, lateral of 4 lph at 20 cm depth
5	T5	F2D2	100% of fertigation level, lateral of 4 lph at 20 cm depth
6	T6	F3D2	80% of fertigation level, lateral of 4 lph at 20 cm depth
7	T7	F1D3	120% of fertigation level, lateral of 4 lph at 30 cm depth
8	T8	F2D3	100% of fertigation level, lateral of 4 lph at 30 cm depth
9	T9	F3D3	80% of fertigation level, lateral of 4 lph at 30 cm depth
10	C		Control

T1-120% of fertigation level, lateral of 4 lph at 10 cm depth

T2-100% of fertigation level, lateral of 4 lph at 10 cm depth

T3-80% of fertigation level, lateral of 4 lph at 10 cm depth

T4-120% of fertigation level, lateral of 4 lph at 20 cm depth

T5-100% of fertigation level, lateral of 4 lph at 20 cm depth

T6-80% of fertigation level, lateral of 4 lph at 20 cm depth

T7-120% of fertigation level, lateral of 4 lph at 30 cm depth

T8-100% of fertigation level, lateral of 4 lph at 30 cm depth

T9-80% of fertigation level, lateral of 4 lph at 30 cm depth

C- Control

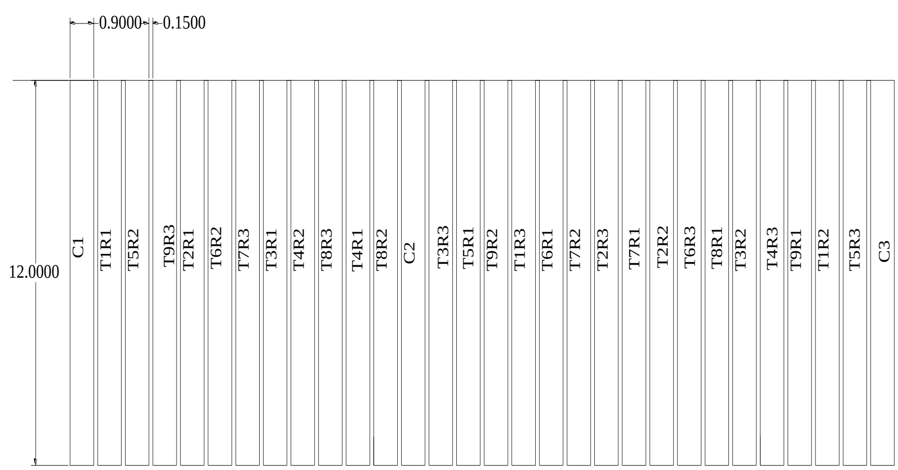

Fig.2 Plan lay out of the field

All dimensions are in cm

3.4 CULTURAL OPERATIONS

3. 4. 1 Land preparation

The soil type of the experiment field was sandy loam. The field was ploughed using power tiller. The plots size of 32x13 m^2 was taken and forming ridges around the plot. Raised beds of size 12x0.9 m^2 of 30 numbers were taken and in between two beds a spacing of 15 cm was given. Each plot was leveled manually and then ridges and furrows were taken.

3.4.2 Amaranth (*Amaranthus spp.*) kannara local

A spacing of 40 cm × 40 cm, recommended for amaranthus in the Package of practices recommendations: Crops (KAU, 2005) was adopted.

3.4.3 Nursery preparations

Amaranth variety kannara local was chosen for cultivation. Amaranthus is a transplanted crop. Seeds were sown in the prepared soil bed of 8x1 $m^2$with a seed rate of 4.2gm/m^2 and two week old seedlings were transplanted to the main field. After sowing the seeds, it was irrigated manually daily in the morning.

3.4.4 Procedure for the installation of drip system and fertigation unit

In order to install the system in the field, proper land preparation was done. After the land preparation, trenches were taken to lay the main line. Water was pumped through 7.5 kW motor pump set and conveyed through the main line of 90 mm diameter PVC pipes after filtering through the screen filter. From the main pipe, sub main of 75mm diameter PVC pipes were installed. From the sub main, laterals of 16mm diameter LDPE were installed. Each lateral was provided with individual tap to control the irrigation. The laterals with inline drippers of 4 lph discharge and 40 cm spacing were placed at three different depths of 10, 20 and 30 cm below the soil surface. Laterals were placed in between two rows per plot. The discharge rate of single dripper was 4 litres per hour. End caps were provided at the end of each lateral line for closing of the line and also for flushing and checking the proper functioning of the system. The system was checked for its best operation. After installation, trial run was conducted to access the mean discharge rate.

3.4.5 Mulching

Mulching is a relevant practice for soil moisture conservation. When compared to other mulches, plastic mulches are completely impermeable to water and it therefore prevents the direct evaporation of moisture from the soil. It thus limits the water losses and soil erosion over the surface. Fertigation along with mulching helps to achieve both the objectives of efficient utilization of available water and the conservation of soil moisture. Effective control of weed growth is also attained under this system. Drip irrigation with plastic mulching is a standard recommendation for controlling the weed growth, reducing the evaporation and increasing the water use efficiency. Hence in this study, black plastic mulch sheet of 30 micron was used for covering the soil. Black mulch sheet of 12m length and width of 1.2 m was used in each plot.

3.4.6 Transplanting

Transplanting was done on 20th October 2012. Before planting, black mulch sheets of 30 micron were spread in all plots except the control treatment. In the mulched plots, holes of 10 cm diameter were punched evenly at 40 cm × 40 cm grid points on the LDPE sheets. Seedlings were then planted in these holes. The transplanting was done at a spacing of 40 cm × 40 cm with 60 plants in each plot. The total plant population was 1800 numbers. Intercultural operations were carried out thrice, at 20, 35 and 55 days after transplanting followed by two hand weeding.

3.4.7 Irrigation requirement

For better establishment of seedlings, immediately after transplanting, irrigation was given manually. Amaranth kannara local requires about 2litre/day/plant. The discharge rate of the inline dripper was 4 lph. The time required for irrigation in order to get 2 litre/day/plant was calculated.

3.4.8 Fertilizer application

Recommended dose of fertilizer was applied as per treatments in sixteen equal splits at four days interval through fertigation. Nitrogen, phosphorus and potassium were the main nutrients required for the growth and these was applied *Rajphos* as a basal dose, urea, multi K and *polyfeed* (19:19:19) through dosmatic fertigation unit. Fertilizer requirement for different treatments were shown in Table. 2

Plate 5. Bed preparation and mulch sheet fixing

Plate 6. Mulch sheet hole making

Plate 7. Prepared beds for transplanting

Plate 8. Seedlings for transplanting in the field

Plate 9. Transplanting of amaranthus seedling

3.4.9 Fertigation Scheduling

The fertigation was given at four days intervals. Nitrogen and potassium were applied through fertigation with sixteen equal splits from five week to thirteenth week after planting. Water soluble fertilizers were used in this experiment. The recommended dose of fertilizer requirement for the amaranth crop was 50:50:50 kg/ha. The recommended soluble fertilizers were applied through drip irrigation to the plant root zone. The calculated amount of urea and polyfeed (19:19:19) fertilizerswere applied through fertigation. The applied dose of N, P and K for amaranth is given in Table 2.

Table 2. Fertilizer requirement for Amaranthus per bed

(Recommended dose of N: P: K is 50 : 50 : 50 kgha^{-1})					
Treatment (%)	**Fertilizer required (g)**				
	Urea (46 : 0 : 0)	Polyfeed (19 : 19 : 19)	Multi K (13 :0 :44)	Potash (0 : 0 : 50)	Rajphos
120	9.6	22	36	8.4	
100	8.0	18	30	7	
80	6.4	14.5	24	5.6	
Control	8.0			7	9

3.5 Vertical and horizontal advance of water

3.5.1 Horizontal wetting front with respect to time

One hour after the irrigation, from the dripper to the soil surface, the horizontal advance of water front as a function of time was noted by using a measuring scale.

3.5.2 Vertical wetting front with respect to time

The wetting front profile was measured exactly below the dripper position as a function of time by using a measuring scale from 1 hr after irrigation. Measurements were taken at the vertical section of the wetted soil volume downward.

3.6 Collection of experimental data

3.6.1 Biometric observations

For analyzing the growth pattern of the crop, three plants were selected randomly from the net plot area in each treatment and were tagged to record the variations. The parameters and procedures followed are given as follows

3.6.1.1 Girth of the plant

The average girth of the randomly selected plants grown under each treatment was taken. The measurement was taken at the bottom of the selected plants in a weekly interval.

3.6.1.2 Number of leaves per plant

Numbers of leaves per plant were counted in randomly selected three plants in a weekly interval.

3.6.1.3 Root length

Root length of the plant was taken for different lateral depths and in control.

3.6.1.4 Yield (kg/ha)

Harvesting of the crops was done after attaining maturity. After the first harvest, other harvests were done at an interval of 7 days. The first yield was taken one month after transplanting. The total of the seven harvests were taken.

3.7 Statistical Analysis

Statistical analysis was done by analysis of variance. Analysis was compared between the treatments.

3.8 Determination of Fertilizer use efficiency

The fertilizer use efficiency was computed as described

$$\text{FUE} = \frac{\text{Yield (kg/ha)}}{\text{Total quantity of nutrient applied (kg/ha)}}$$

Plate 10. Harvesting of amaranthus

RESULTS AND DISCUSSION

The study has been undertaken with the objectives to optimize the fertigation level and the depth of laterals under subsurface drip irrigation for amaranthus under plastic mulching and work out the cost economics of the drip system for amaranthus. The results obtained from the study were analyzed to provide basic information of different fertigation level and depth of lateral under subsurface drip irrigation and its performance on growth and yield of crop. The results of the study were discussed in this chapter

4.1Hydraulics of In line Drip Irrigation System in the Field

4.1.1Discharge variation in inline emitters

The discharge variation in inline drip irrigation system was calculated. The pressure applied for operating the system was 1 kg/cm^2 and discharge was measured by using catch cans for three repeated trials. The value shows that the discharge is around 3.9 lph ~4 lph.

4.1.2 Horizontal advance of soil moisture front

The horizontal advance of soil moisture front with elapsed time for 4 lph in line emitter was noted. The Fig.3 shows that initially 1 hr after irrigation, the horizontal movement was about16 cm, and 24 hr after irrigation it is about 18 cm.The data obtained is shown in Table 3.

4.1.3 Vertical advance of soil moisture front

The vertical advance of soil moisture front with elapsed time for 4 lph in line emitter was noted. The Fig.4 shows that initially after 1 hr vertical advance was about 14 cm and 24 hr after irrigation it was about 30 cm. The data obtained was shown in Table 3.

Table 3.Vertical and horizontal advance of water

Elapsed time (min)	Horizontal advance (cm)	Vertical advance (cm)
60	16	14
300	16.2	16.7
780	17	22.3
1200	17.5	28
1380	17.8	29.3
1440	18	30

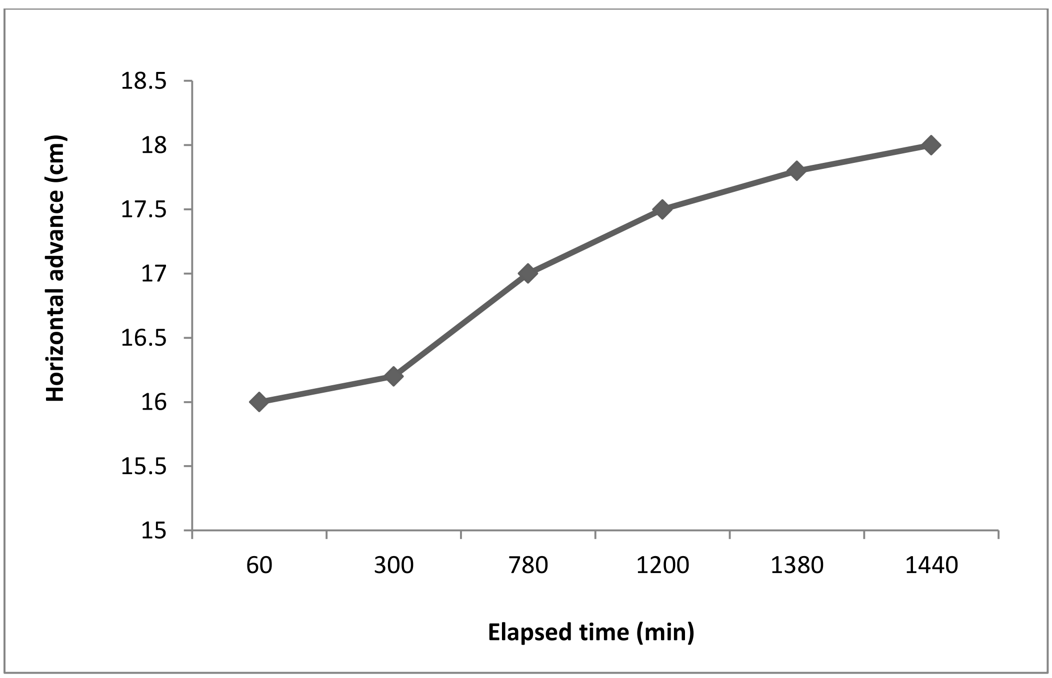

Fig. 3 Horizontal advance of water front with elapsed time

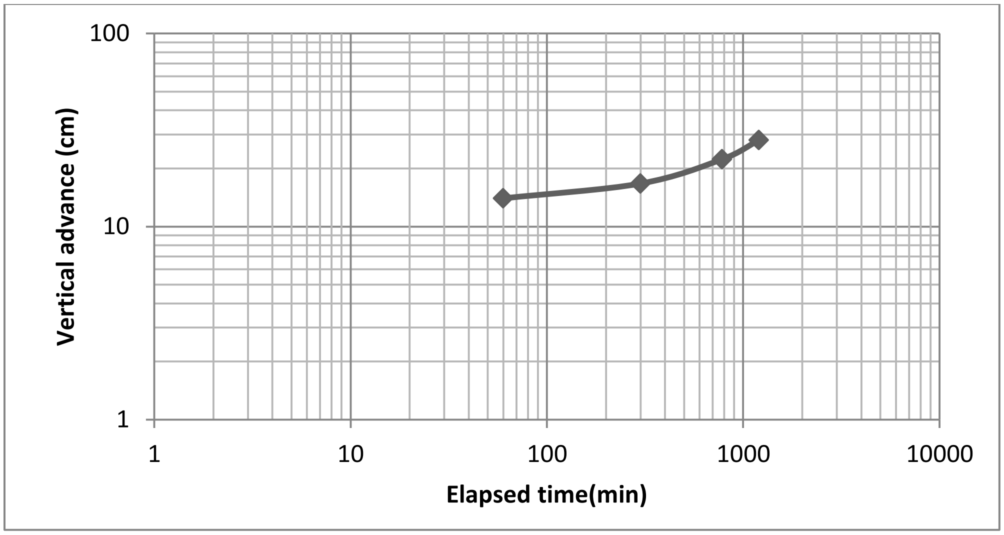

Fig. 4 Vertical advance of water front with elapsed time

4.2 Biometric Observations

4.2.1 Stem girth

The observation on stem girth was first taken two weeks after planting. After that, the observations were taken in a weekly interval. The influence of different fertigation levels and lateral depth on stem girth is shown in Fig.5. The readings were taken up to 7 week after transplanting shown in appendix I. The maximum value obtained in the case of stem girth was observed for the treatment T_2 (5.6 cm) and the treatment T_1 (5.3cm). From the first observation onwards, it is clearly seen that maximum stem girth was observed in case of T2 and T1, i.e., 100 and 120% fertigation level with in line lateral at 10 cm depth, compared to other treatments. The minimum value is seen for the treatment T_8 (4.2 cm) i.e., 30 cm lateral depth with 100% fertigation level. Statistical analysis was done using Analysis of Variance (ANOVA). The analysis shows that the stem girth at different days after planting did not differ significantly with respect to the different treatments shown in Table 4. The analysis also shows that for the stem girth, there was no significant difference in between replications and treatments.

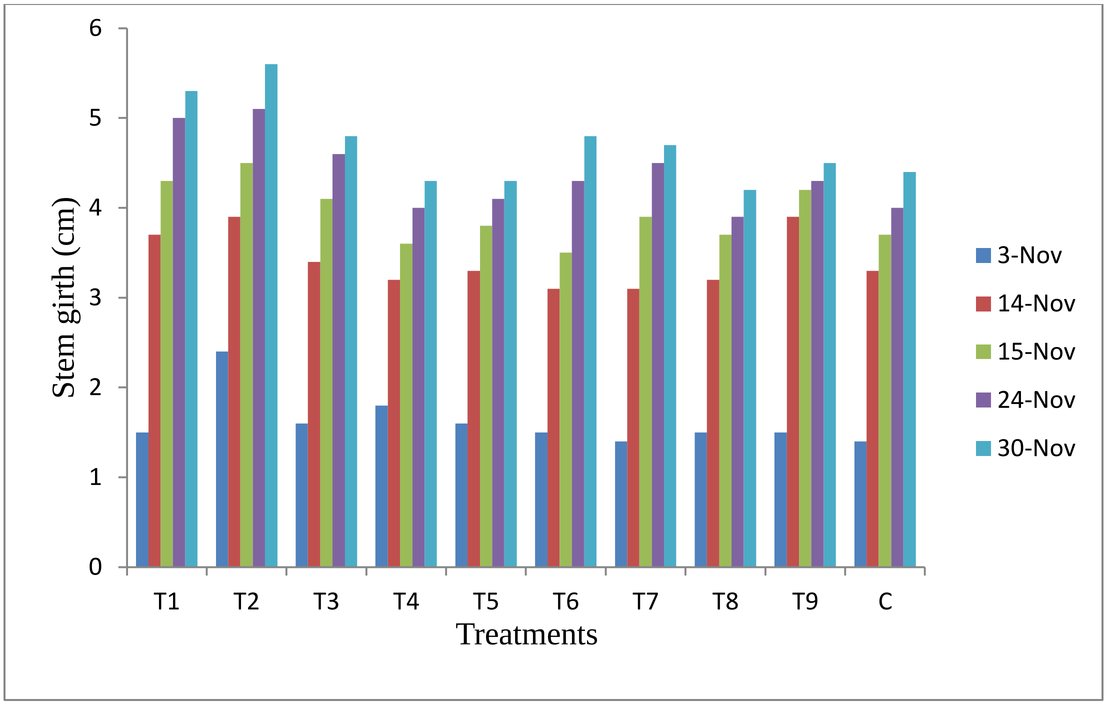

Fig.5 Variation of stem girth with days in different treatments

Table 4. Analysis of variance for stem girth

Source	DF	SS	MS	F Ratio	Tab- value	Remarks
Block	2	1.07	0.54	4.37	3.63	NS
Treatment	8	240	0.30	2.44	2.59	NS
Error	16	1.97	.12			
Total	26	5.44				

4.2.2 Number of leaves

The observation on number of leaves was first taken two weeks after planting. After that, the observations were taken in a weekly interval. The influence of different fertigation levels and depth of laterals on number of leaves is shown in Fig.6. The readings were taken up to 7 week after transplanting. The number of leaves with different treatments, different levels of fertigation and lateral depth is shown in Fig. 6

The maximum number of leaves was observed for the treatment T_2, i.e., 100% fertigation level with in line lateral at 10 cm depth. The minimum number of leaves was seen in control. From the first observation onwards, it is clearly seen that maximum number of leaves was observed in case of T_2 i.e., 100 % fertigation level with in line lateral at 10 cm depth, compared to other treatments. The minimum value is seen for the control in almost all observations followed by T_4 and T_8. In case of fertigation, it was observed that maximum fertilizer utilization is at a depth of 10 cm. More number of leaves was noted in treatments T2, T1 and T3 in almost all observations. i.e., in the case of laterals at a depth of 10 cm. As amaranthus is a leafy vegetable, fertilizer is mainly used for producing more leaves. The maximum root zone of amaranthus is about 45-60cm, having fibrous root system, more extraction of water and fertilzer is happening in upper 25% of the root zone area, i.e, up to 15 cm depth. The study clearly indicates that, for different fertigation levels, more extraction of fertilizer, we can see in 10 cm depth compared to 20 and 30 cm depths. But there were no significant variations in number of leaves in other treatments, i.e., with 20 and 30 cm depths. This result is in agreement with Rama Kant *et al.* (1998) studies on the soil moisture extraction pattern of spring and summer pruned mulberry gardens. They reported that maximum water was extracted from the upper layer of root zone.

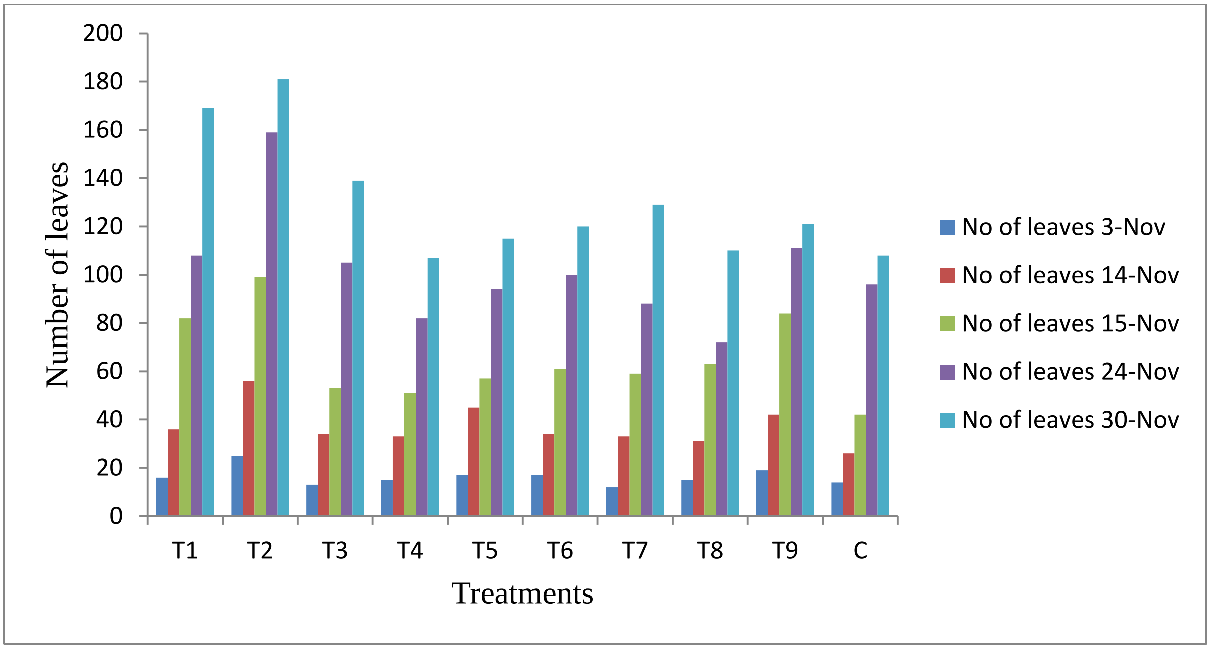

Fig.6. Variation of number of leaves with days in different treatments

Table 5. Analysis of variance for number of leaves

Source	DF	SS	MS	F Ratio	Tab- value	Remarks
Block	2	62.77	31.38	7.16	3.63	NS
Treatment	8	4930.81	616.35	140.63	2.59	*
Error	16	70.13	4.30			
Total	26	5063.70				

The statistical analysis was done by ANOVA. From the ANOVA table, shown in table 5, it is understood that the number of leaves at different days after planting differ significantly with respect to the different treatments. The number of leaves was influenced by both fertigation level and depth of laterals. From that T_2 was showed significant difference as compared to other treatments. The treatment T_2 has 100% fertigation level and 10 cm lateral depth. There was a high variation showed by T_2 over control.

4.2.3 Root length

A comparative view of root development in subsurface irrigation and surface irrigation is shown in plate 11. It is clearly seen that the water has distributed all along its roots. The maximum vertical root length was found to be 34cm and horizontal root length of 19 cm for surface irrigation. For subsurface irrigation, the vertical root lengths observed are 14, 28 and 33cm and horizontal root lengths are 8, 12, 15 cm for 10, 20 and 30 cm of lateral depth respectively. This is because in subsurface drip irrigation system, the roots growth is more rapid and more number of fibrous roots can see near to lateral to absorb the water and nutrients effectively. In all the cases the level of irrigation was 2 litres/ day/ plant.

Control	**30 cm lateral depth**	**20 cm lateral depth**	**10 cm lateral depth**

Plate 11. Roots of amaranthus of three lateral depths and control

4.2.4 Yield of amaranthus

The observation on yield was first taken 30 days after planting and is shown in the appendix III and later the yield was taken at weekly interval. The average yield in t/ha in different levels of fertigation and drip system layout in a weekly interval is shown in Fig.7, 8, 9, 10, 11 and 12.

In the first harvest at 30 days after planting, the high yield was observed for treatment T2 (0.6 t/ha) and the plants in the control plot were not matured enough to harvest. This is in agreement with Sivanappan and Natarajan (1976) revealed that 26 per cent yield increase on tomato due to drip irrigation compared to surface irrigation. In the case of treatment T1 and T2, the number of leaves was also more as compared with the other treatments. Therefore the average total yield was also more in the case of treatments T1 and T2. In the case treatments T1 and T2 the depth of laterals was at 10 cm. So the yield obtained also increased due to higher moister extraction. This result is in agreement with Rama Kant *et al.* (1998) studies on the soil moisture extraction pattern of spring and summer pruned mulberry gardens. They reported that maximum water was extracted from the upper layer of root zone. In control treatment, conventional practices were followed and yield per beds were observed minimum when compared to other treatments, fertigation with plastic mulching. This is in agreement with the Singh *et al.* (2001) who indicated that the biometric growth of the treatments irrigated at 60 percent level through drip system with plastic mulching performed better yield. Almost similar variations were found in the case of other harvests also shown in fig.8 to 12.

From the fig13, it is seen that the maximum values of total yield was observed for the treatment T2, then T1 and T3 (which have 10 cm lateral depth). Among these three treatments T2 (8.51 t/ha) shows high yield. The treatment T1 (7.41 t/ha) has 120% fertigation level, T2 has 100% fertigation level and T3 (7.21 t//ha) has 80% fertigation level. In treatments T4,T5 & T6, i.e, laterals at 20 cm depth, in different fertigation levels, total yield varies between 5.53 to 6.3 t/ha and in treatments T7,T8 and T9, i.e, laterals at 30 cm depth, total yield ranges between 6.11 to 6.4 t/ha, almost similar to 20 cm depth. The total yield was less in control plot, only 4.59 t/ha. It is seen that in all fertigation levels, maximum yield was obtained at in line laterals in 10 cm depth.

In statistical analysis, it was found that the treatments T1 and T2 were on par with T3, but other treatments were significantly varies with T1, T2 and T3. Statistical analysis is shown in Table 6. Even though, maximum yield was obtained in T2, as per the statistical analysis, difference in yield was not that much significant between T2 and T1 and T2 and T3. In treatment T3, 80 % fertigation level, it is possible to save 20% fertilizer. Hence, this study suggested that treatment T3, i.e, 80 % fertigation level, is better because it needs less amount of fertilizer than T1 and T2. This shows the saving of 20 per cent of fertilizer in T3 with a better yield as compared to the other treatments.

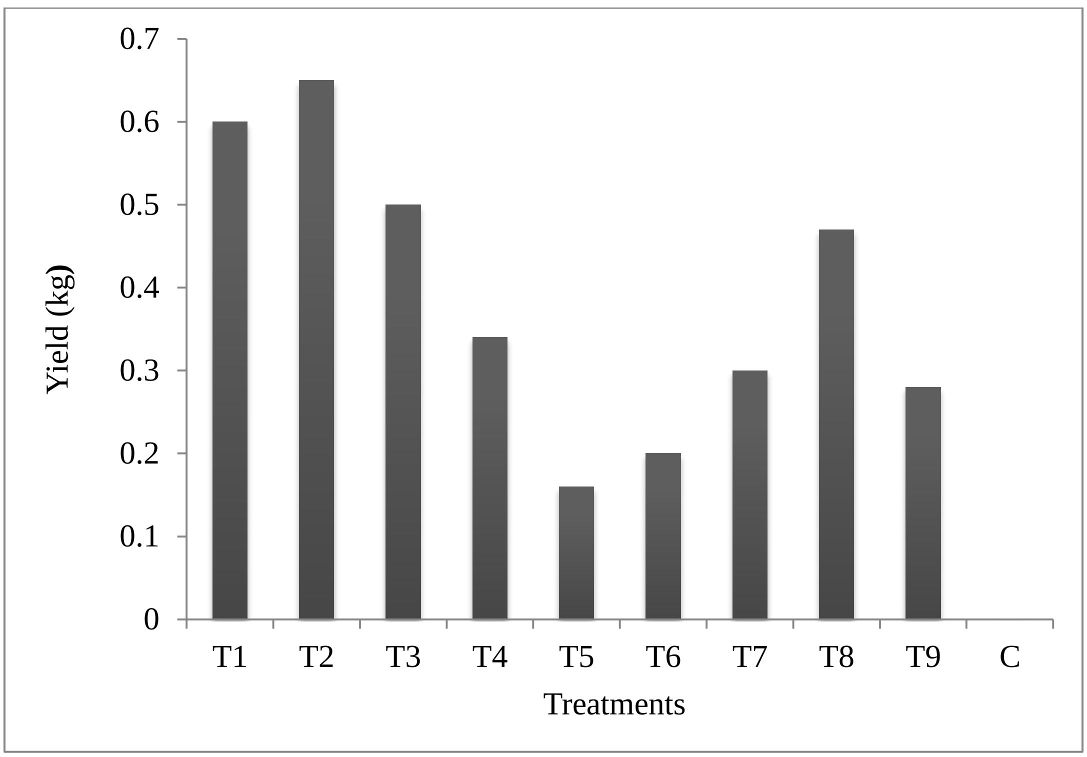

Fig.7 Variation of yield in different treatments after first harvest

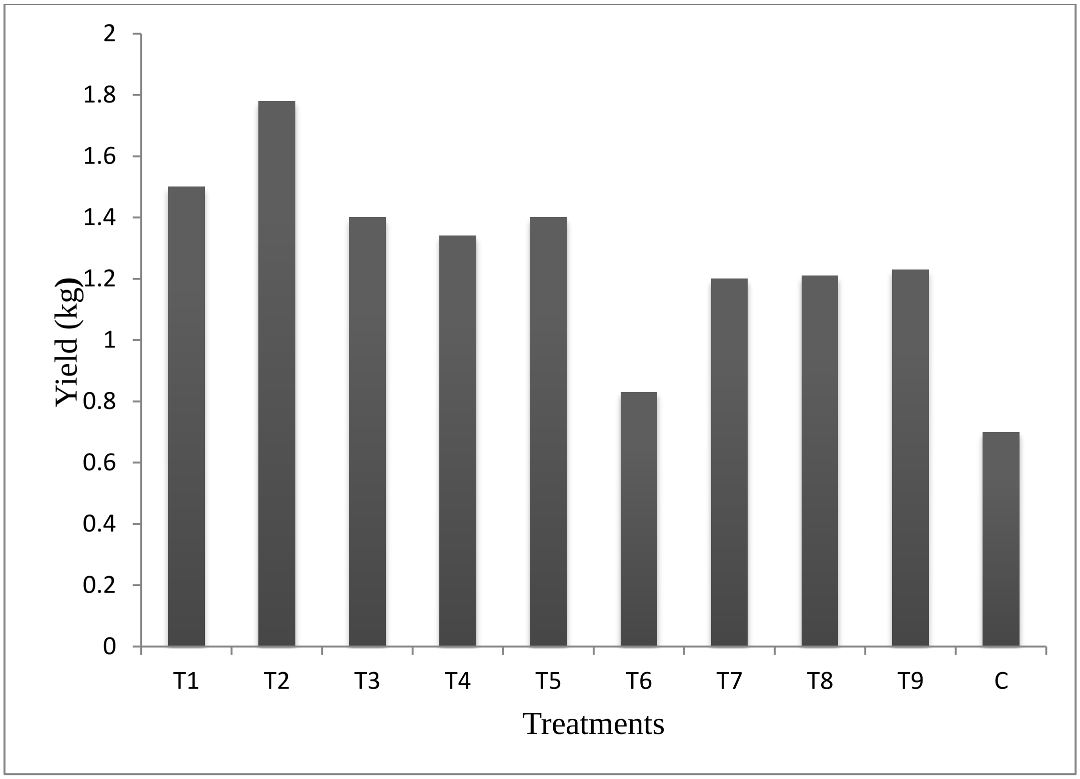

Fig.8 Variation of yield in different treatments after second harvest

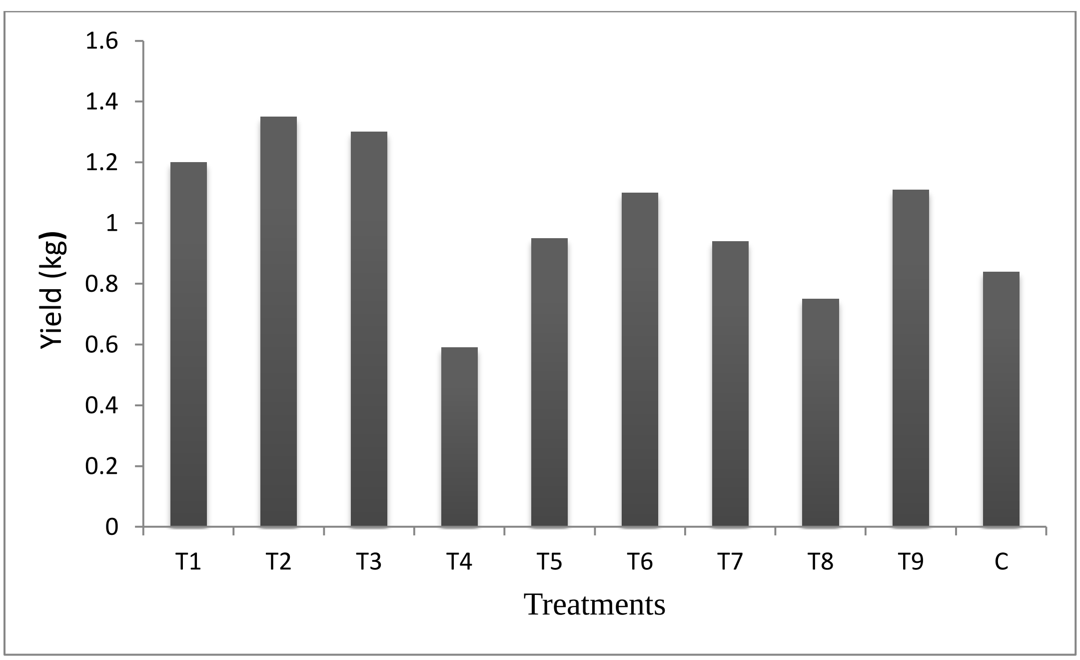

Fig.9 Variation of yield in different treatments after third harvest

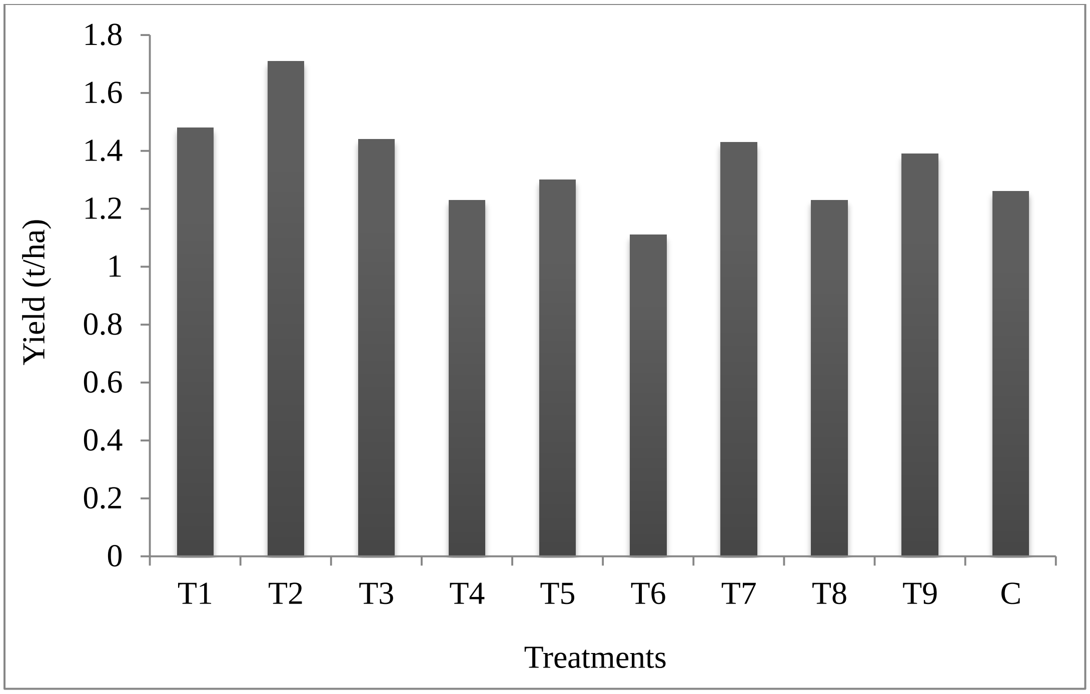

Fig.10 Variation of yield in different treatments after fourth harvest

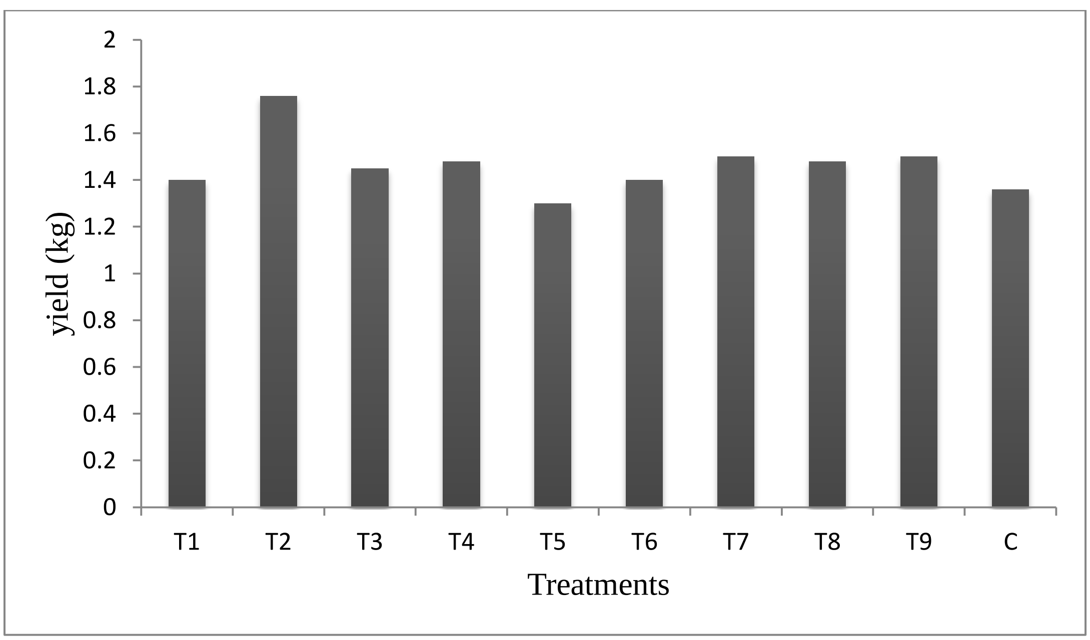

Fig.11 Variation of yield in different treatments after fifth harvest

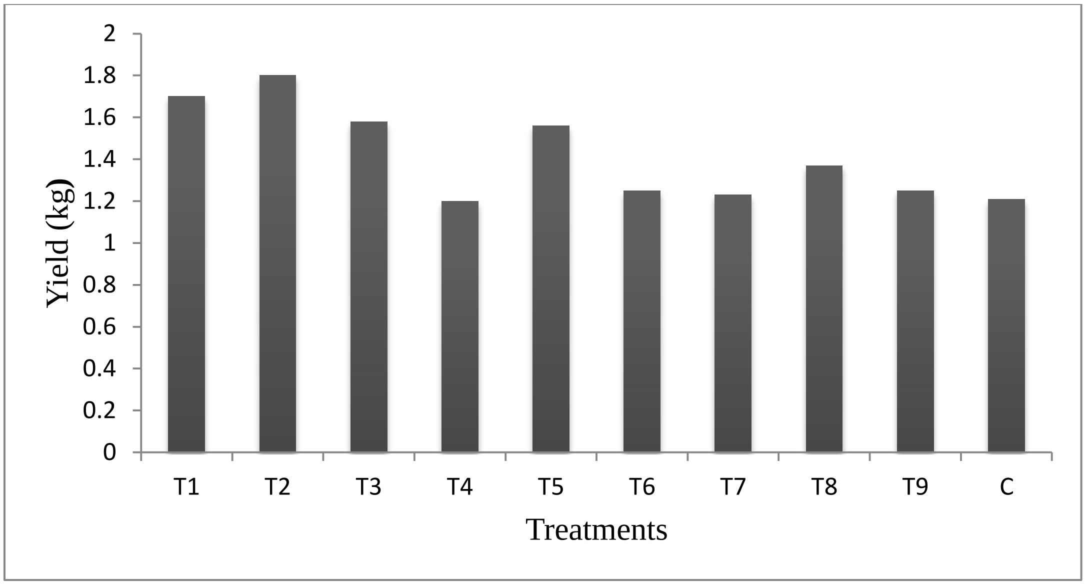

Fig.12 Variation of yield in different treatments after sixth harvest

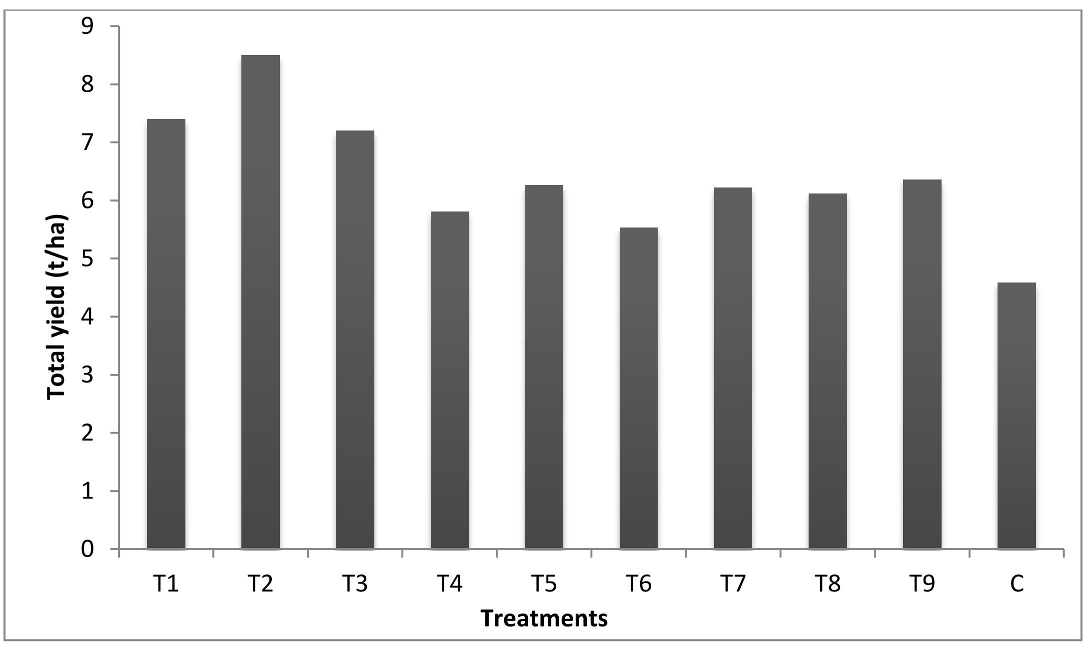

Fig.13 Variations of total harvesting yield of amaranthus in different treatments

Table 6. Analysis of variance for yield

Source	DF	SS	MS	F Ratio	Tab- value	Remarks
Block	2	229.75	114	0.49	3.63	NS
Treatment	8	17796.13	2224.52	9.49	2.59	*
Error	16	3749.75	234.30			
Total	26	21775.63				

3.4.10 Fertilizer use efficiency

The fertilizer use efficiency in amaranthus crop is presented in the Table 7. Increased FUE such as Nitrogen use efficiency (NUE) and Potassium use efficiency (KUE) with the decreased levels of fertilizer doses were observed in the amaranthus crop. The highest NUE of 318.11kg of produce / kg of N was recorded in the treatment T3 i.e., 80% fertigation with lateral depth at 10 cm. For the treatment T2 the NUE of 300.7kg of produce / kg of N was recorded and for the T1 it was about 217.9 kg of produce / kg of N. The lowest NUE was observed in the case of control and was about 183.2 kg of produce / kg of K.

The similar trend was observed in KUE in amaranthus crop. The maximum KUE of 441.1and 417.1 of kg of produce / kg of K was observed in the case of the treatment T3 and T2. The lowest KUE was observed in the case of control and was about 225.0 kg of produce/kg of K. The study shows that maximum fertilizer use efficiency was observed in case of T3 i.e., 80% fertigation level with inline lateral at 10 cm depth, compared to other treatments.

Table 7. Fertilizer use efficiency for amaranthus crop

Treatments	Fertilizer applied kg/ha		Yield kg/ha	NUE kg of produce / kg of N	KUE kg of produce / kg of K
	N	K			
T1	3395.04	2448	7400	217.9	302.2
T2	2829.2	2040	8510	300.7	417.1
T3	2263.36	1632	7200	318.11	441.1
T4	3395.04	2448	5810	171.13	237.3
T5	2829.2	2040	6260	221.2	306.8
T6	2263.36	1632	5530	244.3	338.8
T7	3395.04	2448	6220	183.2	254.0
T8	2829.2	2040	6110	215.9	299.5
T9	2263.36	1632	6350	280.5	389.0
Control	2829.2	2040	4590	162.2	225.0

4.3 ECONOMICS OF SUBSURFACE DRIP FERTIGATION SYSTEM

The economic of the system was worked out by making the following assumptions.

1. The number of crops raised per year was considered as three.
2. The life span of the drip irrigation system was taken as 7 years and the total cost of drip was divided equally for the seven years.
3. The life span of motor was taken as 5 years.
4. Land preparation is done by labour with full day wage taken as Rs.300.
5. The spacing is taken as 40 x 40 cm and the number of plants in 10.8 m^2 is taken as 60.
6. Soluble fertilizers are completely used for the experimental plot and not for the control plot.

The amaranthus yield, gross income (₹/ha), net returns (₹/ha) and Benefit Cost ratio of amaranthus as affected by the level of fertigation requirement and lateral depth were determined.

Table 8. Cost of materials used for the subsurface drip fertigation system for an area of one hectare

Description	Unit	Quantity	Amount, ₹
PVC pipe 90mm	m	54	5508/-
PVC pipe 75mm	m	164	3780/-
Laterals with inline dripper	m	9000	127350/-
Control valve	75mm	2nos	300/-
Dosmatic fertigation unit	¾’’	1 nos	10000/-
Screen filter	10 m^3/hr	1nos	2500/-
Fitting and accessories			4000/-
Total			**1,53,438/-**

Table 9. Cost of inputs used for the subsurface drip fertigation systems for an area of one hectare

Description	Quantity	Amount, ₹
Mulch sheet	10000 m	30500/-
Potash	0.8 kg	16/-
Urea	0.7 kg	5 /-
Rajphose	0.3 kg	6/-
19:19:19	4 kg	320/-
Multi k	3.3 kg	250/-
Total		**40097/-**

Table 10. Cost of labour charges for 3 season crop

LABOUR COST	Amount, ₹
Installation Charges	30000/-
land preparation	5000/-
Bed formation	7000/-
Laying Mulch sheet	2000/-
Nursery preparation	1500/-
Transplanting	10000/-
Fertilizer application	4000/-
Fertigation	10000/-
Harvesting	10000/-
Total	**79500/-**

Total fixed cost for drip fertigation system = ₹1,53,438/-

Consider life span as 7 years

Total Annual fixed cost for drip fertigation system = ₹21920/-

Cost of 2hp motor pump set and accessories = ₹5500/-

Consider life span as 10 years

Annual fixed cost for motor = ₹550/-

Total fixed cost = ₹22470/-

Total cost for planting materials = ₹80000/-

Cost of fertilizers and chemicals = ₹40097/-

Labour costs = ₹79500 /-

Total variable cost = ₹202597/-

Total annual cost **= ₹222067/-**

Total income from crop after 1 year three crops **= ₹ 573750/-**

B/C ratio of the drip fertigation system **= 2.6**

Table 11. Benefit Cost Ratio for different treatments

Treatments	Total yield (t/ha)	B/C
T1	7.4	2.2
T2	8.51	2.6
T3	7.2	2.18
T4	5.81	1.76
T5	6.26	1.9
T6	5.53	1.54
T7	6.22	1.89
T8	6.11	1.85
T9	6.35	1.93
Control	4.59	1.39

The total annual cost for the subsurface drip fertigation system was ₹222067/- and the total income from the crop production after 1 year three crop was ₹573750/-. The benefit cost ratio determined as 2.6. The benefit cost ratio for each treatment with the assumption made as explain earlier is presented in Table 11. The benefit cost ratio treatment T2, 100% of fertigation requirement with lateral depth at 10 cm was 2.6. The benefit cost ratio for T1 was 2.2 and T3 was 2.18. The benefit cost ratio for control was minimum i.e., 1.39. Subsurface drip fertigation with plastic mulching is cost effective as compared to surface irrigation without plastic mulching.

SUMMARY AND CONCLUSION

The study entitled "Optimization of fertigation level and depth of lateral under subsurface drip irrigation for amaranthus" was aimed to optimize the fertigation level, the depth of laterals under subsurface drip irrigation for amaranthus under plastic mulching and work out the cost economics of the drip system for amaranth.

A plot of size 32x13 m^2 was selected for the study. The field was ploughed and plots of size 12x0.9 m^2 of 30 numbers were made. The laterals were laid at three depths viz. 10, 20 and 30 cm from the ground surface and plastic mulch was used for covering the bed. The three fertigation levels viz. 80%, 100% and 120% were used for the study. The variation in emitter discharge rate and vertical and horizontal advance of soil moisture front was studied. The result shows that vertical advance of moisture front was maximum i.e., 30 cm, 24 hr. after irrigation compared to horizontal advance of 18 cm. This is because in sandy loam soil, movement of water is more in vertical compared to horizontal. The data on number of leaves, stem girth and yield were taken in a weekly interval, 30 days after transplanting.

The maximum number of leaves was observed for the treatment T2, i.e., 100% fertigation level with in line lateral at 10 cm depth. The minimum number of leaves was seen in control. From the first observation onwards, it is clearly seen that maximum number of leaves was observed in case of T2 i.e, 100 % fertigation level with in line lateral at 10 cm depth, compared to other treatments. The minimum value is seen for control in almost all observations followed by T4 and T8. In case of fertigation, it was observed that maximum fertilizer utilization is at a depth of 10 cm. More number of leaves was noted in treatments T2, T1 and T3 in almost all observations. i.e., in the case of laterals at a depth of 10 cm. In the statistical analysis, it was observed that, there were significant variations between treatments. The number of leaves was influenced by both fertigation level and depth of laterals. From that T2 was showed significant difference as compared to other treatments. The treatment T2 has 100% fertigation level and 10 cm lateral depth.

The maximum value obtained in the case of stem girth was observed for the treatment T2 (5.6 cm) and the treatment T1 (5.3cm). From the first observation onwards, it is clearly seen that maximum stem girth was observed in case of T2 and T1, i.e, 100 and 120% fertigation level with in line lateral at 10 cm depth, compared to other treatments. The minimum value is seen for the treatment T8 (4.2 cm). The maximum yield was observed for the treatment T2 (8.51 t/ ha), 100% of the fertigation requirement with 10 cm of lateral depth. Statistical analysis shows that stem girth at different days after planting did not differ significantly with respect to the different treatments. The data shows that for the stem girth, there was no significant difference in between replications and treatments.

The maximum vertical root length was found to be 34 cm and root zone length of 19 cm for surface irrigation. For subsurface irrigation, the vertical root lengths observed are 14, 28 and 33cm and the horizontal root lengths are 8, 12 and 15 cm for 10, 20 and 30 cm of lateral depth respectively. This is because in subsurface drip irrigation system, the roots growth is more rapid and more number of fibrous roots can see near to lateral to absorb the water and nutrients effectively.

The maximum values of yield were observed for the treatment T2, then T1 and T3 (which have 10 cm lateral depth). Among these three treatments T2 (8.51 t/ha) shows high yield. The treatment T1 (7.41 t/ha) has 120% fertigation level, T2 has 100% fertigation level and T3 (7.21 t/ha) has 80% fertigation level. In treatments T4,T5 & T6, i.e., laterals at 20 cm depth, in different fertigation levels, yield varies between 5.53 to 6.3 t/ha and in treatments T7,T8 and T9, i.e., laterals at 30 cm depth, yield ranges between 6.11 to 6.4 t/ha, almost similar to 20 cm depth. The yield was less in control plot, only 4.59 t/ha. It is seen that in all fertigation levels, maximum yield was obtained at in line laterals in 10 cm depth.

Even though, maximum yield was obtained in T2, as per the statistical analysis, difference in yield was not that much significant between T2 and T1 and T2 and T3. In treatment T3, 80 % fertigation level, it is possible to save 20% fertilizer. Hence, this study suggested that treatment T3, i.e., 80 % fertigation level, is better because it needs less amount of fertilizer than T1 and T2.

Increased FUE such as Nitrogen use efficiency (NUE) and Potassium use efficiency (KUE) with the decreased levels of fertilizer doses were observed in the amaranthus crop. The highest NUE of 318.11kg of produce / kg of N was recorded in the treatment T3 i.e., 80% fertigation with lateral depth at 10 cm. For the treatment T2 the NUE of 300.7kg of produce / kg of N was recorded and for the T1 it was about 217.9 kg of produce / kg of N. The lowest NUE was observed in the case of control and was about 183.2 kg of produce / kg of K. The similar trend was observed in KUE in amaranthus crop. The maximum KUE of 441.1and 417.1 of kg of produce / kg of K was observed in the case of the treatment T3 and T2. The lowest KUE was observed in the case of control and was about 225.0 kg of produce / kg of K. The study shows that maximum fertilizer use efficiency was observed in case of T3 i.e., 80% fertigation level with inline laterals at 10 cm depth, compared to other treatments.

The total annual cost for the subsurface drip fertigation system was ₹222067/- and the total income from the crop production after 1 year for three crop was ₹573750/-. The benefit cost ratio obtained was 2.6. The benefit cost ratio for the treatment T2, 100% of fertigation requirement with lateral depth at 10 cm was 2.6. The benefit cost ratio for T1 was 2.2 and T3 was 2.18. The benefit cost ratio for control was minimum i.e., 1.39. Comparing with the benefit cost ratio between T2, T1 and T3, it was found that there was not much difference in ratios. Hence the treatment T3 i.e., 80% fertigation level with 10 cm lateral depth that shows comparatively better yield with maximum fertilizer use efficiency. Hence, this study suggested that treatment T3, i.e, 80 % fertigation level with 10 cm lateral depth, give comparatively better yield with maximum fertilizer use efficiency was more effective for amaranthus cultivation.

Subsurface drip fertigation with plastic mulching is cost effective as compared to surface irrigation without plastic mulching.

The specific conclusions that are drawn out from the current study are:

1. The subsurface drip fertigation under plastic mulching is a good option as compared with traditional methods.
2. For amaranthus, 10 cm lateral depth with 80% fertigation level under plasti mulching is more effective.
3. Benefit cost ratio obtained as 2.6

Scope for further study

1. This study can be extended by using different irrigation levels.
2. This study can be modified by using different fertigation units.
3. This study can also be done under green house.

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APPENDIX I

Stem girth (cm) at different days as influenced by 10 treatments

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	C
3 Nov	1.5	2.4	1.6	1.8	1.6	1.5	1.4	1.5	1.5	1.4
10 Nov	3.7	3.9	3.4	3.2	3.3	3.1	3.1	3.2	3.9	3.3
17 Nov	4.3	4.5	4.1	3.6	3.8	3.5	3.9	3.7	4.2	3.7
24 Nov	5	5.1	4.6	4	4.1	4.3	4.5	3.9	4.3	4
30 Nov	5.3	5.6	4.8	4.3	4.3	4.8	4.7	4.2	4.5	4.4

APPENDIX II

Number of leaves at different intervals of days as influenced by 10 treatments

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	C
3 Nov	16	25	13	15	17	17	12	15	19	14
10 Nov	36	56	34	33	45	34	33	31	42	26
17 Nov	82	99	53	51	57	61	59	63	84	47
24 Nov	108	159	105	82	94	100	88	72	111	96
30 Nov	169	181	139	107	115	120	129	110	121	108

APPENDIX III

Yield (t/ha) of amaranthus as influenced by different treatments

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	C
First harvest	0.56	0.60	0.46	0.31	0.15	0.19	0.28	0.43	0.26	0.00
Second harvest	1.39	1.65	1.30	1.24	1.30	0.77	1.11	1.12	1.14	0.65
Third harvest	1.11	1.25	1.20	0.55	0.88	1.02	0.87	0.69	1.03	0.78
Fourth harvest	1.48	1.71	1.44	1.23	1.30	1.11	1.43	1.23	1.39	1.26
Fifth harvest	1.30	1.63	1.34	1.37	1.20	1.30	1.39	1.37	1.39	1.26
Sixth harvest	1.57	1.67	1.46	1.11	1.44	1.16	1.14	1.27	1.16	1.12

APPENDIX IV

Total yield (t/ha) of amaranthus

	T1	T2	T3	T4	T5	T6	T7	T8	T9	C
Total yield (t/ha)	7.40	8.50	7.20	5.81	6.26	5.53	6.22	6.11	6.35	4.59

ABSTRACT

The study “Optimization of fertigation level and depth of lateral under subsurface drip irrigation for amaranthus” was taken up with the objective to optimize the fertigation level and the depth of laterals under subsurface drip irrigation for amaranthus and workout the cost economics. The effect of different fertigation levels and depth of laterals under plastic mulch on the performance of Amaranthus (*Amaranthus hypochondriacu,* variety: kannara local) were studied. The observations on number of leaves, stem girth root length and yield were taken. The number of leaves, root length and yield showed significant difference between the treatments. The yield showed significant difference with different levels of fertigation and depth of laterals. Maximum yield of 8.51t/ha was observed for the treatment T2. The yield for treatments T1 was 7.41 t/ha and T3 was 7.2 t/ha. Even though, maximum yield was obtained in T2, as per the statistical analysis, difference in yield was not that much significant between T2 and T1 and T2 and T3. The treatment T3 is of 10 cm lateral depth with 80 per cent fertigation level. The study suggested that treatment T3 is better due to the fact that it gives higher crop yields with substantial saving in fertilizer usage. The benefit cost ratio treatment T2, 100% of fertigation requirement with lateral depth at 10 cm was 2.6. The benefit cost ratio for T1 was 2.2 and T3 was 2.18. The benefit cost ratio for control was minimum i.e., 1.39. Comparing with the benefit cost ratio between T2, T1 and T3, it was found that there was not much difference in ratios. Hence the treatment T3 i.e., 80% fertigation level with 10 cm lateral depth that shows comparatively better yield with benefit cost ratio of 2.18. The study shows that maximum fertilizer use efficiency was observed in case of T3 i.e., 80% fertigation level with inline laterals at 10 cm depth, compared to other treatments. Hence, subsurface drip irrigation of 10 cm lateral depth with 80 per cent fertigation level under plastic mulching for amaranthus is a good option as compared to 20 and 30 cm lateral depth with 80, 100 and 120% of fertigation levels.