Performance Assessment of Surface and Subsurface Drip Irrigation System for Crops and Fruit Trees

Ph.D Thesis

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Performance Assessment of Surface and Subsurface Drip Irrigation System for Crops and Fruit Trees

By

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07-UET/PhD-CE-28

Thesis submitted in partial fulfilment of the requirement for the Degree of Doctor of Philosophy in Water Resources and Irrigation Engineering

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March-2011
Dedicated

To Almighty Allah without whose support and blessing, this task was not possible. To My Beloved Father whose decent and inspiring personality always encouraged me to face real hard task in this world. May Almighty Allah rests his soul in peace and Heaven. Ameen
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Declaration

The substance of this thesis is original work of the author and due references and acknowledgements have been made, where necessary, to the work of others. No part of this thesis has been already accepted for any degree and not being currently submitted in candidature of any degree.

Engr. Talat Farid Ahmed

07-UET/PhD-CE-28
ABSTRACT

The continuous increase in population the water demand by agriculture, domestic and industrial sectors have caused great stress on world water resources. Population in emerging countries is expected to grow; 4.3 billion in 2002, 5.5 billion in 2025 and 6.2 billion in 2050. For the least developed countries these figures will be 0.8, 1.1 and 1.6 respectively. Agriculture sector consumes about 70-72 % of total water resources. Average irrigation efficiency of the world is 37%. The water resources of Pakistan are under immense stress due to increased agricultural expansion, population growth and associated urbanization and industrialization. The gap between water demand and supply is growing rapidly. Based on current population growth rate, the shortage of water in country will increase to 50% in 2025. To overcome this shortage of water, adoption of efficient water saving techniques is the need of day and future food security. The current study was carried out to evaluate the appropriateness of surface and subsurface drip irrigation system for crops and fruit trees. The efficiency of these irrigation systems in relation to yield, yield to water ratio and economic viability of drip irrigation systems under different cropping schemes and varying flexibility drip pipes were also carried out. Three field experiments were conducted, one in greenhouse and two in open field area at Al-Qassim (Buraidah), Saudi Arabia. Under these experiments, surface and subsurface drip irrigation systems were studied in detail in crops and fruit trees. Important parameters of these systems such as hydraulic performance of flexible drip pipes used, water consumption, yield of crop/fruit, yield to water ratio of crop/fruit and cost analysis of surface and subsurface drip irrigation type under crops and fruit trees were determined. The yield under vegetable crop from the subsurface drip irrigation system was found to be 28% and 25% (Notorah and Red rock varieties of tomatoes) more than that from the surface drip irrigation system. The yield under fruit trees from the subsurface drip irrigation system by using three varying flexible drip pipes (Low, medium and high) and was found to be 42% and 49% more than that from medium and high flexible drip pipes, while under surface drip irrigation system, it was found 46% and 51% more from medium and high flexible drip pipes. The water use efficiency of subsurface drip irrigation system is much more than that of surface drips irrigation system in both vegetable crops as well as in fruit tree because all water utilized by plant in case of subsurface drip irrigation but as for surface drip
irrigation system partly utilized by plant and partly evaporated, Bigger wetted volume of soil in root zone was observed in the case of subsurface drip irrigation while it is smaller wetted volume of soil in case of surface drip irrigation system. Further investigation of subsurface drip irrigation system needs to be undertaken for other crops and fruit trees to confirm the benefits of the use of low flexible drip pipes.
### Nomenclature

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<td>ASAE</td>
<td>American Society of Agricultural Engineer</td>
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<tr>
<td>AW</td>
<td>Applied Water</td>
</tr>
<tr>
<td>ADI</td>
<td>Alternate irrigation</td>
</tr>
<tr>
<td>Br</td>
<td>Bromide</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon mono oxide</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
</tr>
<tr>
<td>Cl</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Co₃</td>
<td>Carbonate</td>
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<tr>
<td>CWSI</td>
<td>Crop water stress index</td>
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<tr>
<td>CV</td>
<td>Coefficient of variation of emitter discharge</td>
</tr>
<tr>
<td>CU</td>
<td>Christiansen uniformity coefficient</td>
</tr>
<tr>
<td>CVₗ q</td>
<td>Emitter coefficient of flow variation</td>
</tr>
<tr>
<td>CVₗ hs</td>
<td>Soil variation coefficient of variation</td>
</tr>
<tr>
<td>CDI</td>
<td>Conventional drip irrigation</td>
</tr>
<tr>
<td>DN</td>
<td>Nominal Diameter</td>
</tr>
<tr>
<td>DSS</td>
<td>MIRRIG Model for design of microirrigation system</td>
</tr>
<tr>
<td>ETo</td>
<td>Reference Evapotranspiration</td>
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<tr>
<td>Etc</td>
<td>Crop Evapotranspiration</td>
</tr>
<tr>
<td>E1</td>
<td>Emitter with turbulent flow</td>
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<tr>
<td>E2</td>
<td>Emitter with laminar flow</td>
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<tr>
<td>E3</td>
<td>Emitter with online pressure compensating flow</td>
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<tr>
<td>EU</td>
<td>Emission uniformity</td>
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<td>ES</td>
<td>Early season</td>
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<td>FAO</td>
<td>Food Agriculture Organization</td>
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<td>FI</td>
<td>Furrow irrigation</td>
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<td>FDS</td>
<td>Family drip system</td>
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<tr>
<td>Gph</td>
<td>Gallon per hours</td>
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<td>GRN</td>
<td>Gross return nitrogen</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HCo₃</td>
<td>Bi-Carbonate</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>HFDP</td>
<td>High Flexible Drip Pipe</td>
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<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
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<tr>
<td>Ha</td>
<td>Hectare</td>
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<tr>
<td>IE</td>
<td>Irrigation Efficiency</td>
</tr>
<tr>
<td>ICID</td>
<td>International Centre of Irrigation and Drainage</td>
</tr>
<tr>
<td>IS</td>
<td>Multiple in-season</td>
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<tr>
<td>IWUE</td>
<td>Irrigation water use efficiency</td>
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<tr>
<td>K</td>
<td>Potassium</td>
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<tr>
<td>KPa</td>
<td>Kilo Pascal</td>
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<td>KPK</td>
<td>Khyber Pakhtunkhwa</td>
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<td>LFDP</td>
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<tr>
<td>LDPE</td>
<td>Low Density Polyethylene</td>
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<td>MFDP</td>
<td>Medium Flexible Drip Pipe</td>
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<tr>
<td>Mg</td>
<td>Magnesium</td>
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<tr>
<td>MAF</td>
<td>Million Acre feet</td>
</tr>
<tr>
<td>Mil</td>
<td>unit of measurement equal to one thousandth of an inch (.001”).</td>
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<tr>
<td>Na</td>
<td>Sodium</td>
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<tr>
<td>N</td>
<td>Nitrogen</td>
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<tr>
<td>Oxygation</td>
<td>Aerated irrigation water</td>
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<tr>
<td>PWP</td>
<td>Pakistan Water Partnership</td>
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<tr>
<td>PE</td>
<td>Polythylene</td>
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<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
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<tr>
<td>P</td>
<td>Phosphorus</td>
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<tr>
<td>PMDI</td>
<td>Precision mobile drip irrigation</td>
</tr>
<tr>
<td>rft</td>
<td>Running Foot</td>
</tr>
<tr>
<td>SDI</td>
<td>Subsurface drip irrigation</td>
</tr>
<tr>
<td>SSD</td>
<td>Subsurface drip</td>
</tr>
<tr>
<td>SD</td>
<td>Surface drip</td>
</tr>
<tr>
<td>TDS</td>
<td>Total Dissolve Salts</td>
</tr>
<tr>
<td>TSE</td>
<td>Treated sewage effluent</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nation Environment Program</td>
</tr>
<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
</tr>
<tr>
<td>V0</td>
<td>Without irrigation</td>
</tr>
<tr>
<td>V1</td>
<td>Intensive irrigation</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<td>V2</td>
<td>Economical irrigation</td>
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<tr>
<td>WWAP</td>
<td>World Water Assessment Programme</td>
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<td>WUE</td>
<td>Water use efficiency</td>
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<td>Y</td>
<td>Yield</td>
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6.7 Comparison of Dates Production Per Tree Per m$^3$ of Water Consumption under Three Drip Pipe Types and under Subsurface Drip Irrigation System
1.1 Introduction

More than 70% of our Earth surface is enclosed by water: so due to this name of our planet would be revised from “Earth” to “Ocean”. Even though water is copious, but actually factual matter is the quantity of accessible freshwater. Salt water on Earth is about 97.5% of all water, while rest 2.5% of freshwater. More than 70% of this as freshwater is present in the shape of frozen ice caps of Antarctica and Greenland, rest is present as soil moisture, or is in deep underground aquifers, which is not accessible for human use (Figure 1.1 and 1.2). Less than 1% of freshwater on the globe, this is 0.007% of Earth water used directly accessible to humans. The freshwater is available in lakes, rivers, reservoirs and aquifers that are low enough to be carrying out at reasonable cost. Rain and snow causes it’s frequently renewal. Only this kind of water is accessible on sustainable basis. Improvement need is required in the efficiency of water used for irrigation system, which is presently lost more or less 60% of all pumped water, before it comes to planned agricultural activities. By using latest knowledge and effective management may even extend limited water to a large extent. For example, Israel helped its people, its rising industrial need, and rigorous irrigation with only 500 m$^3$ for one individual in a year. Water is frequently exhausted due to it is undervalued. Subsidies for agricultural use is still applied in developed and in developing countries. As an example removal of subsidies and give permission to increase in water prices can give incentives for protection and investment looked for the dissemination of more efficient technologies. In main European countries like Germany and France, the renewable water resources per capita have up to two times more, which is from 2,300-3,000 m$^3$. a lot of renewable water resources lies in The United States, in comparison with India, China and foremost European countries. They have 9,800 m$^3$ for one person in a year. Some writers reported that Russian Federation and Brazil have biggest renewable water resources with ranging from 31,900 - 42,500 m$^3$ for one person in a year (L.S.Postel, et al, 1996).
Figure 1.1: Global water distribution and breakdown of fresh water resources and their use

Source: unwater.org
Pakistan is becoming a country, short of water that its contribution has dropped significantly from 5650 m$^3$ to 1,200 m$^3$ per person in a year during five decades. Water shortage is a possible hazard for agricultural sector which helps to achieve near 21 per cent in gross domestic product. Less than 1,000 m$^3$ per person per year will be available in 2025, which would make the area of water scarcity. If water situation continue like this then country may lose about 60 percent of our water per year, particularly for those area having poor ground water quality and not useable. Although Pakistan water resources has increased in the past four decades because of construction of dams, canals and use of groundwater, as area under irrigation increased, yet the development of water resources not in such a way, as increasing population growth rate. Experts reported that even though Pakistan had biggest irrigation network system, however highest water losses were observed from this system. Water is a key factor sustainable agricultural yield, economic growth and environmental security. Although Pakistan has copious water resources, yet it has been afflicted with common low income, hunger and low human growth index. The only way out to overcome this situation is to increase water productivity by adopting modern and efficient technologies for sustainable agriculture, which in turn lead to reduced poverty to some extend through amplified agricultural output and profitability, improved food safety and making of large jobs. Large water reservoirs are the need of the day (Khan Israr, 2010).
Water resources of Pakistan are under considerable stress due to agricultural expansion, population growth and urbanization and industrialization shareholders. The gap between water demand and supply is growing rapidly. Based on current population growth rate, there would be 21% shortage of water in the year 2011 will increase to 50% in 2025 as shown in Table 1. Two three-pronged strategies are proposed to manage the water resources of Pakistan: (i) construction of new large / medium reservoirs and (ii) the conservation of water resources through efficient use. There is potential for the construction of large as well as small dams in the country, however, it involves huge investment and the national consensus. Other options that can be adopted are appropriate technologies for conserving water and using non-conventional water resources such as rainwater (PWP, 2000).

<table>
<thead>
<tr>
<th>Description</th>
<th>Year 2001 (MAF)</th>
<th>Year 2004 (MAF)</th>
<th>Year 2011 (MAF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Water Available at Farm gate:</td>
<td>134.39</td>
<td>134.88</td>
<td>146.92</td>
</tr>
<tr>
<td>Surface water</td>
<td>84.34</td>
<td>84.86</td>
<td>96.90</td>
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<tr>
<td>Groundwater</td>
<td>50.05</td>
<td>50.02</td>
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<tr>
<td>Water Requirement:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Irrigation</td>
<td>135.1</td>
<td>143.3</td>
<td>169.6</td>
</tr>
<tr>
<td>– Other Uses</td>
<td>5.9</td>
<td>6.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Total</td>
<td>141</td>
<td>149.8</td>
<td>178.4</td>
</tr>
<tr>
<td>Shortfall</td>
<td>5%</td>
<td>11%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Table 1.1 Present & Future water availability and demand

Source: (PWP, 2000)

Globally Agriculture is being considered the major water resources user. In some arid countries like Kingdom of Saudi Arabia consumed 90% of total annual water for its agriculture. It could be the main cause for water degradation due to lack of proper water management, therefore, it is a time demand for its efficient use in agriculture sector and The utmost priorities should be given to managing of water to stop contamination of water, which causes worsening, quality of water. For this context, trickle irrigation system is most feasible
as well as successful applications of water for irrigation system in comparison with other irrigation techniques (Al-Amoud A.I., 2000).

1.2 Strategies to Overcome Water Shortage

To increase the efficiency of irrigation water is one of economically viable alternatives to overcome water scarcity. This is not only vital for sustainable agricultural productivity, but also to meet the challenges of environmental issues and justice, financial problems and physical barriers in developing countries. To overcome these situations modern irrigation techniques for high efficiency irrigation system like drip or center pivot irrigation system can be used. Keeping in view the world water scenario for depleting water resources for domestic and agriculture for water scarce countries like Kingdom of Saudi Arabia, a strategy would be needed for its efficient use/management to meet water shortage challenges and ensure food security.

- Development of additional storage facilities - inherited problems / conflicts and long-term interventions.
- Improve system efficiency in all - dominated by the different institutional and management complexities.
- Technology Resource Conservation - promoting the adoption and need at the micro level: in the short term, but sustainable option:
  - On efficient irrigation and farming techniques / practices.
  - Reuse of wastewater.
  - Rainwater to alleviate water shortages

The term trickle, drip or micro irrigation is an irrigation technique, which reduced water use and fertilizer by permitting water to flow little by little to roots of plants either onto the soil surface, named as surface drip irrigation or directly onto the root zone, through a network of valves, pipes, tubing, and emitters, named as subsurface drip irrigation system. Which are suitable for arid and semi arid areas where other water sources of water are scarce. In the developing countries like Asia and Africa, the method of subsurface drip irrigation has not been due to its high initial cost and doubt over its life span. But, as for its rising adoption trend concern about water saving and its security features, growers are looking for more effective irrigation techniques.
1.3 Pakistan – Drip Irrigation Potential

Pakistan is rapidly moving from being a water strained country to water scarce country reported by World Bank in its 2006 report due to high population growth rate trend and resulted water becomes a burning issue for country development. The majority of the water infrastructure like some of the main barrages is in deprived condition and the whole arrangement of water management is not economically viable. Groundwater is over pumped and polluted in many areas. But Pakistan has excellent environmental conditions for agriculture like good soil, sunshine and hard worker farmers on its larger parts, which could help to triumph over a lot from existing flow. Pakistan lies among the 25 most populous countries list like South Africa, Egypt having limited water. But, regarding per capita renewable water resources of India and China are not far behind from these countries, which are 1,600 and 2,100 cubic meters per year. Pakistan is facing numerous challenges in water sector due to water deficiency, rising demand for agriculture, domestic water users and industry, environment, scheme efficiency, increased working and maintenance costs and low operational and management cost recovery, small outcome from land and water, old and unreliable irrigation systems, decreasing reservoir capacities due to sedimentation and constant drought conditions. So only way to overcome these problems, there is a need of launching/introducing high efficiency irrigation systems to i.e. drip or sprinklers irrigation.

Pakistan has great potential for practical system of drip irrigation as described below (Khan Israr, 2010).

- Irrigated areas (Punjab, Sind, KPK, Balochistan): 30-40%
- Rainfed areas (Punjab, Sind, KPK, Balochistan): 60%
- Desert areas: (Punjab, Sind): 70-80%
- Coastal areas: 70%
- Hill Torrents: 20%

There are many methods developed for supplemental irrigation for crops and fruit trees. Among these methods, performance evaluation of drip irrigation method of surface and subsurface irrigation under control of water application for crops and fruit trees was the objective of this study. Considering the importance of water under present water scenario and food security, a comparison is needed to know the efficient and economical viable irrigation technique among the available modern irrigation systems. Two methods were selected for this comparison is: i) surface drip irrigation system, ii) subsurface drip irrigation system
1.4 Need of the Study

Nobody can deny the importance of drip irrigation system; either it is surface or subsurface for the development of agriculture particularly in the growth of Date Palm tree, which is the most popular fruit crop of Saudi Arabia. More than 19 million date palm trees are present and there is a still tendency for increasing its number every year. In 1999, 0.71 million tonnes date yield was obtained from 0.141 million hectares of land. If the development of date palm tree plantation continues at this prevailing rate in the country, then large amount of water for irrigation would be forecast for new plantation. As Saudi Arabia has scarce water resources so it is significant to adopt efficient water saving irrigation methods such as recently introduced drip irrigation systems either surface or subsurface drip. So, necessary studies under this water shortage scenario may be conducted with the objective to evaluate actual water is needed for date palm tree which help to know a correct application amount of irrigation water without excessive use.

1.5 Objectives of the Study

Keeping in view the best and efficient utilization and management of scarce available water resources for development of agriculture in Saudi Arabia, three field experiments were designed for crop and fruit trees with the following objectives;

- Evaluation of drip irrigation system for surface and subsurface in crops/fruit trees under scarce water situations areas.
- Evaluation of varying flexibility drip pipes performance used in surface and subsurface drip irrigation systems.
- Efficiency of these drip irrigation systems in relation to water, yield and yield to water ratio.
- Economic viability of drip irrigation systems under different cropping schemes.

1.6 Scope of the Study

As international and national food requirement is likely to increase with increase in population. On the other hand water availability for food production is gradually shrinking. Shortage of water has turn out to be the only major threat to food security, human health and natural ecosystem. The only way to match higher food production with declining water resources seems
to be optimization of available water resources through efficient water management. Application of micro irrigation particularly drip irrigation system has not only demonstrated a great saving of water and fertilizer but also increase in crop and fruit tree yield and improvement of quality of produce.

Keeping in view the present and future water scenario and food security the present study was initiated and designed for arid climate countries like Saudi Arabia and it will equally helpful for Pakistan, who is also facing shortage of water for agriculture. The outcome of this comparative study would provide base source to judge the best and efficient drip irrigation system for crop and fruit tree in arid climate. This study would not only provide a recommended efficient drip irrigation system for crop and fruit tree as well as would provide a guideline for the planning, design and development of a drip irrigation system and its efficient operation. Scope of the study is not limited to small scale but it would be useful for areas with shortages of water for irrigation. The developed procedure could be applied in predicting the extent of drip irrigation system planning and preliminary design of irrigation system development projects and irrigation system development in hydrologically homogeneous regions by using these surface and subsurface drip irrigation methods.
CHAPTER NO 02

Surface and Subsurface Drip Irrigation
2.1 General
Among other natural resources, water resources have a unique position. On our world water is the main extensively distributed substance. It contributes a key role in the human life and surrounding environment. It exists, the world over in different quantities. Fresh water is the most important among them. No activity of human beings and life itself is impossible without it, because it cannot be replaced by anything. The human being is still using fresh water and uses for its wants. About 1.4 billion km$^3$ water is available on our earth. On our earth approximately 35 million km$^3$ freshwater resources are present or nearly 2.5 percent of total volume, the distribution is shown in Figure 2.1 (UNEP, 2001).

Due to global warming, snow and ice in the Himalayas, which give huge quantity of water for agriculture in Asia, is estimated to reduce 20% by the year 2030. At present Irrigated agriculture contributes 40% food production worldwide. Irrigation increases crops yields from 100-400 % but poor drainage and irrigation practices have led to water logging and salinization of about 10% of irrigated land in the worldwide (UNDP, 2006).

Natural resources are tends to depletting due to exceeding demand and consumption ratio. As a result of over pumping and demanding human activity, water quality is worsening in the sources. By considering worldwide population of 8 billion and with a raise of 2 billion dollars and as a common situation of business-as-usual, with enhance in water exploring of 22% over 1995 levels is predicted by 2025. It means irrigation demand raise to 17%, 20% demand for industrial water and 70% demand for municipalities’ water. Global warming spells out such water shortage (Rosegrant W. Mark et al., 2002).
Figure 2.1: Global distribution of the world’s water

Source: UNESCO, the United Nations World Water Development Report 2
Steps for better management of water, more effectively support sustainable agriculture using less irrigation water and chemical pesticides. In other words, replace the traditional methods of irrigation, such as the basin, furrow or border irrigation, which consumes more water resulting with less efficiency of irrigation. The high efficiency irrigation includes center pivot sprinklers, drip or trickle irrigation, surface and subsurface drip irrigation. Different options of high efficiency irrigation system like online drip system, inline drip system, mini sprinkler and high flow bubbler. These methods are suitable for arid / semi-arid areas where other water sources are scarce. These methods successfully achieved adoptability worldwide. The actions based on the use of natural control mechanisms of the water cycle must be supported by technical means that enable to collect excess water during the heavy rainfall season and to apply during dry period.

2.2 Surface Drip Irrigation System – World Practice

2.2.1 Introduction

The word trickle, drip, and spray irrigation is familiar in various areas over the world for the past 15 years, have been supplanted by the term micro irrigation and just adopted by the American Society of Agricultural Engineers. Micro irrigation includes all methods of common water use for irrigation, with minute flow rates, on or below the soil surface. Preferably quantity of water is applied directly to the root zone in quantities, which move toward for the use of plant consumption (Haman, D.Z and Izuno, T.F., 2003).

Drip irrigation is the sluggish and exact application of water method for chosen plantings. Flexible polyethylene tubing with devices is being uses for dripping water by emitters and low volume sprays. The drip irrigation methods are simple to fix, no trenching require, and the only requisite tools are pruning shears and a punch. An ideal moisture level in the root zone of plants is maintained by this irrigation method and restricted too wet or too dry swings, mainly of overhead application of water. These systems are managed by a self control timer device or manually and can also be used for fertilizers application directly to plants roots. These methods are being widely used and useful for all kinds of landscape, mainly shrubs, trees, perennial beds, ground covers, annuals, and lawns. It is the best choice to irrigate roof gardens, containers on decks and patios, row crops, kitchen gardens, orchards, and vineyards. Drip irrigation methods are feasible for a variety in size, from a small number
of hanging baskets to several thousand acres of crops.

Methods of drip irrigation refer to any irrigation system which applies water in the soil very gradually. Currently, this technology is the most effective from water and energy consumption point of view. Technique of drip irrigation is a system of pipes with tiny holes, which permit water to move over the plants root zone. It is an irrigation system that saves water. Drip irrigation is an effective and targeted irrigation method, where water is given as drops directly on the plants roots with exact rates. Drip irrigation uses a hose or tube perforated with small holes to carry water drop at a time directly into the soil around each plant. Drip irrigation is an irrigation method by which plants are kept hydrated by perforated pipes above or just below ground. These techniques have been developed to keep plants hydrated with as little water as possible. It is an irrigation system, having controlled delivery of water directly to individual plants through a network of tubes or pipes.

### 2.2.2 Past Development and Use

In ancient age Middle East farmers developed an efficient method to irrigate desert trees by using minimum water application. They observed that most of the water seeps away from the plant and did not reach the roots, when it was provided directly to the plants. As a remedial measure, they buried a rough mud pot near the tree. Instead of watering the plant directly they used to fill it with water regularly to channelize the flow of water properly. Water seeped into the roots zone slowly through the mud walls of the pot and created a bed of wet soil around the tree. The watering of dessert plant in this manner resulted in the healthier crops and fruits for the farmers. A research was undertaken at Colorado State University by EB House in 1913, concluded that slow irrigation could help in providing water to plants root zone more effectively. The German scientists developed a controlled irrigation system with the help of a perforated pipe in 1920. However, none of these systems proved as efficient as modern drip irrigation technology. With the introduction of the modern plastic molding technique and cheap polyethylene tubing in 1950 gave a new shape and boost up microirrigation technology first time in England and France. However, Symcha Blass, a retired employee of British Water Agency can easily be said to be the father of drip irrigation system. He applied his expertise in micro tubing to develop an effective and advance drip method. He formally marketed his system in 1959 and the emitter used in that system is regarded as the first
precursor of today’s drip irrigation method.

The first drip tape termed as Dew Hose was initially developed by Richard Chapin Watermatics during early 1960s in United States and at the same time, first drip irrigation system was recognized during 1964. Jain Irrigation Company contributed a lot and led the way for valuable management of water by drip irrigation in India in 1989. Jain Irrigation also introduced several drip irrigation promotion approaches to Indian farming sector as "Integrated Systems Approach", One-Stop-Shop for growers, and “Infrastructure Status to Drip Irrigation and Farm as Industry”. Modern advancements in the field resulted even further lessening in drip rates being delivered and fewer tendencies to obstruct.

The method of drip irrigation was being used usefully, as very old tradition in certain parts of India to water tulsi plants kept in the courtyard. The plant was watered by an overhanging pot having water and a little outlet at its base to allow water trickling on the plant, during the summer season. In the state of Arunachal Pradesh, tribal growers exercised an ancient shape of drip irrigation system by means of a trim bamboo as the waterway for flow of water. Drip irrigation system has occupied a phenomenal area of irrigated land during the last 15 years which comes to 0.35 million hectare, while it was just 40 hectares in 1960. The states of Maharashtra, Karnataka and Tamil Nadu are the major contributors in this regard. The system is mainly used for irrigating trees, vine crop, vegetables, field crops, flowers etc. and other corps (Research Bulletins, 2009).

### 2.2.3 Present Development and Use

In the late 1960s several farmers of America and Australia adopted a new drip irrigation technology to irrigate their farm lands, which resulted in decreased water consumption by 30 % to 50 %. However, the system was used for commercial landscaping in 1980s. The adoption of this technology also resulted in reduced labor costs and weeds growth on the one hand and enhanced yield on the other. The system has been very successfully applied to sugar cane plantation in the hilly terrains of Hawaii, where producer’s have totally abandoned the sprinkler system and have shifted to low flow drip irrigation system. This conversion from
sprinkler system to drip irrigation system took 16 years with total cost of $30 million. One plantation spanned 37000 acres of drip irrigated sugarcane field.

The expansion process has spread during 1960s in Australia, North and South America and now it is used worldwide, mainly in high risk areas of water scarcity and desert areas to raise yield and save precious water. A drip irrigation project is being run by an agricultural community, which provides programs of drip irrigation with vegetables and other crops in Masvingo, Zimbabwe. Growers can grow now three crops in a year, of which at least one of vegetables due to drip irrigation method. Method of drip irrigation is also being practiced in China, Turkey, India, Colombia, Ecuador, Haiti, Egypt and a number of other third world countries, mostly worked under the guidelines of the World Bank, USAID, Engineers for a Sustainable World, the United Nations and a number of other organizations.

Drip irrigation method had been used from ancient time. Ancient people knew how to irrigate their crops and they made it in possible by any means. Finally these people got solution that how to put these pots in the ground near the plants. These pots had minute openings in them which intercept rainwater and allow it to run away gradually near the plants. At last researchers in 1866 work out a complete irrigation system using pipes, they got some minor victory. Plastic was used frequently worldwide after Second World War. Due to popularity of plastic and its frequent use, an Australian inventor got the idea to use plastic to hold and distribute water to his crops. To make distribution of irrigation water more even, Hannis Thill developed a technique for water movement, which was released by mean of an extended passageway in the tubing to ensure supply more even. Netafim is Prime Corporation who deals totally with drip irrigation and they took Thills concept and formed an emitter which allows water distribution to crops as efficiently as possible. Drip irrigation system may be operated through a control panel having a timer to irrigate crop automatically without remembering to irrigate their plants like many other systems. Microirrigation systems can be operated with fresh rainwater unlike other systems. Collected rain water would be distributed through the irrigation lines. This system has some demerits like emitters blockage, so keeps it regular clean or use proper filter on it to avoid emitter clogging. There is a good idea prior to start drip irrigation system, check and ensure that none of the drip emitters are blocked.
Today’s latest drip irrigation kits use a tube or pipe system having drippers at exact distances to give water from a tap. In order to atomize the system, the user needs to attach a timer to the device to properly regulate the supply of water as per need of a particular plant. This gives a suitable way out for orchard irrigation, particularly, if not available on holiday. There are many advantages of drip irrigation especially if analyzed from commercial point of view. The yield is generally higher as the way the water is properly provided in a gentler way and so avoids soil erosion. The nutrients and fertilizers are directly injected to roots zone without any leakage from this method, which results reduction in cost, healthier plants, and saving money on fertilizers. Similarly, the foliage remains dry due to direct supply of water to root system that prevents crop diseases. In other techniques the danger of crop failure due to wet foliage is always looming on the horizon. There are a variety of irrigation attachments types, which can be used for effective results in different kinds of crops, which provide ample opportunities to the farmers to choose the peculiar equipment which suited their respective crops to the optimum. Micro sprinkler system frequently change dripper heads for trees and vines due to wideness of root distribution and these plants types required, a extra extensive irrigation technique, creating a versatile method of watering plants for garden or a field crops.

Souza F, et, al. in 2009, were performed an experiments to separate dynamics and trend of soil solution inside wet bulb developed, due to drip irrigation methods under marginal water quality. To examine potassium nitrate (KNO₃) and water distribution from drippers delivering water at regular flow rates of 2, 4 and 8 L h⁻¹ in soil-filled containers with the help of time-domain reflectometry sensors were used. In different profiles, greater solute storage near the dripper, that gradually decreasing towards the wetting front was observed. They suggested on the basis of quantity and frequencies applied that apply little quantity of solution at more frequent intervals, resulted to lessen deep percolation losses of applied water and solutes would be beneficial (Souza F, et. Al., 2009)

A long term investigation was performed by Halil et, al., (2009) to identify the response of second crop of watermelon under water stress on yield and crop water stress index parameters for drip irrigated. On the basis of replenishment of soil water depletion of 100, 75, 50, 25, and
0%, from 90 cm soil depth, at 3-day irrigation gap, an irrigation scheduled was prepared. Due to irrigation water stress, yield was significantly reduced. 1.14 was average water-yield response factor during whole study period. Under full irrigation application maximum yield ranging from 34.5 and 38.2 t ha$^{-1}$ in first and second year was obtained. Water stress effected canopy dry weights, leaf relative water content, and total leaf chlorophyll content. Values of yield and seasonal ET were linearly correlated with mean CWSI values (Halil Kirnak and Ergun Dogan, 2009)

On oleic sunflower, a long term study was designed by applying five saline water applications levels like 1.6, 3.9, 6.3, 8.6, and 10.9 dS/m, to evaluate effects and strategies of drip irrigation method. Results showed that with the increase of irrigation water salinity level, amount of applied water decreased, plant height and yield decreased with the increase in irrigation water salinity level. The yield decreased ~2 % for every 1 dS/m increase in irrigation water salinity level, and irrigation water use efficiency increased with the increase of irrigation water salinity level. They found that saline water could safely be used to irrigate oleic sunflower through drip irrigation even at 10.9 dS/m irrigation water salinity level at or above ~20 kPa soil matric potential with 0.2 m directly under drip emitter in mulched beds (Ming, et.al., 2009).

Under normal and paired-row sowing methods on green pepper, a field study was conducted to detect the response of different levels of drip irrigation and sowing methods on yield and yield components like number of fruits, number of primary and secondary branches per plant, and plant height for three irrigation levels ($I_{50}$, $I_{75}$ and $I_{100}$ of $ET_c$ ). It was found that in normal sowing method gave high yield and yield components than paired row sowing method in both $I_{50}$ and $I_{75}$ irrigation levels. Results indicated that paired row sowing method, with the application of $I_{100}$ irrigation level, could be used for green pepper yield in water shortage area. It was also found that average yields found from the $I_{75}$ irrigation level for paired row sowing method was quite higher than the national average value (Takele Gadissa and Chemedea, 2009).
Daily drip irrigation was studied for a cropping cycle to see the response of changing hydraulic features on the water movement of loamy topsoil. Neutron probes were used for continuous measurement of soil water contents and capacitance sensors kept in access tubes and were compared to predications made by the Hydrus-2D model. Predictions accurateness of used model was found good. Graphical and statistical comparisons of computer-generated and calculated soil water contents and thus total water storage showed a similar trend for monitoring period of all three different sets of parameters. Usually hydraulic features changes over time in topsoil had no significant response on soil moisture distribution in our agro-pedo-climatic situation. During daytime irrigation, it is possible because, high crop evapotranspiration, could minimize the effects of temporal changes and other soil problems (Ibrahim Mubarak, et.al, 2009).

To compute 12-years irrigation response of drip emitters kept on one side of apple trees trunk on the rooting pattern, with three irrigations levels, namely without irrigation (V0), intensive irrigation (V1), and economical irrigation (V2), an investigation was carried out. To map the root distribution number and location in clay loam soil, a profile trench observation method was used. There were no major differences in roots number between both sides of the tree trunk with irrigation level V2. Besides spatial roots distribution over the whole soil profile was seen to be the most uniform compared to other irrigation levels (V0 and V1). Study results showed that high yield was obtained with less frequent water application. (Sokalska I.D., et.al, 2009).

A laboratory experiment was designed by X to examine the performance of three emitters, like inline-labyrinth with turbulent flow (E1), a laminar flow (E2) and online pressure-compensation type (E3), under freshwater and treated sewage effluent (TSE), water application. They found more severe emitter clogging, larger coefficient of variation, lesser emission uniformity and Christiansen uniformity coefficient in case of E2 emitter type in comparison with emitter types E1 and E3 under both freshwater and TSE. They also found better anti-clogging function in emitter type E3 than emitter types E1 and E2 and was recommended for irrigation with treated sewage effluent water (Haijun Liu and Guanhua Huang, 2009).
A study was designed to know the application efficiency of DSS MIRRIG model of micro irrigation system for a citrus orchard. A variety of changes were done by taking into account of different emitter kinds, variable pipe sizes and layout design with and without pressure regulator valves, and variable pressure head and discharge at the upstream end of the systems. The application was explained and level of substitute designs was analyzed by using recommendations suggested by the farmer to the hydraulic, economic and environmental criteria. A sensitivity analysis was done to check the strength of algorithms used for ranking with respect to changes in concordance and discordance threshold values, that showed the values selected by the model were those providing for a more clear ranking of design substitute (Pedras G.M.C. and Pereira S.L., 2009).

A study was carried out to know exact quantity of irrigation water of muskmelon grown in a greenhouse under four treatments of irrigation water (T100, T90, T80 and T70). The results showed that plant development, yield and quality were much influenced with changed quantity of irrigation water. Under T70 to T100, height of plant, stem diameter and yield were much reduced. Best fruit quality was observed in T90 treatment of irrigation water. Results showed that water use efficiency increased with the application of lesser quantity of irrigation water. They suggested on the basis of study findings that under irrigation water treatment T90, fruit quality and quantity was improved and could save irrigation water (Zeng Chun-Zhi, et.al, 2009).

By using surface drip irrigation, the infiltration and redistribution of soil moisture by taking into account hysteresis on loamy sand and silt loam soils were studied. To know hysteresis in soil water retention characteristic curve, evaporation from soil surface, and water taking out by roots, cylindrical flow model was used. Constant response against alternating use of 1, 2 and 4 L h⁻¹ water to soils was analyzed. Results showed that under both cases (with and without hysteresis), pulse irrigation, reduces a little water losses in root zone, in comparison with continuous irrigation. Hysteresis decreases much water losses in root zone under both kinds of irrigation over total simulation time. Results showed that response of hysteresis was observed to be larger at high discharge rate (4 L/h) and as a result at high water content on the soil surface (Elmaloglou S. and Diamantopoulos E., 2009).
To examine the effects of various drip irrigation treatments like (irrigation treatments $T_{100}$, $T_{75}$, $T_{50}$ and $T_{25}$ respectively), an experiment was performed on water use efficiencies (WUE) and fiber quality parameters of cotton variety N-84. Results showed that drip irrigation treatment $T_{100}$ could be best option under semi-arid conditions. It was also confirmed that $T_{75}$ had considerable effect on WUE under limited water supply conditions. Although 25.0% water could be saved with this treatment yet 34.0% decrease in net income also occurs. In other words $T_{100}$ treatment would be beneficial in water shortage areas (Dağdelen N., et.al, 2009).

A study was initiated by X with the objectives to investigate the temporal variations of the emitter discharge rate and the distribution of clogged emitters in the drip irrigation system and to quantify the impact of emitter clogging on system performance by using stored secondary sewage effluent and groundwater. Six types of emitters with or without a pressure-compensation device were used. They found that the emitters applying sewage effluents were clogged much more severely, producing a 26% lower average mean discharge rate than those applying groundwater. A more random distribution of clogged emitters was found for the sewage application. Clogging of emitters could badly degrade system performance. Results also suggested that more frequent chemical treatments to drip irrigation system should be applied, while using sewage effluent than to groundwater to maintain a high system performance (Li, et.al, 2009).

The effect of hydraulic head and slope was evaluated on water distribution uniformity for low cost drip irrigation system. It was tested in the laboratory for uniformity distribution water for different system hydraulic heads and slope setting. Appropriate recommendations were formulated, on the basis of study findings to reduced non-uniformity of distribution of water in sloping lands. The results showed that uniformity coefficient and uniformity distribution, normally increase with increasing hydraulic heads and decrease with increasing slope. Under all slopes, they found that hydraulic head of 3.0 m would be recommendable from both hydraulic and practical standpoints, with respect to the junction of most upstream lateral (Ella B.V., et.al, 2009).
2.2.4 Summary

In the early 1860 in Germany, experiments on drip irrigation were performed by using clay pipes with open joints for irrigation as well as for drainage. Evidence showed that some work on drip irrigation was done in 1913. Drip technology concept was promoted to some extent by the introduction of plastic pipes in Germany, Canada and USA. This irrigation system gains very much importance due to supported results of work of an Israeli engineer, Symcha Blass to drip irrigation concept in 1940. By the continue efforts and work on this drip irrigation concept, high quality results were obtained particularly at Arava in Israel during 1960. Keeping in view its salient features in agriculture, a number of experiments/studies were designed on each parameter of this rapidly worldwide nourishing irrigation system.

A lot of research work is being done on all of its aspects in agricultural crops as well as on fruit trees, which are presented in the following paragraphs during recent years like response of water stress on yield and other physiological parameters include crop water stress index for drip irrigated second crop watermelon grown in semi-arid climatic conditions, effects of different levels of drip irrigation and planting methods on yield and yield components i.e. number of fruits per plant, number of primary and secondary branches per plant, and plant height of green pepper under normal and paired-row planting methods, effect of changes in the hydraulic properties of loamy topsoil on water transfer under high-frequency drip irrigation, effect of drip emitters placed on one side of the tree trunk on the rooting pattern of apple trees under three levels of irrigations.

Further research studies was done on a wide range of drip irrigation aspects as distribution and storage features of soil solution for drip irrigation, response and strategies of drip irrigation with saline water on oleic sunflower with five saline irrigation water treatments, emitter efficiency of three emitters; namely inline-labyrinth, with a turbulent flow, a laminar flow and online pressure compensation emitter with the use of freshwater and treated sewage effluent, application efficiency of DSS MIRRIG model for design of micro irrigation system for a citrus garden, most feasible irrigation water quantity of muskmelon in greenhouse under
four irrigation water treatments, infiltration and redistribution of soil moisture under surface drip irrigation by taking into account of hysteresis in loamy sand and silt loam soils, response of different drip irrigation levels on water use performances and fiber quality parameters; yield from cotton (variety N-84), temporal variations of the emitter discharge rate and the distribution of blocked emitters in the drip irrigation system and to quantify the impact of emitter blockage on system performance by using stored secondary sewage effluent and groundwater, effect of hydraulic head and slope on water distribution uniformity of low cost drip irrigation system.

Considering the rapid growth of surface drip or trickle irrigation seven international congresses have been organized so far: the first one in Israel in 1971, the second in California, USA in 1974, the third in California in 1985, the fourth in Australia in 1988, the fifth in Florida, USA in 1995, the sixth in south Africa in 2000, and the seventh in Malaysia in 2006. Drip system components were developed approximately step by step and sold in different countries. As per one survey this system is adopted in about 35 countries and is installed in an area of ~1.79 mha (Chauhan, S. H., 2007).

2.3 Subsurface Drip Irrigation System – World Practice

2.3.1 Introduction

American Society of Agricultural Engineering defined subsurface drip irrigation as," application of water below the soil surface through emitters, with discharge rates typically in the same range as drip irrigation". At the beginning, “sub irrigation” and “Subsurface irrigation, sometimes referred for both SDI, and sub irrigation (water table management), and “Drip / trickle irrigation” could include either surface or subsurface drip / trickle irrigation or both. SDI may also be defined as placement of drip pipe or hose along with drip lateral under specified depth so that normal mechanical operations carried out to ensure its use for several years. Subsurface drip irrigation was mostly used for the last 15-20 years efficiently. Under this system mainline, sub-mainline, laterals and drip pipes installed below the soil surface at specified depth i.e. less than 2 cm deep (ASAE, 1999a).
Drip or tickle irrigation is defined as practice of irrigation where water is dispensed drop by drop in the desired location. This technology is available for many years and recently (over the past 15 years) has been promoted for application in humid climate areas. Some of the feature associated with the implementation and management of drip irrigation system or subsurface drip system are similar, whether the system is being used in humid or arid conditions. However, there are few considerations that are quite unique where precipitation is in important factor.

2.3.2 Pest Development and Use

Charles Lee, California obtained a patent for a tile that include irrigation holes on the crest raised the pipe, as irrigation tiles were planned to be used in tile drainage, their use was in fact not proposed to form a water table, as in the case of sub-irrigation irrigated but to wet the soil around the tile, this shows maybe it was early shape of subsurface drip irrigation (Lee, 1920).

After the Second World War development of drip irrigation covered its development stages rapidly with the introduction of plastics in its different shapes like polyethylene and polyvinyl chloride. United Kingdom may be adopted this technology first and perhaps other countries and later on Israel and the United States adopted this new technique of drip irrigation. Development of subsurface drip irrigation started as part of drip irrigation in the United States in early 1959 mainly in California (Davis, 1967; Vaziri and Gibson, 1972).

Many researchers reported about the start of laterals. Majority of the researcher reported in their reports that during the period of 1960s, laterals were built with polyethylene or polyvinyl chloride pipe with holes or slots drilled into these pipe and distinct emitter inserts by punched in pipe (Braud, 1970; Hanson et al., 1970; Zetzsche and Newman 1966 and Whitney, 1970).

Normally drip irrigation systems either surface or subsurface were run at low pressure with untrustworthy quality of water and filtration. They studied on several emitters to find out the reasons of emitters blocking along with their performance. They concluded from study findings that the plastic insert orifice was the recommended kind (Whitney and Lo, 1969).
By 1970, study experiments were conducted on farms and sugarcane fields through specifically designed emitters, laterals and equipment specially manufactured from commercial point of view. The results showed that commercial drip emitters and tubing were more trustworthy. In addition to that surface drip irrigation system grew at a quicker rate than subsurface drip irrigation system, maybe due to plugging of emitter and root intrusions (Davis and Nelson, 1970 a, b; Davis and Pugh, 1974; Gibson, 1974; Hanson and Patterson, 1974).

Subsurface drip irrigation techniques was tested on a variety of crops including citrus sugarcane, pineapple, cotton, vegetable, fruit, grass, turf, avocado, corn and potatoes. Most of the researchers pointed out the same problems linked with system poor uniformity, system maintenance and emitter blocking which is because of iron oxide or soil particles (Davis and Nelson, 1970a; Davis and Pugh, 1974; Edwards, et al, 1970; Hanson et al., 1970; Hanson and Patterson, 1974; Isobe, 1972; Phene, 1974; Phene and Beale, 1976, 1979; Phene and Sanders, 1976).

Most of the writer reported about the equipment needed for the installation of drip pipe in a field mechanically. The writer pointed out in his report of subsurface irrigation engineering research that mechanical equipment was developed in 1970s for the installation of subsurface drip irrigation (Zetzsche and Newman, 1966; Whitney, 1970).

Many researchers reported in their reports about the installation equipment needed for fixing system components. Some researcher indicated these equipment needed for lateral and emitters fixing. They reported in their reports like sub-irrigation with plastic pipe and review of subsurface drip irrigation described a number of the equipment including punched holes or plastic inserted emitters in the tubing were needed during the installation of laterals (Whitney, 1970).

Most of the Writers reported in their reviews about the development of fertilizer equipment for the drip irrigation. Majority of scientists was agreed that fertilizer injection equipment developed by Israel and they included in the surface drip irrigation system (Zetzsche and Newman, 1966, Whitney, 1970).
In the early 1980s importance of subsurface increased may be due to its awareness regarding material and equipment costs, enhanced nutrient management and lower system cost accounting was the ultimate outcome of its use for several years. Research reports published during the first half of 1980 of many scientists discussed and presented brief information on water and filtering, lateral depth and spacing chemical injection through drip irrigation system, crop/fruit production and also presented and discussed a comprehensive comparisons of drop irrigation technique with other types of irrigation systems (Bucks, et. al, 1981; Chase, 1985a; Mitchell, 1981; Plaut, et. al, 1985; Rose, et. al, 1982; Sammis, 1980; Wendit, et. al, 1977).

Some scientists reported that modern technique of subsurface drip irrigation system had been adopted in their research program for 10 years and from this program they are able to present or proposed a guidelines for system design layout, installation and management of these systems. The reports showed the experiences of the writer with usage of subsurface drip irrigation in cotton and wheat crop which were started in 1979 on a large commercial agriculture farm. Subsurface drip irrigation Interest increased mainly after 1985, it was the period when most of the reports of replicated research experiments were published (Mitchell and Tilmom, 1982; Tollefson, 1985 a, b).

Most of the experts reported in their reports about the latest and efficient technique of drip irrigation. On account of its importance, the subject of subsurface drip irrigation became an integral part of debates which found placement in many reviews on drip irrigation (Howell, et al. 1980; Buck, et. al., 1982 and Bucks and Davis, 1986). They reported and present an impression about subsurface drip irrigation technique theoretically in detail as well as its applications range in agriculture.

Many scientists discussed and presented a comprehensive brief or review regarding the salient advantages and limitation of the latest developed subsurface drip irrigation system in their different reports like future of irrigation is buried which means future adoption of this irrigation technique would be more particularly with permanent corps. Writer provided a wide-ranging review on subsurface drip irrigation. The review included the history, system advancement and research conducted on agriculture by using this technique of irrigation (Camp, 1998).
He published a review of his 15 years research undertaken at the water management research laboratory on the subsurface drip irrigation on row crops (perennial and annual). The research was carried out on tomato, cotton, sweet corn, alfalfa, and cantaloupe for both plot and field applications. Results showed from these studies that significant yield and water use efficiency increases in all crops. Under reports of raisin grower buries drip and buried drip gains more ground, a complete discussion was done comprehensively regarding the subsurface drip irrigation system. Also brief discussion of growers experiences were presented and shared (Ayars, et. al, 1999).

Availability of water for crop growth for agricultural production was the main issue of developed and developing countries. Low rainfall areas like arid and semi-arid and areas having low rainfall distribution throughout the year are always facing problems of water shortage for their crops. For example in larger parts of Nepal having distinct rainy season followed by a prolonged dry period (UNEP, 2001).

Out-of-season vegetables such as cucumber, tomato, pepper and cauliflower needed additional water for getting good production. In many parts of the country enough water is not available during dry season i.e. November to May and June where water conservation and minimizing its use for irrigating crops which is vital for sustainable economic production of vegetable and other cash crops (Randhawa and Abrol, 1990).

Drip irrigation offers a practicable solution for water scarce and low rainfall areas for economic production of agricultural crops. Drip irrigation provides an irrigation system to crops where water is applied directly to each plant drip by drip on a phased basis and continues (Schwab et. al., 1993).

A study was carried out to know the efficiency of surface drip irrigation system and subsurface drip irrigation system under vegetable crop like cucumber and tomatoes. The results of the study indicated that surface drip irrigation gave good establishment of crop and higher yields than sub-surface drip method. Further work is needed to establish cause-effect relationships and actual viability of sub-surface drip irrigation method (Bajracharya and Sharma, 2005).
Drip irrigation System proved its dominance to other irrigation systems due to increasing yield, reducing labor costs and energy, in addition to its own properties like enhanced efficiency and minimized water wastage on account of evaporation and percolation. On the other hand traditional surface drip irrigation system has certain drawbacks like possible damage, exposure of the pipeline system to the sun and salt deposition. Recent development of subsurface drip irrigation provided an alternative to traditional surface drip irrigation system. It cooped up with present scenario to fulfill the irrigation demand to some extend as it prevents or reduces evaporation from soil surface and process of evapotranspiration is persuaded due to the water movement to upward direction in the root zone, which enhancing water use efficiency, so more water is added to the root zone of the plant and minimized weeds growth around the crop (Ayers et. al, 1995).

As a result of three decades research on subsurface drip irrigation system, the subsurface drip irrigation developed rapidly due to its prime characteristics of high system efficiency and yield. By these research and experimental work majority of the issues related to subsurface drip irrigation have been addressed like emitters blocking with small roots, lateral installation and application of fertilization. Various study results finding have shown significant increase in water efficiency and nitrogen utilization causing a sharp increase in yield and quality improvement. This system has provided a support in reducing groundwater pollution by nitrates and salts for long term. Since the system work below ground surface, so it has advantage to surface drip irrigation system because from this system economic water saving as well as nutrients to other traditional methods. Moreover due to salinity control, and deep percolation, system sustainability ensured, it is because of soil wetting spherically in subsurface drip technique while half in the sphere in case of surface drip technique (Phene, 1995).

A Comparative study was carried out by using three irrigation systems like drip subsurface, traditional drip surface and sprinkler irrigation, findings showed that 50% water reduced in subsurface drip technique, in comparison with sprinkler irrigation while 30% water reduced in comparison with traditional surface drip irrigation method. In addition to that 30% to 70%, yield increased in subsurface drip method, in comparison with surface drip method of irrigation. Automatic programming system of water application was used in tomatoes experiment under drip below surface irrigation technique have shown excellent saving of
water as well as increase in the yield, when system compared, without the use of automatic programming of water application (Mohammad and Al-Amoud, 1994).

Using of surface drip technique in arid and semi-arid areas, evaporation rate from the soil surface, increases considerably, due to low rainfall and air high temperature will result accumulation of salts on the top layer of soil, which in turn leads to reduced efficiency of the system. To overcome this situation of accumulation of salts due to evaporation to some extent, subsurface drip irrigation system be used, which have ability to wash salts away from the root zone. Subsurface drip irrigation technique was successfully applied on grown-up pear trees, where the laterals of the subsurface have been installed at depths of 30-60 cm below the soil surface (Oron, et. al, 1995). On permeable subsurface irrigation systems findings showed that working pressure causes a solid effect on the efficiency of these irrigation pipes. At 80 to 150 kPa, working pressure range performed best results (Mohammed, 1998).

According to Ayres and Wescot have observed in their research paper on “water Quality for agriculture” that date palm is a drought-resistant desert tree plant, which can bear salinity up to 4 dSm⁻¹ without affecting its actual produce. While predicting crop water requirement that date palm tree, the researcher have observed that its root zone depth ranges between 1.5 to 2.5 m. 65% to 80% of water consumes in date palm, within its root zone depth and not exceeded to 1.2 meters (Yaacob, 1996).

Traditionally, basin irrigation method being used for irrigating date palm tree, which consumed copious water amount and application quantity of irrigation water is generally decided on the basis of growers practice. A grown-up date palms tree required 115 to 306 m³ irrigation water, equal to 1.15 to 3.06 m per hectare (Albaker, 1972).

Many reports indicated that now due to modernized research equipment, it is quite feasible to calculate approximate requirements about the crop water for date palms. For example experimentation conducted in the area of Al-Hassa, Saudi Arabia. Some writers pointed out in their reports that application of irrigation water with low frequency to date palm tree is better than application of irrigation water with high frequency irrigation water (Hussain, 1986; Helal, et. al, 1986; Hussain and Hussain, 1982 and Furr, 1975). In order to ascertain
effects of irrigation on the development, yield and quality of date palm tree, a study was conducted in Egypt on Sakoti type date palm fruit under arid conditions. The study result indicated that optimum benefit from irrigation of date palm tree can be extorted if the plant is watered for the four weeks with an application amount equivalent to 71 mm per irrigation (Helal, et. al, 1986; Hussein and Hussein, 1982).

A comparative study to ascertain the impact of drip irrigation and sprinkler irrigation on the growth of date palm tree was also conducted. From the study findings it was concluded that growth and performance higher under drip irrigation as compared to sprinkler system. The study results indicated increase in leaves, flowers, fruits and yield of the date palm tree under drip irrigation system, due to smallest area moistened soil (Reuveni, 1971, 1974). Some writers pointed out in other comparative study of two systems on the dates palm trees, it has been further revealed that there was an increased accumulation of salts on the surface layer was in case of drip irrigation vis-à-vis to bubbler irrigation system(Nimah, M, 1985).

A comparative study was carried out using three irrigation methods namely drip, bubbler and basin to know the system performance, yield and economics. An Average amounts of water was applied to date palms per year under three irrigation system as 108 m$^3$/tree (1.08 m / ha), 216 m$^3$/tree (2.16 m / ha) and 324 m$^3$/tree (3.24 m / ha) at 50%, 100% and 150% of evaporation rate. Economic analysis of yield of these trialed irrigation systems were carried out which showed highest yield in drip irrigated palm trees then basin irrigated palm trees. It was observed that differences in water treatments were minimal in all three systems of irrigation, so to get maximum water use efficiency, 108 m$^3$ per year per tree water is enough for date palm. From this comparison it was observed that water use efficiency on date palm trees was highest in drip irrigation system followed by basin and bubbler irrigation system. It was due to the fact that under drip technique water is applied drop by drop for a comparatively long period of time by emitters. This slow process of water application shows efficient control and supply of water through the soil profile, so deep percolation and losses due to evaporation minimized. Therefore, the entire quantity of water was consumed by the palm trees (Al-Amoud, et. al, 2000).

Subsurface drip irrigation technology proved its dominancy economically over the centre pivot sprinkler irrigation method for irrigating crops and trees. They reported that per hectare
total all cost, which includes, operational, management and investment was less than 30%, compared with center pivot irrigation system method (Dhuyvetter et al, 1995).

2.3.3 Advantages and Modern Development
The subsurface drip irrigation has the benefit of multiple year life, reduced interference with cultural practices, dry plant foliage, and a dry soil surface. Multiple year life allows amortization of the total system cost over several years, often more than a decade. If all system components installed below the tillage depth, surface cultural practices can be completed with the least interest to system damage. Dry soil surfaces may reduce weed growth in dry climates and can reduce the evaporation of applied water because the plant canopy is not irrigated, the foliage remains dry, which can reduce the incidence of disease. Subsurface drip irrigation is also very adoptable irregular shaped fields and low capacity of water supply that can provide design limitation with other irrigation systems. The key advantages of the subsurface drip irrigation include accounting system cost, difficulty in locating and repairing system leaks and plugged emitters, and poor soil surface. Most system components are installed below ground surface and are not easily found or directly observable. In properly designed and managed subsurface drip irrigation system, the soil surface should seldom be wet. As a result, seed germination, particularly for small seeds, can be very difficult.

The subsurface drip irrigation system offers significant flexibility both in design and operation. For example, subsurface drip irrigation systems can apply small, frequent water applications, often several times each day to very specific sites within the soil profile and plant root zone. Fertilizers, pesticides and other amendments can be used through the irrigation system directly in to the active root zone, often a modest increase in equipment costs. In many cases, operating costs may be lower than that for applying for the purposes of these chemicals through conventional surface equipment. The value of subsurface drip irrigation promoted during the initial period of 1980s, rapidly promoted during the second half of 1980s and continuing its development at present, mostly in areas having insufficient water, with environmental problems linked to irrigation, and where the wastewater used for irrigation. Originally, the subsurface drip irrigation is used mainly for sugarcane, vegetables,
tree crops and pineapples in Hawaii and California. Later subsurface drip irrigation use was extended to other geographic areas and to agronomic and vine crops, corn, cotton, and grapes and grapes.

The subsurface drip irrigation system has gained popularity during 1980s and onwards, due to the publication of a large number of research papers and articles internationally and availability of appropriate and profitable products in the market. Significance action of subsurface drip irrigation was continued as a burning topic for both research and private sector during 1990s, particularly on account of its efficiency for areas with declining water supplies and environmental issues related to irrigation. There was also special interest in the use of waste water, particularly for turf and pastures. Interest in adoption of subsurface drip irrigation technique has blossomed during last two decades due to its economized water consumption and simplicity of its components. Awareness about this technology exists in the United States of America for more than 40 years but they did not made any attempt to document the available information regarding this technique of subsurface drip irrigation until now.

A field experiment was conducted to see the response of placement depth of drip lateral (surface; 0, 5, 10, 15, 20 and 30 cm) in a sandy loam soil under different levels of irrigation (60, 80 and 100% of the crop evapotranspiration) on onion crop yield. It was found that placement depth of the lateral drip affected onion yield considerably. High yield (25.7 t ha\(^{-1}\)) and highest irrigation water use efficiency (0.55 t ha\(^{-1}\) cm\(^{-1}\)) was got in drip lateral inserted at 10 cm soil depth. Neelam and Rajput, (2009), to get higher onion crop yield, insertion of drip lateral should be at low depths.

Under subsurface drip irrigation by using municipal wastewater and freshwater on alfalfa field, a long term experiment was carried out to evaluate soil salinity and phosphorus distribution and yield. The results indicated that phosphorus speciation described phosphorus distribution and plant uptake in terms of phosphorus forms. In addition to that around the emitters, large values of microbial phosphorus were formed, as a result of two irrigation waters mostly for freshwater. The results also showed that much well-built inorganic phosphorus contents were seen in freshwater irrigated soils, though no external sources were
added through irrigation water, which could have contributed by faster phosphorus cycling (Palacios-Díaz, et.al, 2009).

A study was designed to determine the efficiency of mathematical model in simulating soil water dynamics, in comparison with predicted soil water content values and those values come from analytical solution of buried single strip source with both Hydrus 2D models. Water distribution trends under loamy sand, silt, silty clay loam soils at four different times by using two discharge rates of 2 and 4 L m$^{-1}$ h$^{-1}$ were studied. The numerical results showed that soil wetting trend mostly depends on soil hydraulic features. The results indicated that soil water is more easily taken up by the plant roots, as the soil evaporation is neglected (Elmaloglou and Diamantopoulos, 2009).

An experiment under surface and subsurface drip irrigation systems, in sandy soil on potato was carried out to estimate the response of humic substances application on yield, quality, and nutrient quantity in tubers and soil fertility after ploughing up crop. Study results showed that tuber yield, starch content and total soluble solids were increased with the increase of humic substances application rates up to 120 kg ha$^{-1}$. The results also showed that subsurface drip irrigation system was more efficient than surface drip irrigation system due to enhancement in tubers yield, quality and soil fertility after ploughing up (Selim, et.al, 2009).

To know the response of subsurface drip method on corn by applying three irrigation levels (No irrigations, 60% and 100% of approximate daily water use), a long term investigation was conducted. The results showed that higher irrigation water use efficiency and high yield was observed with lesser water application under subsurface drip irrigation method. Additional comments would be required to decide whether corn yield under subsurface drip irrigation was feasible in the area and to develop recommendations for growers selecting to accept the method. In addition better weather forecasting and developed crop coefficient in particular for the area should also give more well-organized irrigation management (Vories, et.al, 2009).
Under subsurface drip irrigation systems, a field study was carried out to test the agronomic response of uniformities distribution on cotton yield over a period of six year. Three water distribution uniformities, 5%, 15%, and 27%, of flow variations with two irrigation water levels, as a base irrigation quantity and 60% of base irrigation quantity were used under this study. Results showed that at lesser irrigation level, the slightest uniform layout gave a high net present value. The grower’s jeopardy aversion level affected their choice of design uniformities. A more risk unwilling grower chosen a more uniform design and was willing to pay a high installation cost for a more uniform system. A less risk unwilling grower favoured a less uniform system design with a lesser initial cost (Wilde, et.al, 2009).

2.3.4 Current Status and Use

Due to salient features and worldwide success of latest subsurface drip irrigation system, a lot of work is being done on all of its aspects in agricultural crops and fruit trees, which are presented in the following paragraphs.

An ample review was carried out of published information on subsurface drip irrigation to know the modern development of this technique. He presented more than 30 different applications from results of published research on subsurface drip irrigation technique of his review. The researched applications mostly related to food and fibre crops, trees, turf and ornamented plants. In case of turf and landscaping plants, recycled or waste water sources were utilized (Camp, 1998).

A long term study was performed to compare two nitrogen application methods i.e. multiple in-season and early-season with three nitrogen rates (128, 186, and 278 kg N ha\(^{-1}\)) under subsurface drip irrigation. The study results showed that greater losses of NO\(_3\)-N below the root zone in early season treatment had a negative effect on corn production. The results also showed that under subsurface drip irrigation systems, fertigating at recommended N rate for various corn growth stages could increase yields, gross return nitrogen, and reduce NO\(_3\)-N leaching in soils compared to concentrated early-season applications (Tarkalson and Payero, 2008).
Another long term study under subsurface was designed with definite aim, to judge the response of insertion depth of drip laterals on yield and simulation of soil water for onion crop by using Hydrus-2D model. Results showed that high yield (25.7 t ha$^{-1}$) was obtained at 10 cm depth of drip lateral insertion and use of Hydrus-2D model verified the movement of soil water at depth 20 and 30 cm drip laterals insertion. Soil water was evaluated by comparing the calculated and predicted values by using three parameters specifically, AE, RMSE and model efficiency. Results showed that Hydrus-2D model application helped in corroborating the findings resulting from the field testing made on soil water distribution at various insertion depths of drip laterals. Result finding indicated that Hydrus-2D model helped in layout designing of subsurface drip irrigation system for efficient use of water with least drainage (Neelam and Rajput, 2008).

A two year study was planned under subsurface drip irrigation on corn field to estimate the response of irrigation application with evapotranspiration (ETc), yield, water use efficiencies and dry matter yield. The results pointed out; yield increased with improved irrigation, water use efficiency enhanced non-linearly with seasonal ETc and yield, and irrigation water use efficiency quickly reduced yield with irrigation. Results showed that on average grain accounted for bulk for above-ground plant; dry mass ($\approx$59%), stover ($\approx$33%) and cob ($\approx$8%). The dry mass of plant and that of each plant component leaned to boost with seasonal ETc. From this study a good relationships was got between crop efficiencies indicators and seasonal ETc, which showed exact estimates of ETc on daily and seasonal basis which could be used for making planned in-season irrigation management decisions for strategic irrigation planning and management (Payero O José., et.al, 2008).

A two successive growing seasons study was designed to know the response of sowing methods under subsurface drip or sprinklers irrigation, 0.18 & 0.25 m, insertion depth of irrigation tape and irrigation water salinity (1.5 & 2.6 dS m$^{-1}$) on salt and bromide distribution. First Season result showed that high salt concentrations was observed in top 3 cm and below 3 cm of soil, soil EC decreased and remained constant to 1.05 dSm$^{-1}$. A bromide concentration was seen maximum in the top 3 cm of soil. Study results also showed that there were no main differences among applications in the mass of either salt or bromide in the top 3cm or 16cm of the soil profile after second season (Roberts L.Trenton, et.al 2008).
A study was designed to determine the variation in dripper discharge of irrigation laterals under subsurface drip irrigation method. The emitter coefficient of flow variation (CVq) was calculated by taking 2 and 4 L/h drippers in laboratory and was laid both on and under the soil. Soil pressure coefficient of variation (CVhs) was measured in buried emitters. Under operating and uniform conditions of sandy and loamy soil, irrigation uniformity was simulated for both surface and subsurface drip irrigation laterals. The results of the study showed that irrigation uniformity of subsurface drip irrigation of non-compensating emitters was performed better than surface drip irrigation. It was also concluded from the study that irrigation uniformity with pressure-compensating emitters would be similar in both cases if excess pressures in subsurface drip irrigation were given fewer than or equal to the compensation range of lesser limit (Gil, et.al, 2008).

By using subsurface drip irrigation method, an investigations were carried out in glasshouse and field trials on soybean, chickpeas, and pumpkin crops under various emitters depth (5, 15, 25, and 35 cm), to verify the effects of oxygation water on yield, water use efficiency and rooting patterns for various emitter depths were evaluated. The study results showed that with rising emitter depths oxygation water effect was outstanding due to lessening of hypoxia. Furthermore, response of oxygation water on yield in the low-rooted crop soybean was best (~43%), moderate on medium (chickpea ~11%) and deep-rooted crops (pumpkin ~15%). The results also showed that moisture content at depth with a lower soil oxygen concentration caused hypoxia. Oxygation offsets to a degree, the negative response of deep emitter insertion on yield and water use efficiency of subsurface drip irrigation crops (Bhattarai, et.al, 2008).

A two year study was designed to determine the possibility of planting corn in narrow rows under subsurface drip irrigation with three specific objectives i.e. (compare narrow-row corn yields in surface and subsurface drip irrigation with lateral spaced at 1 and 2 m, compare the effects of pulsed subsurface drip irrigation applications to move irrigation water further away from the laterals on narrow-row corn yield and evaluate the impact of corn row distance from subsurface drip irrigation laterals on plant biomass, nitrogen concentration, and yield. Study results showed that the distance of the corn rows from the subsurface drip irrigation lateral greatly influenced the crop growth and grain yield. Plant biomass, nitrogen concentration, ear length, and grain weight decreased significantly with distance from the subsurface drip
irrigation laterals. The results also indicated a great deal of variability among rows when corn was grown in 0.38m spacing over subsurface drip irrigation laterals for wider row crops. Higher plant populations placed closer to the laterals may increase productivity (Stone, et.al, 2008).

A two year study was designed to determine hay yields, biomass, soil nutrients and soil water nutrients by using treated swine wastewater effluent in a subsurface drip irrigation system. The specific objectives of the study were to compare bermudagrass hay production using commercial and wastewater effluent for nutrients, two subsurface drip irrigation lateral spacing’s 0.6 and 1.2 m installed at 0.3 m below the surface, with two irrigation application rates 75% or 100%. Study results showed that no major differences between the subsurface drip irrigation lateral spacing’s or irrigation application rates. Treatments using wastewater effluent had considerably higher hay yields and notably higher nutrient biomass removal rates than the commercial fertilizer treatments. Nitrate-N observed in soil water lysimeters increased with depth, pointing out potential for leaching without proper management. Soil nitrogen and carbon were not much different for any of the treatments (Stone, et.al, 2008).

An experimental study was designed to evaluate irrigation system water distribution uniformities having flow variations (Qvar) = 5%, 15%, and 27% at both moderate and near full irrigation levels under subsurface drip irrigation in cotton crop for six years. Flow variation treatments were established by installing and irrigating cotton with different diameter drip laterals in field plots. Subsurface drip laterals with diameters of 17, 22, and 25 mm, pressurized at 72, 83, and 45 kPa, respectively which resulted in different irrigation uniformity treatments defined as poor, very good, and acceptable (Bordovsky and Porter, 2008).

To evaluate the effect of five drip tape placement depth of (0.0, 5.0, 10.0, 15.0 and 20.0 cm) by applying three levels of irrigation (60, 80 and 100% of crop ETO), a three long term field study was done on potato crop on potato yield. Highest cost benefit ratio (1.7) was resulted with T3 treatment while lowest (0.9) was in T5 treatment. The drip tape placement depth notably influenced potato yield. Irrigation application with 100% of crop ETO provided
Chapter 2  Surface Drip and Subsurface Drip Irrigation

highest yield having drip tape placing depth of 10.0 cm. It was observed that the gravity forces predominated over the capillary forces, resulted greater downward action of water at the study site. It was concluded that 10.0 cm depth was found to be the best to get higher yield of potato crop. But placement depth of drip tape would be differing with crop and soil type (Neelam and Rajput, 2007).

Subsurface drip irrigation is being frequently used in most of fruit trees and vegetables like tomatoes followed by lettuce, potatoes and sweet corn yield. Now a day’s these techniques are also being used for fruit trees i.e. apples, asparagus, bananas, papaya, etc. its application is further extended to vegetables like peppers, broccoli, cabbage, cantaloupe, carrot, cauliflower, peas, green beans, okra, onion, rape, squash and as well as in flowers.

Subsurface drip irrigation system is successfully used in agronomic crops like cotton and corn and others crops like alfalfa, sorghum, peanuts, millet. So many justifications are available now days for installation of this modern technique of subsurface drip irrigation on specific crops. The technique is also effective in controlling plant diseases of plants of strawberries to a great extent since it keeps the surface relatively dry. Its Multipurpose use throughout the year decreases the annual cost of the system and makes it suitable for low-value crops like cotton and corn. The targeted provision of water and fertilizer in the plants root zone is the inbuilt capability of subsurface drip irrigation is an important factor with trees and vines.

2.3.5 Comparison with other irrigation system

A comparative study was carried out by using effluent against fresh water under three irrigation methods namely; surface drip, subsurface drip, and furrow irrigation methods to see effect on yield, water savings, and irrigation water use efficiency. On the basis of soil moisture and rooting depth monitoring, irrigation scheduling was prepared. Irrigation water use efficiency differences were observed significantly higher for these irrigation methods. The high irrigation water use efficiency was obtained in case of subsurface drip (2.12 kg m$^{-3}$) and least, in case of furrow irrigation method (1.43 kg m$^{-3}$). The study results also indicated that irrigation water use efficiency was more with effluent water, in comparison with fresh water but variation was not statistically vital (Hassanli Morad Ali, et.al, 2009).
A comparative study was carried out under drip and furrow irrigation systems for two seasons to see the response of saline drainage water on tomato crop were evaluated together with soil moisture and salt distribution. The study results showed that with the raise of salinity leaf area index, plant dry weight, yield and individual fruit weight were reduced. It was also observed that yield, growth parameters and water use efficiency were more in drip than furrow irrigated plants. But, furrow irrigation gave high individual fruit weight and salinity followed the water front. They suggested that vigilant and well-organized management of irrigation with saline water could leave groundwater salinity levels unchanged and suggested that under drip irrigation method, yield per unit of water used was on average one third higher than furrow irrigation method (Malash, et.al, 2008).

A two year oasis fields experiment was performed by using drip irrigation on cotton crop to determine effect of limited root zone irrigation. Two irrigation applications conventional drip irrigation; irrigated both sides of plants row, and alternate drip irrigation; alternatively irrigated both sides of plants row, were used under plastic mulch. Study results showed that stomatal conductance in alternate drip irrigation method were found lesser than conventional drip irrigation method for same irrigation level. Results showed that in alternate drip irrigation application method, with reduced stomatal conductance and water loss formed high water use efficiency. The study results concluded that alternate drip irrigation would be helpful water saving irrigation method in arid oasis fields where cotton crop was greatly reliant on irrigation water and scarce water resources (Du Taisheng, et.al, 2008).

By using six variable irrigation water applications as 0, 25, 50, 75, 100, and 125% of class a pan evaporation rates, a study was designed for surface and subsurface drip irrigation methods for muskmelon under semi arid conditions to find out the response of surface and subsurface drip irrigation method and best irrigation water application. The study results showed that high yields were got at 83 and 92% of class a pan from subsurface and surface drip irrigation methods. Better yields were got with best irrigation quantity under both irrigation methods. But there was no clear sign of irrigation water quantity on total soluble solid and flesh thickness of muskmelon fruits (Dogan, et.al, 2008).

A field experiment was carried out to determine the crop coefficient and water requirements for irrigated garlic by using three irrigation systems like simulated furrow irrigation,
subsurface drip irrigation, and surface drip irrigation with irrigation treatments i.e. 50%, 75%, 100%, and 125% of crop evapotranspiration (ETc) which were calculated with a weighing lysimeter. Study results showed that highest yield was obtained at 100% ETc, and irrigation in excess of 100% ETc did not had any additional yield. When compared irrigation systems statistically then there was very small difference in yield and quality parameters. They found that statistical differences were found between irrigation levels. Peak crop coefficient values were calculated in the range of 1.3 to 1.4. The Kc was linearly related to the day of the year. Which represents the development segment of the crop coefficient curve as presented in FAO Irrigation and Drainage Paper 56 (Ayars, 2008).

An experimental study was carried out on a standard sized center pivot system in a farmer field irrigated with Precision Mobile Drip Irrigation (PMDI) system and an in-canopy spray nozzle method to know that PMDI system could increase irrigation efficiency by reducing irrigation evaporative losses, reducing runoff potential, and help to reduce wheel track rutting problems. Study results showed that no yield differences were found between the application methods. Decreased water flow due to emitter clogging was observed in PMDI, even though applied water was filtered. Higher water use efficiency values were observed then did the spray nozzles, when accounting for decrease in flow for PMDI. But clogging of this PMDI system would make execution on big acreage potentially difficult (Olson and Rogers, 2008).

A study was performed on twelve years old ‘Hass’ avocado trees over the three planting seasons, planted in fine and coarse textured soil to find out the variability and position of the active root systems of soils under drip and micro sprinkler irrigation systems. In the first meter from tree trunk, maximum root frequency was got for every combination but with some variations between irrigation types. They also found a number of changes in both tree roots quantity and locality of most root activity zones were observed which was vary with seasonal soil temperatures, soil texture, and type of irrigation used all over the growing season (Salgado and Cautín, 2008).

By using three irrigation applications; conventional drip irrigation, alternate drip irrigation and fixed drip irrigation, on table grape, A two year field experiments were designed to find out the response of alternate partial root-zone drip irrigation on yield, quality and water use
efficiency. Study results showed that decreased transpiration rate were observed in conventional drip irrigation and alternate drip irrigation of irrigation applications methods, resulted high leaf water use efficiency of table grape but these methods had same photosynthetic rate. Both conventional and alternate drip irrigation gave same yield with enhanced WUE$_{ET}$ by 26.7–46.4% and better than before edible grape percentage from 3.88–5.78%, vitamin C content in the fruit from 15.3–42.2% and ratio of total soluble solid concentration/titrated acid in both years. So without negative effect on yield, alternate drip irrigation method saved irrigation water, better water use efficiency and quality of fruit (Du Taisheng, et.al, 2008).

Three years field trials were conducted on onion crop with four irrigation treatments; 0.60, 0.80, 1.00 and 1.20 of irrigation water to cumulative pan evaporation ratio to know the feasibility of micro sprinkler and drip irrigation methods for yield under canal command area. Micro sprinklers resulted better economics than a drip irrigation method. On the whole results of this study showed that micro sprinkler system was better than existing irrigation methods for onion yield in a canal command area by giving more profit in limited available surface water (Kumar Satyendra, et.al, 2008).

2.3.6 Summary
Initially the technique was used for irrigating vegetable crops, fruits trees and nuts, but with the passage of time, it was extended agronomic and forage crops like cotton, corn and alfalfa. There was great resemblance in the design of early sub surface drip irrigation system and surface drip irrigation technique but now it has been transformed with the inclusion of air inlet ports, flushing valve and fertilizer unit. Use efficiency either for crop yields or water by using subsurface drip irrigation was seems to be equal or greater than other irrigation techniques. Fertilizer requirements are same or less from other methods of irrigation. The inbuilt capability of subsurface drip irrigation to maintain a comparatively dry soil is a positive point under certain situations, cultures, particularly when objective to harvest or reducing weeds growth. However, it causes problems like germination of seeds planted shallow, root intrusion in emitters which obstruct the timely and smooth provision of water and nutrients to plants root zone besides, frequent clogging of the emitters.
Surface drip irrigation has been practiced in the United States of America since 1959 initially with the help of plastic pipes having holes/ slits/ punched cuts. As plastic pipe and emitters enhanced to provide a steadier and consistent operation, the development of surface drip irrigation technique grew faster than subsurface drip irrigation applications. It may be due to clogging of emitters or root intrusion. Knowledge of subsurface drip irrigation has full-fledged popularity during the last 20 years for being commercially viable products, its long life and economized water consumption.

Subsurface drip irrigation has gained full-blown popularity during the last 20 years due to the continuous efforts of scientist and engineers on its each aspect and makes it for being commercially viable products due to its long life and economized water consumption. They designed different studies like Compare two nitrogen application methods i.e. multiple in-season and early-season with three nitrogen rates, evaluate effect of irrigation applied on corn in respect of evapotranspiration, yield, water use efficiencies, irrigation water use efficiencies and dry matter production, effect of this irrigation system on salt concentration, EC and Br concentration, effects of Oxygation i.e. aerated irrigation water under subsurface drip irrigation crops like soybean, chickpeas, and pumpkin yield, water use efficiencies and rooting patterns in glasshouse and field trials by using different emitter depths and also determine hay yields, hay biomass, soil nutrients and soil water nutrients by using treated swine wastewater effluent under this subsurface drip irrigation system,

Some scientists also performed studies to test Simulation model in onion crop irrigated through subsurface drip system with specific objective like effect of depth of drip laterals placement on crop yield and application of Hydrus-2D model for the simulation of soil water, effects of germination method i.e. irrigation with subsurface drip irrigation or sprinklers, depth of subsurface drip irrigation tape and irrigation water salinity on salt and Bromine distribution, variation in dripper discharge analysis in subsurface drip irrigation laterals, possibility of planting corn in narrow rows under subsurface drip irrigation with three specific objectives, evaluate irrigation system for water distribution uniformities with flow variations at moderate and near full irrigation levels in cotton crop, effect of placement of drip tape under five depth and three irrigation application levels on potato yield.
Most recent work was done on the aspects like result of drip lateral placement depth and application of different levels of irrigation on Onion crop yield, evaluate soil salinity and phosphorus distribution and yield by using municipal raw water and freshwater under this drip system on alfalfa fodder crop, to know mathematical model performance in simulating soil water dynamics by comparing the predicted soil water content values with both Hydrus 2D model and with an analytical solution for a buried single strip source, effect of humic substances application in sandy soil under surface and subsurface drip irrigation systems on potato tubers yield quantity, quality, nutrients concentration in tubers and soil fertility after harvesting, response of subsurface drip irrigated corn with three irrigation levels, agronomic impacts of distribution uniformities on cotton production with three water distribution uniformities and two irrigation levels.

Several comparisons were performed on different irrigation system on different irrigation system like effects of saline drainage water to irrigate field grown tomato using drip and furrow irrigation systems were evaluated together with the distribution of soil moisture and salt, effect of subsurface and surface drip irrigation systems and to know best irrigation water application by using six different irrigation treatments on muskmelon under semi arid climatic conditions, comparison of a standard sized center pivot system in a farmer field irrigated with Precision mobile drip irrigation system and an in-canopy spray nozzle method to know that Precision mobile drip irrigation system could increase irrigation efficiency by reducing irrigation evaporative losses, reducing runoff potential and help to reduce wheel track rutting problems, effect of alternate partial root-zone drip irrigation on fruit yield, fruit quality and water use efficiency of table grape by using three irrigation treatments i.e. conventional drip irrigation, alternate drip irrigation and fixed drip irrigation, Further comparison was made which were Effect of three irrigation methods namely subsurface drip, surface drip and furrow irrigation using effluent versus fresh water, on water savings, yields and irrigation water use efficiency, effect of partial root zone irrigation by drip irrigation on the water use and yield of cotton in oasis fields, to establish crop coefficient and water requirements of irrigated garlic by using three Irrigation systems i.e. simulated furrow irrigation, subsurface drip irrigation and surface drip irrigation with four irrigation treatments, variability and location of the active root systems of old ‘Hass’
avocado trees planted in fine or coarse textured soils under either drip or micro sprinkler irrigation systems, viability of using micro sprinkler and drip irrigation systems for onion vegetable production in a canal command area with four irrigation levels application.

Awareness of wastewater usage in crops has been started over the last decade by using subsurface drip irrigation system with the added benefits of minimum odor and deeper injection of phosphorus in the soil fabric. Under the recent scenario, when the world is exposed to acute scarcity of water resources and the ever growing need for more and more water, the latest technique of subsurface drip irrigation has an assumingly very bright future and its adoption increasing rapidly all over the world day by day. This technique allows very precise and timely application of water, fertilizers, and allied chemicals to the crops through deep penetration. Obviously with these significant benefits, the technique of subsurface drip irrigation proves to be an effective and viable irrigation system for the next couple of decades globally.
CHAPTER NO 03
Microirrigation
3.1 Micro irrigation

The commonly used mechanism for micro irrigation is called Drip Irrigation. Under this technique polyethylene tube or taps having tiny holes are used for irrigating the plants, this result in economizing the use of water and fertilizer, since the water drips slowly and directly into the root zone. The technique is also known as trickle sub surface and micro irrigation High value crops growers were among the first one who adopted this technology. Different options of high efficiency irrigation system are available like online systems, inline drip systems, mini-sprinklers and high flow bubbler. It is suitable for arid / semi-arid areas where other sources of water are rare. It has been successfully used worldwide.

The system comprises simple parts and machine, which are easily available in the market like water pump, backflow valves, injector, filter, pressure gauge and regulator, valves, and properly hold plastic pipes, tube (laterals) etc., which can be atomized with the addition of Solenoid valves and a controller. Besides irrigation the plants/ crops, the system is equally effective for injecting the nutrients and nutrients and pesticides in the root zone of the plants. The system has its own merits and demerits. There are strong pro pounders, who opine that the technique results in more yields enhance profits, less labor, fertilizers, and pesticide requirements. However, installation of hand drip irrigation requires more skilled labors and enhanced installation costs, besides contaminating the tubing, getting rid of old crops and developing beds for new crops. Moreover, high degree of expertise is needed to supply timely and steady supply of water and nutrients to the entire irrigated area, acidification, chlorination, flushing and to avoid clogging of the drip pipes or tubes. Due to availability of a limited number of pesticides, which are suitable for injection, the danger of total loss of crop is always there. In spite of these drawbacks, it is the considered opinion of a large majority of the farmers, who have adopted the drip irrigation, that the technique is quite plausible and enjoyable.

Microirrigation is the slow application of water on, above, or below the soil by surface and subsurface drip, bubbler, and microsprinkler systems. Water is applied as discrete or continuous drips, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line adjacent to the plant row. In some parts of the world, microirrigation is called localized irrigation, which emphasizes; the only part of the soil volume is wetted. Thus, with the localized aspect, there are implications concerning
evaporation, transpiration, deep percolation, soil water, nutrient, and salinity distributions with respect to crop spatial position and root distributions. The shape or design of the emitter reduces the operating pressure from the supply line, and a small volume of water is discharged at the emission point.

### 3.2 Classification of Micro irrigation

The classification of microirrigation system mainly under two categories i.e. Drip irrigation that includes Drip Tapes/Lines (Surface/Subsurface drip), Bubblers, Flexible gated pipes, Family Drips and Sprinkler irrigation which includes Centre Pivot, Rain Gun, Impact Sprinkler, Popup sprinkler, Towable is as follow:

**Drip irrigation**
- Surface Drip Irrigation
- Subsurface Drip Irrigation
- Bubblers
- Flexible gated pipes
- Family Drip

**Sprinkler irrigation**
- Center Pivot
- Rain Gun
- Impact Sprinkler
- Popup sprinkler
- Towable
- Linear Move

### 3.3 Drip irrigation System

These systems are suitable for all row crops (vegetable/fruit, cotton) and have either dripline or drip-tapes. On-farm storage is required if water is supplied from a canal or other intermittent water source. They have low investment costs and good distribution uniformity. However they need to be replaced after every year (if handled carefully they may last up to three years). A layout design view of surface drip irrigation system is shown in Figure 3.1.
3.3.1 Surface Drip or Trickle Irrigation

Drip irrigation (also called trickle irrigation or micro-irrigation up to the minute) running through irrigation slowly, directly to the top soil through drip tape or lines as shown in Figure 3.2 and 3.3. The drip tape or drip lines and application emitters are shown in Figure 3.4, 3.5 and 3.6. The results of drip irrigation and high efficiency of two factors: the leaking water to the soil before it can disperse or flow, water is the application of the right to the roots of plants instead of spraying everywhere. While drip systems are clear and forgiving of errors in the design and installation, on which a few can provide the best irrigation system Drip technology is considered to be an effective technique for uniform supply of water and fertilizers to the crops since long. It helps in economizing the water usage by almost 50% and increasing the yield through improved water and fertility management.

The drip methodology is only beneficial, if it is properly installed and maintained. The system allows injection of water and nutrients to the roots zone of the plants through a network of valves, pipes tubes and emitters.
Figure 3.2: A view of Surface drip irrigation

Source: agricultureguide.org

Figure 3.3: Surface drip irrigation with loop design

Source: acarainstitute.wordpress.com

Figure 3.4: Surface drip tape
3.3.2 Subsurface Drip Irrigation

Drip irrigation subsurface is a method of irrigation, which minimizes the use of water and fertilizer by allowing water to flow slowly to roots of plants directly in the root zone through a network of valves, pipes, and drip lines as shown in Figure 3.7. Drip irrigation subsurface frequent slow application of water to the soil profile by emitters placed along a delivery line under the surface. Although subsurface drip irrigation is one of the oldest modern irrigation methods, relatively recent advances in plastics technology and equipment subsurface drip irrigation made more affordable and sustainable. A comparison of subsurface over surface drip irrigation is presented in Table 3.1.
In this system, water is applied slowly below the surface through the discharge of emitters which is less than 12 L/h. This is useful for small fruit or vegetables, because it does not require anchorage of lateral lines at the beginning and remove them at the end of the season and has little impact on cultural practices.

Source: ipm.ucdavis.edu

**Figure 3.7: Subsurface drip irrigation**

<table>
<thead>
<tr>
<th><strong>Surface Drip Irrigation</strong></th>
<th><strong>Subsurface Drip Irrigation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Less efficient water consumption</td>
<td>➢ More efficient water consumption</td>
</tr>
<tr>
<td>➢ Shorter life span of the system</td>
<td>➢ Longer life span of the system</td>
</tr>
<tr>
<td>➢ Smaller wetted volume of soil in root zone</td>
<td>➢ Bigger wetted volume of soil in root zone</td>
</tr>
<tr>
<td>➢ Soil surface does not remain dry-more weed control</td>
<td>➢ Soil surface remain dry-less weed control</td>
</tr>
<tr>
<td>➢ Longer time between two crop cycles</td>
<td>➢ Shorter time between two crop cycles</td>
</tr>
<tr>
<td>➢ Mechanical harvesting is not easier</td>
<td>➢ Mechanical harvesting is easier</td>
</tr>
<tr>
<td>➢ Not better water infiltration-surface crust to affect fertility</td>
<td>➢ Better water infiltration-no surface crust</td>
</tr>
<tr>
<td>➢ No labour savings in the coiling and rolling out of the dripper lines</td>
<td>➢ Labour savings in the coiling and rolling out of the dripper lines</td>
</tr>
<tr>
<td>➢ Less efficient of irrigation of awkwardly shaped and problematically sited lawns and landscape areas</td>
<td>➢ Efficient of irrigation of awkwardly shaped and problematically sited lawns and landscape areas</td>
</tr>
</tbody>
</table>
3.3.3 Bubbler or Mini-sprinkler

In this method water is applied to the soil surface in a small stream or fountain with a point source and the discharge rates for point source bubbler emitters are greater than the drip or subsurface emitters, ranging from 110-250 L/h but lesser than 225 L/h (Figure 3.8). The operating pressure of 1.0 to 3.0 bars. A small pond is necessary for proper water distribution. The bubblers are designed for flood irrigation in small localized areas. Demand for water in the soil surface is also a small stream or fountain (Figure 3.9 and 3.10). The heads are mounted bubblers, as are mini sprinklers on little plastic wedges inserted into the ground and connected to a PE lateral with a 7-mm flexible plastic tube 80 cm long. They are placed in a pound of trees one or two per tree. Due to enhanced discharge rate of emitter vis-à-vis the information rate of soil, a tiny tank is used to channelize the flow of water. It has not become popular among farmers because of low efficiency of application.

Mature trees require bubbler or mini-sprinkler systems that provide water to the entire root system. For young trees point-source drippers can be used provided they are expandable with more drippers to account for higher water requirements as the trees grow. In densely planted orchards and with grapes-drip lines are also an option.

Source: fao.org

Figure 3.8: Schematic view of Bubbler Irrigation System
3.3.4 Flexible gated pipes

Pipeline systems are usually fixed to minimize labour and maintenance costs. In addition to that reduce water losses due to seepage, evaporation, spills and no crop vegetative consumption. Underground pipeline constructed of steel, plastic, or concrete is permanently installed whereas above-ground pipeline generally consists of lightweight, portable flexible rubber based hose, aluminium, or plastic. One form of above ground pipeline is flexible gated pipe through which water distributes by mean of gravity flow systems from individual gates.
(valves) along the pipe as shown in Figure 3.11 and 3.12. Pipeline systems are the main means of water conveyance for pressurized application systems.

Source: forestryimages.org
Figure 3.11: Flexible gated pipe for use in irrigating field corn.

Source: ers.usda.gov
Figure 3.12: Gated pipe for use in irrigating field.
3.3.5 Family Drip Systems

Family Drip Systems are suitable for home gardening and peri-urban agriculture. They may also serve as an entry level drip system to allow farmers to experiment and get familiar with the technology. Family drip systems are designed for areas of 500 to 1000 m². They are best be used in peri-urban agriculture where farmers may have limited land and access to small sources of water (dug-well, piped water, ditch). Family drip system consists of only five components (elevated tank, shut-off valve, filter, mainline, drip-line). Drip-lines are being used because of the low pressure being used. Family drip system is cheap, easy to install and to operate. The filling of the tank is done by manual pump, treadle pump or a small electric pump. Family drip system is shown in Figure 3.13 and 3.14.

Figure 3.13: Schematic view of Family Drip System

Figure 3.14: Family Drip System.
3.4 Sprinkler System

Sprinkler systems will be specified for field crops (pulses, maize, sugarcane, some vegetables). On small fields either solid set or semi solid set systems will be installed. Semi solid set systems (hose-move systems) have been used successfully by small hold farmers in many countries. They are relatively cheap (about half the costs of a drip system) and easy to maintain and operated. Their disadvantage is relatively high labour requirements for the movement of sprinklers. The sprinkler systems are shown in Figure 3.15 and 3.16.

Figure 3.15: Linear Sprinkler System

Figure 3.16: Side Role Sprinkler System
3.4.1 Center Pivot

On large fields Center Pivot Systems will be used. This is a solid, time tested technology and relatively cheap per unit of irrigated area. Though, they require a level field, good and reliable source of water (preferably a well because on-farm storage would be too expensive) and a dependable source of energy. Center Pivots should be operated by trained technicians. A centre pivot system is shown in figure 3.17.

![Figure 3.17: Centre Pivot System](image)

3.4.2 Spray Irrigation or Rain Gun

Another technique being used for field irrigation is known as Spray irrigation through which water is sprayed under high pressure on plants as shown in Figure 3.18 and 3.19. This method is also known as sprinkler irrigation and is in vogue worldwide. This system is used as a small water spray mist or fog beam and discharges of less than 175 L / h and is used to irrigate trees and other crops widely separated. They are mainly used for fruit tree crops like, Citrus, mango, guava, avocado, etc. They have a diameter of a small passage, which filtered water is essential with a requirement with a requirement of 60-80 mesh filtrations (250 to 200 microns). The operating pressure is between 1.5 to 2.0 bars. Their heads are mounted on little plastic wedges (or piles) 20-30 cm above the ground and they are connected to the PE laterals with 6-8 mm flexible plastic feeding micro-tubes 60-120 cm long and a barbed wire plunger. They are placed one or two per tree, 30-50 cm apart.
The system is equally effective for irrigating the home lawns and huge crop beds. Similarly, moveable as well as immoveable sprinkles can be used keeping in view the irrigation requirements. However, a lot of cautions for installing these sprinkles which emit water in one direction only, while the rotating sprinkles may cover a much broader area through spray of water in all directions. For this valid advantage the rotator head sprinkles are most common now a day. There are numerous sources of water for spray irrigation. However, city government in the West is now encouraging the usage of treated waste water for this purpose which is environmentally friendly too. But the usage of treated waste water is quite risky for the crops required for human consumption. For food crops, traditional sources of water like Wells, ponds, streams, rivers, lakes etc. may be preferred. The usage of waste water may be beneficial for ornamental flowers and landscaping. Spray irrigation consumes more water as compared to other latest techniques since during the process of spray, not only some water is blown away, but a suitable quality is also evaporated. It is the biggest disadvantage of spray system. Moreover, a sufficient amount of water may not be sprinkled on the targeted area and may be wasted. This results in making the scheme costly and also environmentally unfriendly.

Source: vdh.state.va.us

Figure 3.18: Spray Irrigation
3.4.3 Impact Sprinkler

An Impact sprinkler or an impulse sprinkler as shown in Figure 3.20 is a type of irrigation sprinkler. The impact sprinkler's has long throw radius and uniform water distribution recreates the effect of natural rainfall. It is mostly used in landscaping.

Source: popularmechanics.com

Figure 3.20: Impact Sprinkler

3.4.4 Popup sprinkler

A range of popup sprinkler makes it easy to integrate a durable micro-spray into a low-volume drip irrigation design as shown in Figure 3.21. The popup sprinkler is also ideal for applications that require flexibility and ease of installation and making them ideal for
seasonal flower and planting beds. These work from a variable thickness micro supply tube and have a throw of various ranges.

3.4.5 Towable Pivots

Towable Pivots provides the growers the most economical possible mean to start using mechanized irrigation with following features like it can easily irrigate fields from 5- to 300-acres, take advantage of the investment machine can easily be towing more than one field (shown in Figure 3.22). Each machine can be towed from one field to another even less than an hour; can choose from an on-board engine generator or public power supply.
3.4.6 Linear Move

Linear move equipment which is shown in Figure 3.23 is often times seen as one of the most highly proficient methods of irrigation. Linear irrigation equipment moves through a field by adopting one of several types of provision options like below ground cable, above ground cable, furrow, or NOW GPS Guidance. GPS Guidance increases accuracy and is the best choice for precision irrigation.

Source: clemson.edu

Figure 3.23: A Linear Move sprinkler system

3.5 System Layout and Components of Drip Irrigation

The basic system of drip irrigation surface is presented in Figure 3.24 and Figure 3.25. There are three sub systems in micro-irrigation system: 1) Control head unit 2) Water carrier system 3) Water distribution system. Selection of appropriate components for the specific type of emitter chosen by the cultivator needs particular expertise. For example drip system with emitters spaced wider line is appropriate for irrigating the citrus crop, while, integral drip line source emitter will be suitable for watering the vegetable fields. However, for irrigating the fruit crop, sometimes spray irrigation either micro sprinkles or micro jets may be beneficial.
3.5.1 Pumping Station and Source of Water

The source of water supply can be a tank, a pond or a door open well. Water can also be provided by a collective water distribution network. Clean water is better for a satisfactory functioning without problems, of a micro-irrigation system. Filter may be necessary of the source water is a river or reservoir, because they contain organic material or foreign bodies,
but it is not necessary for the supply of relatively clean. A pump is needed to provide water to
the desired head pressure with all the necessary accessories such as motor protection devises,
fences and shelters, base, sump screen, valves, motor controls. It is generally centrifugal, but
for small systems, a piston pump is entirely appropriate. High containers are also used in
some areas with limited external energy source.

3.5.2 Control Head and Station
The control station includes facilities for water measurement and timing of application (water
meter or metering valve), filter unit, the (or a combination of gravel, disk, screen or filter
hydro cyclone according to the quality of water) for water treatment equipment and
fertigation (fertilizer tank or fertilizer, flow pressure regulators, and prevention of backflow
and other safety valves. A simple control head model is illustrated in Figure 3.26.

Figure 3.26: Control head and scheme for micro irrigation system

3.5.3 Filtration System
Assembly of independent monitoring of the physical components used to remove solids
suspended in water for irrigation. It may be strainer, filter disc; filter unit hydro-cyclone and
gravel filters (Figure 3.27), alone or in combination depending on water quality. The
common source of water supply includes wells, ponds, lakes, municipal lines etc. The water
extracted from the wells is usually clean and carries a small amount of inorganic particles,
which can be purified with the help of screen or disc filters. However, it is prudent if water is
properly got tested from the lab to ascertain the exact quantity of contaminants before
finalizing the selection of specific drip system. Since test reports of water supplied through municipal lines are readily available, this makes the selection process of drip system much easier. The water extracted from streams, ponds, pits or rivers is highly unpurified and carries a verity of bacteria, algae or other aquatic life, expensive sands filters are necessarily required to make it suitable for use in micro irrigation.

Figure 3.27: Filter units for microirrigation system

3.5.4 Air & Vacuum Breaker Valve
These valves are of great importance, because they protect the network of pipes against damage caused by air trapped in the system or a collapse due to a empty space. The presence of free air in the water causes many difficulties in installing the pipe system at startup, during operation and when draining the system. The air valves (Fig. 3.27) are necessary so that air can be either released or admitted into the pipeline. Its operation and the air flow rate cannot be influenced either by the system operator or by the performance of any other electrical devices.

3.5.5 Non Return Valves
Check valves, also known as non return valves, allowing flow in one direction and prevent flow reversal in piping through an automatic control mechanism (Figure 3.27). Water flow keeps the check valves open, and the gravity and flow reversal in piping through an automatic control mechanism (Figure 3.27). Water flow keeps the check valves open and the severity and reverse flow automatically close. They are placed in line with the main unit of control
immediately after the pump. Check valves are made of metal and several brass materials and are screw type (female joints) quoted in inches (1.5", 2.0", 2.5", 3.0" and 4, 0").

### 3.5.6 Pressure gauges

Measurement of pressure in key points in a network is of major importance for the water system operator. The pressure gauge (Figure 3.28) must be installed in locations easily accessible, making it easy to read and maintain in good working condition. The pressure gauges most commonly used in water supply and distribution service are the Bourdon gauge, in which the main element is an elastic metal tube. As the pressure in the tube increases the oval tube tends to become circular, which causes it to uncoil slightly.

![Figure 3.28: Safety valves for microirrigation systems](image)

### 3.5.7 Water Meter

Water meters measure and record the volume of water passing through them, ignoring the time factor (Figure 3.29). Reading the output of a water meter provides information on the volume of water flowing through the device at a time, starting with the last reading or zeroing of the meter. The most common type used for irrigation water is a Wolman type impeller axial flow. The velocity of flow activates the impeller and the turns are translated into total volume of water transmitted to the display dial through a series of reducing gears. They are manufactured in different models, with the cast iron body, and are built as compact units or with an internal interchangeable mechanism. Sizes up to 2 in are available with threaded connections, large sizes with clamps.
3.5.8 Pressure Relief Valves

Safety valves are valves in the line of smaller diameter than the pipeline, spring-loaded or otherwise, in which the outlet is inclined 90° to the inlet (Figure 3.30). When the pressure in the system exceeds the value pre-established, the valves open and release water into the air. Thus they avoid the pipes of failure due to sudden high pressure, which could occur in the system. They are located immediately upstream of the main valve of the system. They are available in sizes from 1-3 in with threads.
3.5.9 Pressure Regulating Valves
Pressure control valves are either direct acting or pilot controlled (Figure 3.31). Pressure regulating valves are often installed at the entrance of the sub-mains to ensure a constant pressure to the side. They are available in brass, bronze or plastic in various sizes with threaded connections.

![Figure 3.31: Pressure regulators](image)

3.5.10 Main Pipeline
This is a larger diameter of the pipe network, able to convey the flow of the hydraulic system under conditions favorable to the speed of flow and friction losses. They are manufactured in standard lengths of 6 m, and in several series and classes indicating the pressure of work, according to various national and international standards. The maximum flow rate should not exceed 1.5 m / s. In accordance with international standards Rigid PVC pipes are available in nominal diameters (DN), which is the approximate outside diameter, in 40, 50, 63, 75, 79, 110, 125, 140, 160, 200 and 225 mm. It supplies water to sub main water supply pipelines. The working pressures are 4.0, 6.0, 10.0 and 16.0 bars at 24 C. At higher temperatures, pressure decrease accordingly. All fittings and valves for PVC pipes should be thrust blocked to prevent them from moving while in operation due to the thrust of water pressure. Very light in weight, they are easy to transport and handle on site. Their only limitation is that they must always be fixed permanently underground, protected against the high or low ambient temperature and solar radiation. The estimated average life of buried uPVC pipe is 50 years.
3.5.11 Submain Pipeline
These are water pipes that carry water from the water main line to feeding laterals. They are placed below the soil and water supply to laterals. They are made of rigid PVC, HDPE and LDPE pipes are typically used, with diameters of 32-75 mm, which are capable of bearing pressures of 2.5kg/sq cm. They are commonly placed on land while it is laud subsurface in case of subsurface drip irrigation system.

3.5.12 Flush Valve or End Cap
In order to stop the leakage of water from the fall tube, End cap is used in micro irrigation. In the drip system, water travels in the pipes very slowly due to which sediment remains unsettled. Resultantly, a thin layer of sediment is created inside the tube which needs to be flushed out regularly. In some climates, algae can grow in drip tubes and should be removed periodically. Usually drip pipe washed once a year. If algae problems continue to occur then needs of drip tubes to rinse becomes more frequent. This problem can be overcome with the installation of automatic valves that flush pipes as soon as water is turned on. Cap or manual drain valve may be only looking at the end of the infusion tube is crimped the flow. Then use a wire or cable / Zip tie to to hold the tube in position crimped and straightening of the tube when ever want to wash.

3.5.13 Control Valve
Control valves are those which are used for channelizing the water flow for separately irrigated areas. Control valves may be automatic i.e. basically powered by an electric solenoid or manually i.e. manual feed, having three control levels, Similarly, these can be only one control valve for the entire system or valves depending upon the requirements of irrigation. For example, there can be separate control valves for water emitters or drippers in the vegetable corner, hanging pots at home and the grassy grounds, which can be turned on and off independently as per requirement of the specific area

3.5.14 Lateral (Irrigation Lines)
Lateral tube or pipe is located between the valve and the drip pipe. Lateral pipe or tube may be PVC, PEX, or PE. Lateral is located after the pressure regulator i.e. downstream, so do not use high-pressure hose or pipe. Class 200 PVC standard polyethylene pipe irrigation works well for this system. Class 125 PVC can also be used, but be careful, because it breaks easily.
PVC damaged in the sun and should be buried or protected. Apply several layers of thick paint or PVC packaging tape with aluminium if it is above ground. Many small systems do not include lateral or branches, drip tube connected directly to the control valve. Laterals are often used for several drip pipes necessary, for example, when the irrigated area is too large for a single tube flow e.g. when the irrigated area is too big for a single drip tube. As an example, a single or multiple lateral branches may extend from a single control valve to several drip tubes located in different regions of a yard (http://www.irrigationtutorials.com).

3.5.15 Emitters

The emitters determine the speed of water flowing over the ground. These are usually made of plastic, which can be easily screwed or snapped onto the drip pipe. The most popular emitter available in the market sprays four liters (4 L / h) or one gallon (1 gph) of water per hour. However, a lot of variety of emitters is available in the market having their own plus and minuses. These can be classified into groups according to type about how the design and the method they use to regulate the pressure. A simple emitter can be created by drilling a tiny hole in a pipe. However, a hole alone does not work well. Unless the hole is extremely low, the water tends to force it to push like a little fire nozzle and way too much water will come out. More importantly, there is little uniformity of the flow using a single hole. A long pipe with holes drilled through the holes in it near the end of the water source will have a significant flow of water from them, while those at the end will have a very low flow.

From a simple hole in a pipe does not work very well, the first pioneers of drip irrigation started playing with mechanical devices that would better regulate the flow. These devices gave the name of "emitters" (or sometimes "drip" is used.) emitters are installed on the pipe and act as small throttles, ensuring a uniform rate of discharge is emitted. Some are built into the pipe or tube, others give using a buckle or threads. The emitter reduces and regulates the amount of water discharged.

3.6 Principles of Drip Irrigation

Micro irrigation is the modified composite nomenclature of the terms “drip " " trickle " and "spray" irrigation, which had been in vogue during the past few decades. It encompasses all techniques through which water is applied at slow rate on or under the soil. In this technique water is injected to the root zone directly as per requirement of the respective crop. A candid
application of micro irrigation systems keeps the root zone of the plants fully moisturized besides ensuring consistent water level essential for plants growth. Moreover, précised and controlled supply of nutrients and fertilizers can also be ensured under this technique. Micro irrigation plays a very clear effect on the quality and quantity of crop, disease control and reaps time particularly under water scarce areas.

3.7 Irrigation Uniformity of Micro irrigation

A uniform provision of water is prerequisite for an effective irrigation management system. It implies an even distribution of water all over the field. It is not an easy task to ensure that all parts of the field receive equal amount of water. The degree of homogeneity is co-related with the adopted irrigation system and smooth and uniform supply of water to the entire area under cultivation.

Uniform supply of water to all parts of a huge field is an uphill task, which not only requires a lot of expertise and completes knowledge of soil properties, but it also needs perfect and fully operational irrigation system. If we want maximum performance from the soil, we will have to ensure that all parts of the field receives uniform water supply which is sufficient for deep percolation. The parts which achieve deep percolation will be considered as “irrigated” while the areas which remain devoid of deep percolation be considered at under irrigated. Obviously the irrigated sections will produce optimum performance, while those having less deep percolation won’t produce the desired results. It is considered opinion of scientist that maximum performance through non uniform irrigation will remain an allusion only.

According to a section of scientist irrigation efficiency (I.E) is a pastier sign but it is not considered to be a sole yard stick due to the reason that there are many a deficiencies of irrigation efficiency. Similarly, the definition of the term "applied water" also varies from scientist to scientist. According to a group of scientist, it is the amount of water distributed in the area including the runoff from the field. Others avoid runoff and water are used to determine the water that seeps into the soil and potentially available for crops. It is clear that a lot of different irrigation performance results, considering definition of water used. For this analysis, we determine the applied water that leaked into the field and irrigation efficiency as ET: AW. However, we can easily change the irrigation water efficiency numbers by disturbing quantity of water used for the purpose. Another approach is to improve the uniformity of irrigation. Increase in yield i.e. more ET and shallow penetration by utilizing
the same amount of water, which ensures enhanced irrigation efficiency. However, more cost will have to be borne to achieve greater uniformity. Technically, the irrigation efficiency gains are not always positive goal, but the uniformity of irrigation increases. We therefore urge the closing of the concept of irrigation efficiency in resource use and potential degradation of groundwater by ensuring the irrigation methods, which can be classified as furrow, sprinkler or drip.

We can ascertain the quantum of uniformity under furrow irrigation method by quantifying the flow of water in the furrow. As there will be more water in the upper portion of the field than its rear portion, the chances of deep percolation would be minimized. However, it will result in non uniform distribution of water in the overall irrigated area. The penetration rate is also affected by the soil properties in the region and may also contribute to uneven watering. Another factor that contributes to deep percolation is no consideration of Heterogeneity of soil variability in the calculations, which at times may be 50% of the total number of non-uniformity. No doubt the runoff water also helps in bringing consistency in the irrigation, but it is not as effective in transporting chemicals into the root zone, as unification can be achieved at the expense of increasing depth percolation.

Containers are placed in the geometric pattern to measure the exact amount of water collected in each tank. The data so obtained is analyzed by Appling various methods like furrow, sprinkler or drip to calculate the uniformity of irrigation numerically but estimation can be adversely affected by weather conditions especially in the case of sprinkler irrigation. Similarly, the size of container is another factor that can affect the uniformity of irrigation in the numerical terms. In other words, for a series of small containers, typically involves a high degree of variability of the estimated distribution of an equivalent number of even large containers. Note that the full measure of change ascertained under this technique during the given time frame. Unified drip irrigation system is usually a combination of the frequency of emission from each emitter and fluctuating pressures applied to the system. Therefore, the heterogeneity variability can easily be measured like the sprinkler system, since the process remains consistent throughout its operation.

The concept of measurement of homogeneity assessed through the application of various irrigation technologies is hazardous. For example, in furrow irrigation, elements of consistency in watering the plants is quite negligible due to the absence of sprinklers or drip,
which are the most appropriate tools for uniform irrigation of the fields. Therefore, we cannot compare the results of furrow irrigations with that of sprinklers or drip irrigation. Similarly, the data of furrow irrigation also varies from field to field and is incomparable. The main advantage of the measurement system is the only way is to steer management. Uniformity of irrigation can be changed through the span of the furrow, the proportion of water utilized as well as time allowed for irrigating the soil. The furrow irrigation system can be significantly improved through a candid and careful assessment of characteristics of homogeneity. Uniformity and quantity of water demand are two important factors relating to degradation of groundwater. And probably contribute to the amount of chemicals deep infiltration of transport. The flow of water can be precisely controlled through Sprinkler system and drip irrigation systems. However, it is a known drawback of the Furrow irrigation system that it is unable to control the quantity of water required to infiltrate the area.

Development of proper layout and its management mechanism are the basic ingredients for performance evaluations of any irrigation technique. Inadequately drip design and poorly managed irrigation with significant changes in pressure or choked emitters can put the entire irrigation system in to jeopardy. Although, a more precise and controlled uniform water supply is observed in the drip system then furrow, the success of the sprinkler system is greatly subservient to the wind factor. Moreover, the installation of drip system cost much higher than the furrows but its benefits do not adjust its higher investment cost at times. Similarly, if the degradation of ground water is properly accounted for, they offer financial incentives to increase the conversion of irrigation technologies.

### 3.8 Advantages of Micro Irrigation Systems

Micro irrigation systems have many advantages over other methods of irrigation potential. However, the major objective of all the system is focused on the conservation of water for irrigation purposes however, the other benefits vary from system to system and their overall combination transforms the micro irrigation into a unique system. Some of the major benefits of the system are explained below:

#### 3.8.1. Water conservation

Requirements of irrigation water compared to other methods of irrigation may be less with micro irrigation. Due to less consumption of water there may be reduced evaporation which
may result in less runoff water. As small surface area under the plant is wetted and well shaded by the foliage under this system so evaporation losses reduced significantly as compared with other irrigation system. As micro irrigation system allows a much better water control application resulted deep peculation minimized or avoided.

3.8.2. Reduced energy requirements

As water application rate in micro irrigation systems is significantly lower than to other systems resulted smaller sources of water can be used for irrigation of the same acreage. Pump, delivery pipes and other system components are so inexpensive enough. As the system’s operating pressure is as low as 5-30 psi, it needs much less power for pumping as compared the systems with high pressure.

3.8.3. Provision of nutrients and pesticides

Micro-irrigation system also offers a precise and controlled application of chemicals to the plants root zone. Since it is directly applied to root zone of the plant, so reduction in fertilizer possible. In humid climate frequent application of fertilizer is also an advantage of this system. Even a very small proportion of the applied chemicals may be washed in the rainy conditions due to which the fertility ratios of the soil won’t be affected adversely.

The application of chemicals and nutrients through micro-irrigation system does not require any additional expenses. Due to economized application of chemicals through the season, there is least possibility of underground concentration of chemicals. Thus, maximum benefits can be extracted from the application of chemicals and nutrients of effectively improve the crops’ growth.

3.8.4. Adoptability to high salt content water

Another significant property of micro irrigation is that the system can effectively use even the water with high salt content. The growth and survival of the plants need that consistent optimal range of water potential is ensured in the root zone. Despite the presence of water in the soil, various other factors also contribute in the proper growth of the plants. For example, in very dry soils, water potential decreases to almost zero level and the crop rise away despite presence of sufficient amount of water in the soil.
Total water potential can be defined as the amalgamation of metric potential and osmotic potential matrix. In micro irrigation the metric potential i.e. high water is simply negligible. Obviously osmotic potential component may impact its negative value, which involve more salt concentration. However, it is not applicable in the same sense in other sense in other irrigation systems.

3.8.5. Improved yield quality
Despite usage of very small amounts of water and chemicals, the micro irrigation system ensures higher yield both in quality. The farmers can also effectively control the harvest period through water management during dry seasons/ climates.

3.8.6. Multiple topographical utility
Specifically designed micro irrigation systems can also provide apt solutions to the problems of rugged terrains. The system can be effectively introduced in all types of terrains including mountainous regions with proved success.

3.8.7. Additional minor benefits
Since the leaves remain dry in micro irrigation, it helps in controlling the crop diseases and insects mushrooming in arid climates and dry months. Similarly, in the absence of water on the soil surface, we can continue with the field operations even when the irrigation process is in operation. Although, the flow of water is not affected by wind in drip irrigation yet it can create significant disturbance in the spray process. Due to selected moistureization of soils under drip irrigation system, the process of weeds mushrooming also remains effectively controlled. The system can be atomized by the installation of a central control panel/timer as per requirements of the irrigation, which results in reduced operating costs and less man power.

3.9 Limitations/Potential Problems in Micro irrigation
To function well, micro-irrigation systems must be accurately designed and operated keeping in view the peculiarity of soil, quality of water, irrigation requirements for the cultivated crops. However, a lot of expertise and time is needed to address to these prerequisites failing which the micro irrigation system may not work to the desired level.
3.9.1. Clogging

Blockage of emitters is the main problem faced by the farmers who adopted micro irrigation for watering their fields. Its tiny holes are easily choked by mud, concentrated chemicals, weeds, organic matters, bacteria, algae etc. however, this problem can be overcome to a great extent by using good quality filters.

3.9.2. Moisture Distribution

Distribution of Moisture mainly depends on the type of soil irrigated by micro irrigation systems. In some soils like deep sand, minimum lateral movement of water observed due to problems created by low capillary forces. Due to dominance of gravity forces, the moisturized volume adopts a cylindrical shape as reflected in figure 3.32. Thus, it becomes quite difficult to properly moisturize the root zone of the plants in such conditions. Besides, it is not easy to ensure desired quality of irrigation in the absence of deep penetration, which allows storage of only a very limited quantum of water in a humid field. Sufficient quantity of emitters will pick up the water supply in the field, which will ultimately result in a healthy harvest and enhance yield. However, the area between the emitters as well as their number needs to be properly worked out in consonance with the requirements of each crop and soil. It should be kept in mind that micro irrigation moisturizes only a small part of soil, which may be suitable for growth of plants in majority of cases. However, there is a possibility that roots are not properly irrigated, which may result in sharp decline in the productivity.

![Figure 3.32: Moisture distributions as a function of soil texture](image-url)
3.9.3. Salt Buildup

As discussed earlier, Micro irrigation systems are equally effective in salt water. But, the situation is aggravated when salts get deposited in large quantity on the earth surface during drought, as reflected in Figure 3.33. These salts are injected into the root zone by heavy rains causing damaged to the crop. The dry areas having a rainfall of less than 10 inches a year, sprinklers or other modes of surface irrigation are used for removing the accumulated salt to ensure that the amount of accumulation may not assume an alarming proportion.

![Figure 3.33: Salt buildups under micro irrigation system](image)

3.9.4. Initial Cost

As compared to the other irrigation methodologies, the initial installation and running costs on micro irrigation systems are definitely on the higher side, which fluctuate significantly on account of atomizing the system as well as the selection of specific micro system. However, the benefit accrued from the micro irrigation system in the long run will out run its initial investment and operating cost.

3.9.5. Additional Drawbacks

The underground weeds and insects also contribute in choking of pipes holes. Similarly, the networks of pipes are also broken by pedestrians who are not aware of their underground presence. Moreover, the methodology does not provide answer to the problem of frost, which is one of the most damaging factors for good harvests.
3.10 Adoptability

It’s been a very fast rate of adoption and deployment of micro irrigation of different countries over the past three decades. According to Reinders (2000), micro irrigation systems made major advances in technology development and the uptake of the technology increased from 3 Mha in 2000 to more than 6 Mha in 2006, as shown in the Figure 3.34. Although, there has been a tremendous increase in the use of micro irrigation continue the total area micro irrigation remain only about 0.8% of the total irrigated area in the world.

![Area under micro-irrigation in the world](image)

Source: Reinders (2000)

Figure 3.34: Area under micro-irrigation in the world

3.11 Agronomic Aspects of Drip Irrigation

3.11.1 Planting Configuration in Drip Irrigated Crops

Cost problems tend optimum drip layout to maximize the distance between the lines or rows. But the line spacing is greater than optimum plant population decreases, and returns. If the plant population remains optimal, it becomes necessary to adjust the lines. In this case, the plants of the line are usually located closer than normally recommended. Several studies have shown that in many crops, a change conventional rectangular planting geometry with lateral support for each how to either square or equilateral planting geometry can lead to a paired row planting in changing plant population / ha (Figure 3.35 and 3.36). Under these conditions, a lateral was able to control each line pair. A common lateral layout for drip irrigation in orchards is sown in Figure 3.37.
Source: californiaagriculture.ucanr.org

Figure 3.35: Planting configurations of tomato plots under drip irrigated crops

Figure 3.36: Planting configurations for drip irrigated crops
Figure 3.37: Common lateral layouts for drip irrigation in orchards
3.11.2 Wetting Pattern under an Emitter

A point delivery system is causing a three dimensional infiltration pattern and the shape of the wetted soil volume is mainly due to capillary forces and gravity. The water distribution in each dripper is a bulb shaped zone where most of the irrigated land is under the soil surface (Figure 3.38). The width of the wetted "bulb" is mainly due to the hydraulic conductivity of soil, while the depth is a function of both the saturated hydraulic conductivity and gravity, for this reason, the vertical axis of the water distribution usually longer than the horizontal axis. The horizontal/vertical length ratio is correlated positively with the hydraulic conductivity of soil, and the ratio is higher in finer textured soils (Figure 3.39).

![Figure 3.38: Wetted bulb under an emitter](image)

Normally, with low level intensity of irrigation, only a portion of the area is wetted (in the orchards and row crops). However, it appears that the wetted part should be certain minimum value that has not been determined experimentally. However, one can conclude that the system has high wetted portions values, provide more insurance against system down time, so they should be easier to schedule and bring more soil into action for storage and delivery of nutrients.
By taking into account, the current knowledge, that is a reasonable design objective is to wet at least one third (wetted portion = 33%) of the potential root volume widely spaced tree crops. In closely spaced crops, most of soil volume must be moistened to ensure an adequate supply of water for each plant. In areas that have significant additional rainfall, lower wetted part values may be accepted. On the other hand, when irrigation widely spaced crops, with drip, wetted part should not be too much because many of the benefits of drip irrigation are dependent on keeping the strips between rows relatively dry. In some cases, not only the extent of wetting portion/part is important, but also the wetting pattern. Figure 3.40 shows some empirically derived graph of the wetted diameter of the emitter discharge rate for different soils, where the wetted diameter is known, the wetted area may be calculated.
3.11.3 Rooting Pattern

The maximum capacity of the roots of water absorption depends on their surface, which is a function of their length, number and diameter. Small roots have a relatively high surface area per cross section per root mass. A large mass of small rootless will therefore have surface areas, which are a few orders of magnitude larger than an equivalent mass of large diameter roots.

In conclusion a high concentration of small rootlets in the confined volume of irrigated soil under the dripper may have an enormous capacity to deliver water to the above ground canopy due to greater root surface area, a relatively low dependence of water movement in soil, a continuous supply to the last part of the root system to the optimal SWP, and the transfer of water between wet and dry roots (Figure 3.41). Such root systems may be formed under drip conditions, subject to high water availability and aeration prevails. Adequate water supply can be maintained through periodic water applications.

![Figure 3.41: Rooting pattern: Drip verses other irrigation methods](image)

3.11.4 Soil Water Availability

In drip irrigation water and fertilizer to the root zone of plants directly applied at frequent intervals (daily) in controlled quantities as required by the plants. Additional cyclical nature of water depletion associated with conventional irrigation methods can be avoided and soil moisture levels can be maintained at optimum moisture content levels, i.e. field capacity continuously, wherever the conditions for plant growth are ideal during the whole period of the crop. Figure 3.42 compares the status of soil moisture status in drip to sprinkler and flood irrigation.
3.11.5 Aeration

Aeration in the root environment is required for inhalation. Plant organs of fruit trees cannot function normally under sustained anaerobic conditions because the effects on respiration process, reduces energy production and use as necessary to maintain the processes such as cell elongation and division, harmonic production absorption etc. Water availability and soil aeration is inversely related to each other, because the water fills the air space between soil particles and thus pushing the air out during the irrigation process (Figure 3.43).

This appears to be a correct assumption for all irrigation methods, which wet most of the soil surface. But in drip irrigation technique, there is always a gradient of soil water potential from the irrigation point to the margins of the irrigated soil volume, and conversely a reverse gradient of air form the margins of the irrigation point. In practice there are many orchards watered daily to drip so much from 10 to 12 hours continuously without showing any sign of water logging effects, such as Iron-induced chlorosis, stunting growth, wilting, or Phytophthora root rots and no root damage or decay even directly under the emitter, where continuous soil water saturation exists over period of weeks or months. Therefore, unlike other irrigation methods, seems no interference between water availability and soil aeration appears to exit in the drip irrigated orchards. This advantage may explain the observation of advanced maturity and improved quality of fruit from drip irrigated trees. The mechanism of
this effect may be connected to the oxygen transfer from roots located at the interface between dry and wet soil, where exposure to air is abundant, the roots in water saturated area directly below the dripper.

![Figure 3.43: Water and air distribution under an emitter in wetted onion bulb](image)

### 3.11.6 Mineral Nutrition

Although minerals are <10% of a plant's dry weight, their level and composition of various plant organs is of fundamental importance for the control of various physiological process of production and quality control of agricultural produce. The main constituent of plants are organic, and depend the quantity and quality and quality of the unique ability of plants to fix atmospheric carbon dioxide via photosynthesis, this process is regulated by environmental factors, including light, temperature, humidity, carbon dioxide concentration on one side and plant evidence to tissue hydration, mineral content and composition, and genetic factors, on the other. The mineral requirement for optimum production varies in many cases at various stages of growth and development, including germination, vegetative growth, fruit bud.

Paired row planting with either square is equilateral planting arrangement not only reduces system cost by 50% but also gives higher yields with superior quality, save water, minimize direct soil evaporation and prevents deep percolation below the root zone. The potential for fertilizer savings also seem significantly with paired row planting. Few examples of the paired row planting with one lateral, serving two crop rows are shown in Figures 3.44, 3.45 and 3.46.
Figure 3.44: Paired row (square) with one lateral irrigation two rows of lady’s fingers

Figure 3.45: Paired row (square) with one laterals irrigating two rows of cabbage
Figure 3.46: Paired row (square) with two laterals irrigating three rows of baby corn
CHAPTER 4

Study Design and Description
4.1 GENERAL

Augmenting the performance of irrigation water is one of the economically feasible alternatives in overcoming the shortage of water. This is not only vital for the sustainable agricultural yield but also to meet the challenges of current environmental issues and justice, financial problems and physical impediments in the developing countries. To overcome these situation modern techniques of high efficiency irrigation system i.e. drip irrigation system may be used. This system attains significant importance in the recent years due to scarcity of water. The drip irrigation system is further categories in to surface and subsurface drip irrigation system. The surface and subsurface methods are effectively used for crops as well as fruit trees. These methods have its specific features and limitations. Surface drip irrigation and subsurface drip irrigation methods may play a significant role in overcoming the shortage of water particularly in arid regions

The aim of this research work is to investigate the efficiency and practicality of surface and subsurface drip irrigation systems for irrigating crop and fruit trees and to compare these two irrigation system as well as to study the effect of surface and subsurface drip irrigation system on yield and water conservation under the arid climatic conditions of Saudi Arabia.

4.2 STUDY-1

A study was designed for varietals organic seed production of tomatoes crop under surface and subsurface drip irrigation system. The aim of the study was to produce varietals (F2) organic seed production, as well as to know the performance assessment of these two irrigation systems in respect of their water used efficiencies; crop yield, yield water ratio and economic analysis of these two systems.

4.2.1 Site Selection

The study area is situated nearby Buraidah city of Al-Qassim province, Saudi Arabia as shown in the Figure 4.1. The study area lies at altitude 574-724 meters with latitude and longitude ranges from 26.1-30.0°N and 37.0–41°E respectively. A small greenhouse
comprising 1200 m² was selected from the existing greenhouses of Al-watania Agriculture Company, for this study as shown in the Figure 4.2. The source of irrigation water was tubewell water of five tubewells. The water analysis of these tubewell is presented in Table 4.1. The study area consists of sandy clay loams.

**Table 4.1: Water Quality of irrigation source (Tube wells)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Experimental Site</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Well#1</td>
</tr>
<tr>
<td>pH</td>
<td>7.79</td>
</tr>
<tr>
<td>Total Dissolved Salts (ppm)</td>
<td>890</td>
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<td>Total Alkalinity (ppm)</td>
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<td>Cl⁻ (ppm)</td>
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<tr>
<td>Mg²⁺ (ppm)</td>
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</tr>
<tr>
<td>Fe³⁺ (ppm)</td>
<td>0.038</td>
</tr>
<tr>
<td>SO₄²⁻ (ppm)</td>
<td>310</td>
</tr>
<tr>
<td>NO₃ (ppm)</td>
<td>23</td>
</tr>
</tbody>
</table>
Figure 4.1: Agro-Climatological areas, Kingdom of Saudi Arabia (Experimental Sites Buraydha, Al-Qassim, Saudi Arabia)
4.2.2 Climatic Conditions

Study area is located in one hydrological region with elevation of 649 meters, latitude of 26° 18' N and longitude of 43° 46' E. The climatic condition of the experimental region is inland moderately hot and dry. The highest monthly temperature varies from 30°C to 48°C. Relative humidity values are ranging from 17 to 57%. Wind speed values vary from 122 km/day to 222 km/day and annual ETo is 2495mm. The climatic data is presented in Table 4.2 and plotted in Figure 4.3.
### Table 4.2: Climatic Data of Buraidah, Al-Qassim, Saudi Arabia

<table>
<thead>
<tr>
<th>Month</th>
<th>Average high (in celcius)</th>
<th>Average low (in celcius)</th>
<th>Highest temp (in celcius)</th>
<th>Relative Humidity (%)</th>
<th>Wind Speed (Km/Da)</th>
<th>ETO mm/mont h</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>17</td>
<td>7</td>
<td>30</td>
<td>57</td>
<td>122</td>
<td>99</td>
</tr>
<tr>
<td>February</td>
<td>20</td>
<td>8</td>
<td>35</td>
<td>48</td>
<td>144</td>
<td>110</td>
</tr>
<tr>
<td>March</td>
<td>25</td>
<td>13</td>
<td>37</td>
<td>41</td>
<td>161</td>
<td>180</td>
</tr>
<tr>
<td>April</td>
<td>30</td>
<td>18</td>
<td>41</td>
<td>32</td>
<td>174</td>
<td>217</td>
</tr>
<tr>
<td>May</td>
<td>36</td>
<td>23</td>
<td>45</td>
<td>26</td>
<td>173</td>
<td>260</td>
</tr>
<tr>
<td>June</td>
<td>40</td>
<td>25</td>
<td>48</td>
<td>17</td>
<td>202</td>
<td>312</td>
</tr>
<tr>
<td>July</td>
<td>41</td>
<td>26</td>
<td>48</td>
<td>20</td>
<td>216</td>
<td>320</td>
</tr>
<tr>
<td>August</td>
<td>40</td>
<td>26</td>
<td>48</td>
<td>22</td>
<td>222</td>
<td>312</td>
</tr>
<tr>
<td>September</td>
<td>38</td>
<td>23</td>
<td>47</td>
<td>22</td>
<td>195</td>
<td>265</td>
</tr>
<tr>
<td>October</td>
<td>33</td>
<td>19</td>
<td>40</td>
<td>33</td>
<td>176</td>
<td>197</td>
</tr>
<tr>
<td>November</td>
<td>25</td>
<td>13</td>
<td>37</td>
<td>47</td>
<td>163</td>
<td>124</td>
</tr>
<tr>
<td>December</td>
<td>20</td>
<td>8</td>
<td>30</td>
<td>54</td>
<td>158</td>
<td>99</td>
</tr>
</tbody>
</table>

Source: www.Qwikcast.com Weather forecast, Buraydah, Saudi Arabia

![Figure 4.3: Average monthly climatic data for Al-Qassim, Saudi Arabia](image1)

Figure 4.3: Average monthly climatic data for Al-Qassim, Saudi Arabia
4.2.3 Experimental Design

One greenhouse comprising 1200 m² was selected for this study. The experimental design layout of this study is shown in Figure 4.4 and the Table 4.4 and. The numbers of beds were 20 with bed spacing 1.2 m. Each bed have two irrigation drip pipes i.e. two rows of plants per bed. Low flexible irrigation pipes were used, physical and hydraulic characteristics of the pipe are shown in Table 4.3. Two varieties of tomatoes, notorah & red rock were selected for F2 organic seed production. The design distribution of these 20 beds are in such a way that out of 20 beds, 10 beds were selected for notorah variety, 10 beds for red rock variety. Out of 20 beds, 10 beds with surface irrigation system while remaining 10 beds with one variety each were selected for sub-surface irrigation system. Same irrigation schedule were adapted to all 20 beds. Organic fertilizer was used during this study. Some healthy plants with good production were selected from each variety. Among selected plants again selected few healthy plant of each variety i.e. from notorah & red rock for the development of F3 organic seed.

Table 4.3: Physical and Hydraulic Characteristics of Pipe used.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Pipe Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Low Flexible</td>
</tr>
<tr>
<td>Diameter(O.D), mm</td>
<td>17</td>
</tr>
<tr>
<td>Discharge, L/H</td>
<td>4</td>
</tr>
<tr>
<td>Emitter distance, cm</td>
<td>50</td>
</tr>
<tr>
<td>Pressure Range, m</td>
<td>0.5-4</td>
</tr>
<tr>
<td>Wall Thickness, mm</td>
<td>1.0</td>
</tr>
</tbody>
</table>
4.2.4 Irrigation Scheduling and System Operation

Irrigation scheduling consists of applying the right amount of water at the right time. Its purpose is to maximize irrigation efficiency by applying the appropriate amount of water needed to replenish the soil moisture to the desired level. Monthly irrigation schedule was prepared, and is presented in Table 5.1.
4.2.5 Data Collection

Crop measurement data like age of plant, length of plant, stem size, internodes distance, one cluster fruit, average size of fruit, shape and color of fruit and average weight of fruit were collected randomly after 15 days interval till the completion of study period for both tomatoes variety under surface and subsurface drip irrigation system. Among selected plants again selected few healthy plant of each variety i.e. from notorah & red rock varieties of tomatoes for the development of F3 organic seed.

Monthly schedule of irrigation was prepared from May to August, which is presented in Table 5.1. Irrigation data was collected regularly during the entire study period. The collected data of this study was used for analysis of crop yield under two varieties, water consumption, yield to water ratio, cost analysis, drip pipe performance, drip irrigation systems performance under surface and subsurface drip irrigation system.

4.3 STUDY-2

For evaluation of surface drip irrigation system performance assessment using pipes of varying flexibility, a field investigation was planned on Date Palm trees. The aims of this study was to assess the performance of varying flexibility drip pipes laid down in surface drip irrigation system with the objectives, to evaluate surface drip irrigation system in water scarce area, evaluation of drip pipes performance, efficiency of this irrigation system in relation to water, yield and yield to water ratio and economic analysis of this irrigation system.

4.3.1 Site Selection

Study area is located in one hydrological region. Field testing was carried out on an experimental site with an area 2.1 ha having 170 old date palm trees of different varieties. The experimental site is situated in Al-Watania Agriculture Company, Buraidah, Al-Qassim, Kingdom of Saudi Arabia. Study area altitude, latitude and longitude are same as that of study 1(Greenhouse experimental study). Soil analysis of study area was carried out and presented in Table 4.5, which shows that study area soil is consists of sandy clay
loams with traces of gravel. The source of irrigation water was tubewell and water analysis of this tubewell was also done and analysis results are presented in the Table 4.6.

Table 4.5: Soil Analysis results of experimental site

<table>
<thead>
<tr>
<th>Soil Characteristics</th>
<th>Values</th>
<th>Soil Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Characteristics</td>
<td>Values</td>
<td>Cations, meq/L</td>
<td>Values</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>65</td>
<td>Ca$^{2+}$</td>
<td>21.3</td>
</tr>
<tr>
<td>Loam (%)</td>
<td>15</td>
<td>Mg$^{2+}$</td>
<td>9.3</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>20</td>
<td>Na$^+$</td>
<td>8.4</td>
</tr>
<tr>
<td>Texture</td>
<td>Sandy clay loam</td>
<td>Anions, meq/L</td>
<td></td>
</tr>
<tr>
<td>Field Capacity (%)</td>
<td>11.2</td>
<td>CO$_3^{2-}$</td>
<td>0.22</td>
</tr>
<tr>
<td>Wilting Point (%)</td>
<td>5.7</td>
<td>HCO$_3^-$</td>
<td>2.3</td>
</tr>
<tr>
<td>Available Moisture (%)</td>
<td>5.5</td>
<td>Cl$^-$</td>
<td>11</td>
</tr>
<tr>
<td>Apparent Density (g/cm$^3$)</td>
<td>1.62</td>
<td>Organic Matter (%)</td>
<td>0.084</td>
</tr>
<tr>
<td>Chemical Characteristics</td>
<td>Available Elements (ppm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil pH</td>
<td>7.8</td>
<td>P</td>
<td>6.56</td>
</tr>
<tr>
<td>EC (d Sm$^{-1}$)</td>
<td>2.57</td>
<td>K$^+$</td>
<td>152</td>
</tr>
</tbody>
</table>

Table 4.6: Water Analysis of experimental site

<table>
<thead>
<tr>
<th>Water Characteristics</th>
<th>Values</th>
<th>Water Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.36</td>
<td>Ca$^{2+}$ (ppm)</td>
<td>44</td>
</tr>
<tr>
<td>Total Dissolve Salts ,(ppm)</td>
<td>950</td>
<td>Mg$^{2+}$ (ppm)</td>
<td>6.27</td>
</tr>
<tr>
<td>Total Alkalinity, (ppm)</td>
<td>140</td>
<td>Fe$^{2+}$ (ppm)</td>
<td>0.026</td>
</tr>
<tr>
<td>EC, (ppm)</td>
<td>1893</td>
<td>SO$_4^{2-}$ (ppm)</td>
<td>354</td>
</tr>
<tr>
<td>Cl$^-$ (ppm)</td>
<td>319</td>
<td>NO$_3^-$ (ppm)</td>
<td>34</td>
</tr>
<tr>
<td>Total Hardness (ppm)</td>
<td>136</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3.2 Climatic Conditions
Chapter 4

Study Design and Description

Study area is located in one hydrological region with elevation of 649 meters, latitude of 26° 18' N and longitude of 43° 46' E. The climatic condition of the experimental region is inland moderately hot and dry. The highest monthly temperature varies from 30°C to 48°C. Relative humidity values are ranging from 17 to 57%. Wind speed values vary from 122 km/day to 222 km/day and annual ETo is 2495mm. The climatic data is presented in Table 4.2 and plotted in Figure 4.3.

4.3.3 Experimental Design
The layout design and monitoring under this study is shown in Figure 4.5 and according to that the site was divided into five blocks, each block having four rows of trees. In order to investigate the effect of pipe flexibility on the experimental parameters like volume of water applied per day, per month and total water consumed, water use efficiency and fruit yield of drip pipes of different brands used in the surface drip irrigation system. The physical and hydraulic characteristics of these used pipes are presented in Table 4.7. These drip pipes consist of continuously self-cleaning pressure compensating emitters welded to the inside walls of the pipes.

The drip pipes used were categorized as low, medium and high as per their wall thickness i.e. 45 mil, 15 mil and 16 mil flexibility respectively. Considering the flexibility of drip pipes, the blocks were designated as low flexible drip pipe (LFDP), medium flexible drip pipe (MDFP) and high flexible drip pipe (HFDP) areas. The medium flexible drip pipe area was divided into two sub block as MDFP-1 and MDFP-2. Similarly high flexible drip pipe area was divided into two sub block as HFDP-1 and HFDP-2 respectively.

Trenches were excavated mechanically and dressed manually for installation of main and submain lines. The main and submain pipe lines were installed at a recommended depth from ground surface. The system of main and submain lines was checked for leakage prior to back-filling.
Figure 4.5: Plan view of experimental site showing irrigation layout and monitoring under surface drip irrigation system

Table 4.7: Physical and Hydraulic Characteristics of Pipes.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Pipe Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Medium Flexible Drip Pipe (MFDP)</td>
</tr>
<tr>
<td>Diameter, mm</td>
<td>22</td>
</tr>
<tr>
<td>Discharge, l/hr/m</td>
<td>3.40</td>
</tr>
<tr>
<td>Emitter distance, m</td>
<td>0.60</td>
</tr>
<tr>
<td>Pressure Range, kPa</td>
<td>28-104</td>
</tr>
<tr>
<td>Wall Thickness, mil</td>
<td>15</td>
</tr>
</tbody>
</table>

At the inlet of water supply line, a main flow control valve, check valve, water meter,
pressure gauges, and a filtration unit were fitted. The main line was connected to sub-
main which leads water to sub-blocks through laterals and then to surface drip pipes
having fabricated emitter, placed around the tree stem in loop. Each sub-block was
divided into two wings fitted with a separate set of valves, which controls respective
wing water supply. The set of valve includes a solenoid valve (Automatic Electric), a
water meter and a flow control valve (Manual). The irrigation of all sub-blocks was
scheduled and controlled by a unit called Total Central Control Panel (i.e. TORO Custom
Command).

4.3.3 Irrigation Scheduling and System Operation

Irrigation scheduling consists of applying the right amount of water at the right time. Its
purpose is to maximize irrigation efficiency by applying the appropriate amount of water
needed to replenish the soil moisture to the desired level. The perennial net surface water
requirement under this region is 17235m$^3$/hectare (100 trees per hectare). The analysis
was carried out from January up to August which is the harvest time of the dates in this
region. Monthly irrigation schedule was prepared as per guidelines suggested by Al-Zeid,
A. A., et. al., 1988 and tabulated as Table 6.2. In order to investigate the effect of pipe
flexibility on the experimental parameters, drip pipes of different brands were used in the
surface irrigation system.

Soil moisture meter was used to monitor the moisture content of the soil before and after
irrigation application. Before using soil meter, it was calibrated using two soil samples
(400 ml and 800 ml). Water quantities ranging from 10-50 ml (millilitre) and 20 to 100
ml were applied to 400 ml and 800 ml soil samples respectively. The corresponding
readings of the moisture meter were recorded. Moisture meter scale ranges from 0 to 10
degrees, zero indicates a fully dry condition, 2-4 represents average dry state, 4-6 average
state, 6-8 average wet state and 10 shows fully wet condition. Soil moisture calibration
curves were plotted for each sample. The calibration curve for 400 ml sample is shown in
Table 4.8 and Figure 4.6.
Table 4.8: Calibration curve of soil moisture sensor.

<table>
<thead>
<tr>
<th>Station</th>
<th>Soil Volume used (ml)</th>
<th>Water Application (ml)</th>
<th>Moisture Meter Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Watania-1</td>
<td>400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 4.6: Soil moisture calibration curve using soil moisture meter
4.3.5 Data Collection

Monthly irrigation schedule was prepared and observed from January to August as shown in Table 6.2. The collected data was analysed for water consumption, fruit yield, yield to fruit ratio, system hydraulic performance, cost analysis, performance of varying flexibility pipes used under surface drip irrigation system for trees.

4.4 STUDY-3

A study for the performance assessment of subsurface drip irrigation system was designed by using different flexibility drip pipes on 17 years old date palm trees. The investigated field and area was the same as it was used for surface drip irrigation system in study-2. The aim of this research work was to investigate the efficiency and practicality of subsurface drip irrigation system use for irrigating date palm trees and to compare it with the traditional surface drip irrigation system and to study the effect of subsurface drip irrigation system under varying flexibility drip pipes on yield and water conservation of date palm trees.

4.4.1 Site Selection

Field testing was carried out on same field area of 2.1 ha having 170 old date palm trees as for surface drip irrigation, having different date palm verities like Fahal, Mukdumi, Halawah, Sameath, Hanew, Kaddab, Kallas, Um Ul Hamam, Kathkath, Kadradiat, Nabthath, Ujwah, Um Kubber and Otanth. The experimental site is shown in Figure 4.7. Study area altitude, latitude and longitude are same as that of study 1 and 2.
4.4.2 Climatic Conditions

Study area is located in one hydrological region with elevation of 649 meters, latitude of 26° 18′ N and longitude of 43° 46′ E. The climatic condition of the experimental region is inland moderately hot and dry. The highest monthly temperature varies from 30°C to 48°C. Relative humidity values are ranging from 17 to 57%. Wind speed values vary from 122 km/day to 222 km/day and annual ETo is 2495mm. The climatic data is presented in Table 4.2 and plotted in Figure 4.3.

4.4.3 Experimental Design

The experimental design of this experiment was the same as for surface drip irrigation system except under this subsurface drip irrigation system, drip pipes were also buried at recommended depth with others water delivery pipes like water mainline, sub-main lines and laterals as shown in the Figure 4.9. The site was divided into five Blocks as did for study 2, for surface drip irrigation system and each possesses four rows of trees, which are shown in the layout design. Drip pipes of different brands were used for this surface drip irrigation system to examine the effect of pipes of different flexibility used under this research study on the experimental parameters. The drip pipes used had varying wall thickness of 45 mil, 15 mil and 16 mil with continuously self-cleaning pressure
compensating emitters welded to the inside walls of the pipes. The physical and hydraulic characteristics of pipes used under this study are the same as used in study-2, for surface drip irrigation system and is presented in Table 4.7.

Considering the flexibility of drip pipes installed, the sub-areas were nominated as low flexible drip pipe (LFDP), medium flexible drip pipe (MFDP) and high flexible drip pipe (HFDP) areas. The medium flexible drip pipe area was divided into two sub areas as MFDP-1 and MFDP-2. Similarly high flexible drip pipe area was divided into two sub areas as HFDP-1 and HFDP-2 as shown in Figure 4.8. Trenches were excavated mechanically and dressed manually. The drip pipes were installed at 40 cm depth from ground surface. The system was checked for leakage prior to back-filling.

![Installation view of drip pipe](image)

**Figure 4.8: Installation view of drip pipe**

At the inlet of water supply line, a main flow control valve, a check valve, fertilizer unit, two pressure gauges (before and after filter unit) and a filtration unit and water meter were fitted. The main line was connected to submain which leads water to sub-blocks through laterals. Each sub-block was divided into two wings fitted with a separate set of valves. The set of valve includes a solenoid valve (Automatic Electric), a water meter and a flow control valve (Manual).
The irrigation of all sub-areas was scheduled and controlled by a unit called Total Central Control Panel (i.e. TORO Custom Command) as shown in Figure 4.10.

**Figure 4.10: Total central control panel**

### 4.4.4 Irrigation Scheduling and System Operation
Irrigation scheduling was made for this subsurface drip irrigation study on month basis, as per suggested/guidelines given by Al-Zeid, A. A., et. al., 1988, Guide for Crop Irrigation Requirements in the Kingdom of Saudi Arabia, tabulated in Table 6.3. Soil moisture sensing device was also used, that can measure moisture at a depth of 0.8 meter or lower. Soil moisture calibration curve using soil moisture meter is presented in Table 4.8 and Figure 4.6. Soil moisture meter scale ranges from 0 to 10 degrees, zero indicates a fully dry condition, 2-4 represents average dry state, 4-6 average state, 6-8 average wet state and 10 shows fully wet condition. Its purpose is to maximize irrigation efficiency by providing appropriate amount of water needed to refill the soil moisture to the required level. The analysis of data was carried out from January up to August, which is the harvest time of the dates in this region.

4.4.5 Data Collection

Monthly irrigation schedule was prepared and observed from January to August as shown in Table 6.3. The collected data was analysed for water consumption, fruit yield, yield to fruit ratio, system hydraulic performance, cost analysis, performance of varying flexibility pipes used under subsurface drip irrigation system for trees.
CHAPTER 5

Performance Assessment of Surface and Subsurface Drip Irrigation System in Crops
5.1 GENERAL

The present study comprises of two stages; experimental and analysis for its comparison in respect of different parameters. In the first stage, the field experiment was conducted in a greenhouse on two varieties of tomato crop, under surface and subsurface drip irrigation method. A control irrigation scheduling was observed throughout the experiment. The main objective of the study was to produce organic tomato seeds, hydraulic performance of surface and subsurface drip irrigation system on yield and efficiency of low flexible inline pipes used under these two irrigation methods. At the second stage, the calibrated values of various parameters were used for water use efficiency analysis, hydraulic analysis of low flexible drip pipe used, yield to water ratio analysis, and economic analysis of these methods. The error accepted was as minimum as possible during this calibration.

5.2 PARAMETERS ASSESSMENT

The parameters to be assessed were; volume of water application per day, per day month, seasonal used, physical and hydraulic properties of drip pipe used, yield to water ratio, and crop parameters; crop duration, age of plant, length of plant, stem girth, internodes distance, one fruit cluster, size, shape, colour, weight of fruit and crop yield.

5.2.1 Performance Assessment on Low Flexible Drip Pipes

Low flexible drip pipe with diameter 17 mm, thickness 1.0 mm, spacing 30 cm, and flow rate 4 L/H were used under surface and subsurface drip irrigations method. During the study period following observations regarding these pipes were noted:

- High resistance to clogging, as each dripper contains continues self-cleaning mechanism.
- The ability to discharge water entirely along an 800 m length of drip pipe.
- Possessing a dual pressure compensating system, labyrinth and diaphragm.
- With Integrated design which protect it from mechanical damages by natural and manmade cause.
- Maintained a constant water flow over a wide pressure range.
- Save water and money.
- Utilizes the most advance pressure compensation technology based on a unique pressure differential mechanism.
- High-resistance to mechanical damage

5.2.2 Performance Assessment on Water Consumption

A water schedule was prepared and observed for this study as presented in Table 5.1 and Figure 5.1. The same quantity of irrigation water was applied to both surface and subsurface drip blocks having notorah and redrock varieties of tomato crop. It was observed that bigger wetted volume of soil in root zone was formed, in case of subsurface and smaller wetted volume of soil was in the case of surface drip irrigation system as shown in Figure 5.2. In subsurface drip system whole water was utilized by plants but on the other hand in case of surface drip irrigation system, water was partially utilized by plants, while the rest was evaporated. It is clear from the data (Table 5.1) that sub-surface drip irrigation method has improved the water use efficiency of tomato crop by minimizing the evaporative loss and delivering water directly to the root zone. Similar findings have also been discussed by Bajracharya and Sharma (2005).
Table 5.1: Irrigation Schedule Observed under Surface and Subsurface Drip Irrigation System

<table>
<thead>
<tr>
<th>Month</th>
<th>Surface Block-A (m³)</th>
<th>Subsurface Block-B (m³)</th>
<th>Subsurface Block-C (m³)</th>
<th>Surface Block-D (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>25.86</td>
<td>25.86</td>
<td>25.86</td>
<td>25.86</td>
</tr>
<tr>
<td>June</td>
<td>28.73</td>
<td>28.73</td>
<td>28.73</td>
<td>28.73</td>
</tr>
<tr>
<td>July</td>
<td>29.69</td>
<td>29.69</td>
<td>29.69</td>
<td>29.69</td>
</tr>
<tr>
<td>August</td>
<td>29.69</td>
<td>29.69</td>
<td>29.69</td>
<td>29.69</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>114</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>Average</td>
<td>28.5</td>
<td>28.5</td>
<td>28.5</td>
<td>28.5</td>
</tr>
</tbody>
</table>

Figure 5.1: Monthly irrigation applications to Tomato crop under surface and subsurface drip irrigation
5.2.3 Performance Assessment on Crop Yield

Study results placed in Table 5.2 shows that under subsurface drip irrigation system, high yield, were obtained either from notorah verity, 3304 kg, or red rock variety, 2447 kg of tomato crop. Furthermore regarding yield results for surface drip irrigation, it was obtained 2379 kg and 1835 kg for notorah and red rock variety of tomato crop that is less in quantity, in comparison with subsurface drip irrigation method. So, it is clear from results that on the whole high yield, was obtained under subsurface drip irrigation method, regardless of its variety as shown in Figure 5.3.

It means that yield under subsurface drip irrigation is 28 % more than the yield under surface drip irrigation system, in case of notorah organic seed production while in case of red rock yield is 25 % more under subsurface drip system than the yield under surface drip irrigation system. The reason for lower yields in case of surface irrigation might be due to insufficient water delivery during growth period and comparatively higher evaporative water losses which
significantly reduced crop yields. This could be supported with the findings of Randhawa and Abrol (1990), Schwab et al (1993) and Bajracharya and Sharma (2005).

![Graph showing yields of two tomato varieties under surface and subsurface drip irrigation systems](image)

**Figure 5.3: Yields of Two Tomato varieties under surface and subsurface drip irrigation System**

### 5.2.4 Crop Yield to Water ratio

The water use efficiency by using low flexible pipes has been calculated as 29 kg/m³, in case of Notorah, while 22 kg/m³ under Redrock varities of tomato by using subsurface drip irrigation method. The yield water ratio under surface drip irrigation was calculated as 21 and 16 kg/m³, under Notorah and Redrock varities of tomato respectively, which is presented in Table 5.2 and shown in Figure 5.3. Quantitative analysis shows that water use efficiency for both tomato varities under subsurface drip irrigation method is 28 % and 27 % more than that of under surface drip irrigation method respectively. As it has been discussed earlier that this might be due to improved water use efficiency and minimized evaporative losses under subsurface, as water delivered directly to the rootzone as compared to surface drip irrigation method (Bajracharya and Sharma, 2005).
Table 5.2: Water Used and Yield-Water ratio under Surface and Subsurface Drip Irrigation System

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Block</th>
<th>Pipe Used</th>
<th>Irrigation Method</th>
<th>Total water Applied (m³)</th>
<th>Total Yield (Kg)</th>
<th>Yield-water Ratio(Kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato (Notorah)</td>
<td>A</td>
<td>Inline</td>
<td>Surface</td>
<td>114</td>
<td>2379</td>
<td>21</td>
</tr>
<tr>
<td>Tomato (Notorah)</td>
<td>B</td>
<td>Low</td>
<td>Subsurface</td>
<td>114</td>
<td>3304</td>
<td>29</td>
</tr>
<tr>
<td>Tomato (Redrock)</td>
<td>D</td>
<td>Flexible</td>
<td>Surface</td>
<td>114</td>
<td>1835</td>
<td>16</td>
</tr>
<tr>
<td>Tomato (Redrock)</td>
<td>C</td>
<td></td>
<td>Subsurface</td>
<td>114</td>
<td>2447</td>
<td>22</td>
</tr>
</tbody>
</table>

Figure 5.4: Yield water ratios under surface and subsurface drip irrigation systems.

5.2.5 Cost Analysis

The irrigation system cost analysis mainly depends on many factors such as price of the irrigation system component, energy requirements, fuel cost, and labour cost. Cost analysis was carried out by using the current dealer prices of the irrigation system and installation according to 2006 price levels, and tomatoes production costs, which was determined according to agricultural census issues of the Ministry of Agriculture in 2006. A simple cost analysis has been carried out to evaluate the gross margin of tomatoes cultivated in the
greenhouse under surface and subsurface drip irrigation method by using low flexible pipes containing fabricated emitters on it. Both fixed and variable costs were calculated for each irrigation system in (US$/ha/season), and the gross margin of the product under the tested irrigation systems was derived to compare among these systems. The fixed costs included the treatments’ share of digging the well, purchasing the pump and engine, main control unit, sub-main control unit and lateral control unit, main and sub-main lines, manifold, laterals, emitters, gathering the system, design and installation of the irrigation system. Seasonal total cost and Gross Margin in US$/ha/season of tomatoes under two tested irrigation systems is presented in Table No. 5.3.

The cost analysis showed that capital cost under surface drip irrigation system was 2048.34 US$/ha while 2072.45US$/ha in case of subsurface drip irrigation system. The fixed costs which includes depreciation, interest, taxes and insurance for surface drip irrigation method was 147.04 US$/ha/season and 148.12US$/ha/season for subsurface drip irrigation method respectively. The operating cost which includes fuel, maintenance and repairing, labours, total annual irrigation cost and total agricultural costs were 755.52 US$/ha/season and 713.85 US$/ha/season for surface and subsurface drip irrigation methods. Total revenue was 2274.05 US$/ha/season and 2425.5 US$/ha/season under surface and subsurface drip irrigation system respectively. Gross margin in US$/ha/season under surface and subsurface drip irrigation was 1518.5 and 1711.7 respectively. The analysis showed that subsurface system was more viable economically.
Table 5.3: Seasonal total cost and Gross Margin in (US$/ha/season) of tomatoes under two tested irrigation Systems of water application

<table>
<thead>
<tr>
<th>Cost Items</th>
<th>Micro Irrigation Systems</th>
<th>Surface drip</th>
<th>Subsurface drip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost (US$/ha)</td>
<td></td>
<td>2048.34</td>
<td>2072.45</td>
</tr>
<tr>
<td>Fixed costs (US$/ha/season, 4 month)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1- Depreciation</td>
<td></td>
<td>54.86</td>
<td>54.86</td>
</tr>
<tr>
<td>2- Interest</td>
<td></td>
<td>81.93</td>
<td>82.90</td>
</tr>
<tr>
<td>3- Taxes and insurance</td>
<td></td>
<td>10.24</td>
<td>10.36</td>
</tr>
<tr>
<td>Sub-total</td>
<td></td>
<td>147.04</td>
<td>148.12</td>
</tr>
<tr>
<td>Operating costs (US$/ha/season, 4 month)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1- Fuel</td>
<td></td>
<td>35.16</td>
<td>34.82</td>
</tr>
<tr>
<td>2- Maintenance and Repairing</td>
<td></td>
<td>20.48</td>
<td>20.72</td>
</tr>
<tr>
<td>3- Labors</td>
<td></td>
<td>2.82</td>
<td>2.82</td>
</tr>
<tr>
<td>Sub-total</td>
<td></td>
<td>58.47</td>
<td>58.37</td>
</tr>
<tr>
<td>Total annual irrigation cost (US$/ha/season, 4 month)</td>
<td></td>
<td>416.58</td>
<td>374.9</td>
</tr>
<tr>
<td>Total agricultural Costs</td>
<td></td>
<td>338.94</td>
<td>338.94</td>
</tr>
<tr>
<td>Total costs (US$/ha/season, 4 month)</td>
<td></td>
<td>755.52</td>
<td>713.85</td>
</tr>
<tr>
<td>Yield Main, (Mg/ha)</td>
<td></td>
<td>75.2</td>
<td>80.21</td>
</tr>
<tr>
<td>Price, (US$/ha) Main</td>
<td></td>
<td>15.12</td>
<td>15.12</td>
</tr>
<tr>
<td>Total revenue (US$/ha/season, 4 month)</td>
<td></td>
<td>2274.05</td>
<td>2425.5</td>
</tr>
<tr>
<td>Gross Margin (US$/ha/season, 4 month)</td>
<td></td>
<td>1518.5</td>
<td>1711.7</td>
</tr>
</tbody>
</table>
5.3 SUMMARY
It has been seen (Figure 5.3) that the quantity of water applied by using low flexible drip pipe is the least in its whole blocks. Although the irrigation schedule was observed uniformly for all the blocks with same discharge rates but irrigation efficiency is more in subsurface as compared to surface drip irrigation method. The high water use efficiency was observed in the blocks containing subsurface drip irrigation system installed due to non evaporation and maximum utilization of water by the plant roots stored in rhizosphere. Under subsurface drip irrigation method, the drip pipes were installed at recommended depth below the ground surface and Pipes leakage or opening of the joints was not found in these low flexible pipes. Water consumption efficiency trend for these pipes under each block of surface and subsurface drip irrigation was good due to its hydraulic properties, so no extra maintenance for this type was required all over the study period.

The water use efficiency under subsurface drip irrigation method was more under both varieties of tomatoes as compared to surface drip irrigation method under the same two varieties. The tomato yields of both the verities was high either under subsurface or surface drip irrigation system containing low flexible drip pipes as compared to medium and high flexible drip pipes i.e. both tomato verities under subsurface drip irrigation system produced more yield than that of under surface drip irrigation system respectively. The comparison of yield under subsurface and surface drip irrigation of two tomato varieties with one cubic meter of water was also carried out.

A cost analysis was carried out to evaluate the gross margin of tomatoes cultivated under surface and subsurface drip using low flexible pipes containing fabricated emitters on it. Both fixed and variable costs were calculated for each irrigation system in US$/ha/season and the gross margin of the product under the tested irrigation systems were derived to compare among these systems. The cost analysis of these two system showed that revenue collected and gross margin in US$/ha/season under subsurface drip irrigation system was more as compared with surface drip irrigation system, although fixed and capital cost of subsurface drip irrigation system was more.
CHAPTER 6

Performance Assessment of Surface and Subsurface Drip Irrigation Systems in Fruit Trees
6.1 GENERAL
Two experiments were carried out on the same field having mature date palm trees to examine the efficiency of varying flexibility pipes installed in surface and subsurface drip irrigation systems along with efficiencies of these two systems at Buraidah city vicinity, Al-Qassim province of Saudi Arabia. The study was also aimed to investigate the response of surface and subsurface drip irrigation method on water requirement and date palms yield. The study outcomes were analyzed for calibration of its important parameters like hydraulic performance of the system, water consumption, yield and water use efficiency. The experimental field was comprises of sandy loam with traces of gravel. A control irrigation scheduling was observed throughout the studying period. The main objectives of this research study were to assess the performance of varying flexibility drip pipes installed in surface and subsurface irrigation systems, to determine the water consumption and efficiency of the systems and to investigate the effect of surface and subsurface drip irrigation on date palms yield.

The calibrated values of various parameters under variable flexibility drip pipes; low, medium and high flexible pipe were used for analysis of water use efficiency of the system, yield to water ratio, and systems economic analysis. The error accepted was as least as possible during this calibration.

6.2 PARAMETERS ASSESSMENT
The parameters to be assessed were, volume of water applied per day, per month and total seasonal water consumed for under variable drip pipe thicknesses used, water use efficiency and fruit yield under various flexible drip pipes used for both surface and subsurface drip irrigation methods.

6.2.1 Performance Assessment on Varying Flexible Drip Pipes
In order to investigate the effect of pipe flexibility on the study parameters, drip pipes of different brands were used in the surface and subsurface irrigation system. The drip pipes had varying wall thicknesses, 45 mil, 15 mil and 16 mil, named as low, medium and high flexibilities drip pipes respectively and consist of continuously self-cleaning pressure compensating emitters welded to the inside walls of these pipes.
Table 6.1: Physical and Hydraulic Characteristics of Pipes.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Pipe Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Medium Flexible</td>
</tr>
<tr>
<td>Diameter, mm</td>
<td>22</td>
</tr>
<tr>
<td>Discharge, l/hr/m</td>
<td>3.40</td>
</tr>
<tr>
<td>Emitter distance, m</td>
<td>0.60</td>
</tr>
<tr>
<td>Pressure Range, kPa</td>
<td>28-104</td>
</tr>
<tr>
<td>Wall Thickness, mil</td>
<td>15</td>
</tr>
</tbody>
</table>

The results show that substantial effect of pipe stiffness was observed on water consumption and yield. It was observed that the quantity of irrigation water reduced to 36% and 56% for drip pipes with low; 45 mil wall thicknesses, flexibility drip pipe as followed by medium; 15 mil wall thickness, and high 16 mil wall thickness, flexibility drip pipes respectively under surface drip irrigation system. The yield of date palms also improved and it was found at least 49% more than that for the other two types.

Study outcome shows that the quantity of water applied for low flexible drip pipe is the least of all three types. Although the irrigation schedule was same for all blocks but discharge rates were varying in low, medium and high flexible pipes due to their different discharge rates of emitters. The high flexible pipe is less efficient due to its wall thickness and blockage of emitters in comparison with other two low and medium flexible drip pipes used. On the other hand, low flexible drip pipe and medium flexible pipe were found to be equally efficient under surface drip irrigation systems (Table 6.1).

Under subsurface drip irrigation, a considerable response of pipe stiffness was observed on water consumption and yield. It was found that the quantity of irrigation water reduced to 49% and 53% for drip pipes with low (45 mil wall thickness) flexibility drip pipe as compared to that for medium (15 mil wall thickness) and high (16 mil wall thickness) flexibility drip pipes respectively under subsurface drip irrigation system. The yield of date palms also increased and it was found at least 50% more than that for the other two types.
Study results shows that the quantity of water applied for low flexible drip pipe is the least to all three drip pipes types, both under surface and subsurface drip irrigation method. Although the irrigation quantity was same for all blocks but their completion time was different due to varying discharge rates of low, medium and high flexible pipes emitters/physical and hydraulic characteristics of pipes used. It is might be due to emitter distance, pressure range and also wall thickness. The high flexible pipe is less efficient for both surface and subsurface irrigation system because it might be due to pressure range and wall thickness. On the other hand, low flexible pipes were found to be equally efficient for both surface and subsurface drip irrigation systems due to its better physical and hydraulic characteristics as compared to other two pipes used. Similar findings have also been discussed by Mohammad (1998)

### 6.2.2 Performance Assessment on Water Consumption

In order to investigate the effect of pipe flexibility on the study parameters i.e. water consumption by using drip pipes of different brands were used in the surface and subsurface irrigation method. Each brand pipe has its own hydraulic features.

In case of surface drip irrigation system, for the same period, total quantity of water were used as, 328 m$^3$, 514 m$^3$ and 744 m$^3$ in the low, medium and high flexible drip pipe types respectively. The high water use efficiency was observed in low flexible drip pipes because of its water pressure bearing capacity, 70-386 kPa, as compared to other two drip pipes and also due to the wall thickness of low flexible drip pipe. So as a result there was no opening of joints, as a result no leakage of water and non-blockage of built-in emitters, in case of low flexible pipes. However frequent leakage of water was observed due to opening of joints in high flexible pipe but less in the case of medium flexible drip pipes. Water consumption quantity is 36% and 56% lower than that used in medium and high flexible pipe types respectively. The quantity of water used under low flexible pipe type for the peak period, i.e., for July and August, was also determined. It was found to be 47 liters per tree per day as shown in Table 6.2 and Figure 6.1.
The result shows that in case of subsurface drip irrigation system, for the same period, the total quantity of water were used as; 229 m$^3$, 451 m$^3$ and 485 m$^3$ in low, medium and high flexible drip pipe types respectively. The highest water use efficiency was observed in low flexible drip pipes due to its better hydraulic characteristics. Water consumption quantity is 49% and 53% lower than that of used in medium and high flexible drip pipe types respectively. The quantity of water used under low flexible pipe type for the peak period, i.e., for July and August, was also determined. It was found to be 35 liters per tree per day as presented in Table 6.3 and shown in Figure 6.2.

Under subsurface drip irrigation, the drip pipes were installed 40 cm deep, as advised by the manufacturer, from ground surface. The overlying soil compacted the pipes due to mechanical operation which resulted in constriction of the high flexible pipes more than medium flexible drip pipes because their less stiffness/hydraulic characteristics. This obstructed water flow and affected the performance of emitters. The increased water pressure in the pipes produced leakage or even opening of the joints. These trickling joints caused water losses. This problem was found less prominent in the medium flexible pipes and the not in the low flexible pipes but more in high flexible drip pipe. Water consumption efficiency trend for all the pipe types can be seen in Figure 6.2. The joints and emitters in the low flexible pipes worked well so no extra maintenance for this type was required throughout the study period. This could be supported with the findings of Phene (1995), Barth (1995) and Mohammad and Al-Amoud (1994).
Table 6.2: Irrigation Schedule Observed under Surface Drip Irrigation System

<table>
<thead>
<tr>
<th>Month</th>
<th>MFDP (m³)</th>
<th>LFDP (m³)</th>
<th>HFDP (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Block-1</td>
<td>Block-2</td>
<td>Block</td>
</tr>
<tr>
<td>January</td>
<td>10.29</td>
<td>12.34</td>
<td>16</td>
</tr>
<tr>
<td>February</td>
<td>7.3</td>
<td>8.76</td>
<td>12.04</td>
</tr>
<tr>
<td>March</td>
<td>21.3</td>
<td>25.56</td>
<td>27.99</td>
</tr>
<tr>
<td>April</td>
<td>33.42</td>
<td>40.1</td>
<td>37.41</td>
</tr>
<tr>
<td>May</td>
<td>35.27</td>
<td>42.32</td>
<td>53.32</td>
</tr>
<tr>
<td>June</td>
<td>29.86</td>
<td>35.83</td>
<td>55.47</td>
</tr>
<tr>
<td>July</td>
<td>46.29</td>
<td>55.54</td>
<td>62.65</td>
</tr>
<tr>
<td>August</td>
<td>49.96</td>
<td>59.95</td>
<td>62.65</td>
</tr>
<tr>
<td></td>
<td>234</td>
<td>280</td>
<td>328</td>
</tr>
<tr>
<td>Total</td>
<td>514</td>
<td>328</td>
<td>744</td>
</tr>
</tbody>
</table>

Figure 6.1: Monthly irrigation applications to date palm using low, medium and high flexible drip pipes under surface drip irrigation system
### Table 6.3: Irrigation Schedule Observed under Subsurface Drip Irrigation System

<table>
<thead>
<tr>
<th>Month</th>
<th>MFDP Block-1</th>
<th>MFDP Block-2</th>
<th>LFDP Block</th>
<th>HFDP Block-1</th>
<th>HFDP Block-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>8.19</td>
<td>9.81</td>
<td>16</td>
<td>11.22</td>
<td>5.48</td>
</tr>
<tr>
<td>February</td>
<td>6.36</td>
<td>7.64</td>
<td>12.04</td>
<td>10.01</td>
<td>4.89</td>
</tr>
<tr>
<td>March</td>
<td>19.09</td>
<td>22.91</td>
<td>27.99</td>
<td>22.79</td>
<td>11.11</td>
</tr>
<tr>
<td>April</td>
<td>29.86</td>
<td>35.84</td>
<td>37.41</td>
<td>45.04</td>
<td>21.97</td>
</tr>
<tr>
<td>May</td>
<td>30.41</td>
<td>36.49</td>
<td>53.32</td>
<td>56.99</td>
<td>27.8</td>
</tr>
<tr>
<td>June</td>
<td>25.95</td>
<td>31.15</td>
<td>55.47</td>
<td>63.65</td>
<td>31.05</td>
</tr>
<tr>
<td>July</td>
<td>40.68</td>
<td>48.82</td>
<td>62.65</td>
<td>69.1</td>
<td>33.7</td>
</tr>
<tr>
<td>August</td>
<td>44.64</td>
<td>53.56</td>
<td>62.65</td>
<td>47.07</td>
<td>22.96</td>
</tr>
<tr>
<td>Total</td>
<td>205</td>
<td>246</td>
<td>229</td>
<td>326</td>
<td>159</td>
</tr>
</tbody>
</table>

**Figure 6.2:** Monthly irrigation applications to date palm using low, medium and high flexible drip pipes under subsurface drip irrigation system
The irrigation water was applied to all blocks as per irrigation scheduling. The quantity of irrigation water applied to each block was presented in Table 6.2 and plotted on monthly basis as shown in Figure 6.1 for surface drip irrigation method and similarly for subsurface drip irrigation method, it is presented in Table 6.3 and shown in Figure 6.2.

It is clear from the Figures 6.1 and 6.2 that quantity of water applied for low flexible drip pipe is the least for all three drip pipe types, either under surface or subsurface drip irrigation system. Although the irrigation schedule was same for all the blocks but their discharge rates was varying in low, medium and high flexible pipes due to different emitter's discharges or their hydraulic characteristics. Different irrigation schedules were observed for surface and subsurface drip irrigations during these studies.

6.2.3 Performance Assessment on Fruit Yield

The yield of the dates per tree under surface drip irrigation method was found as; 126 kg/tree, 71 kg/tree and 61 kg/tree for the area under the low, medium and high flexible drip pipe types respectively. Thus the trees under low flexible pipe type produced 44 % and 52 % more yield than those under medium and high flexible pipe type’s areas respectively. The comparison of the date yield per kg is presented in Table 6.4 and total yield under varying drip pipes is shown in Figure 6.3 for surface drip irrigation method.

Under subsurface drip irrigation method, the dates yield per tree was observed as; 115 kg/tree, 70 kg/tree and 58 kg/tree, for the area under low, medium and high flexible drip pipe types respectively. Thus the trees under low flexible drip pipe type produced 39 % and 50 % more yield than those under medium and high flexible drip pipe types respectively. The comparison of the date yield per kg is presented in Table 6.5 and total yield under varying drip pipes is shown in the Figure 6.4 for subsurface drip irrigation method. A date production view under subsurface drip irrigation system is shown in Figure 6.5.
The outcome results show that yield under surface and subsurface is encouraging in low flexible and medium flexible pipes. Moreover, the yield result of high flexible pipe is not discouraging under both irrigation systems. However, a significant trend in reduction of water was observed in low flexible pipes both under surface and subsurface drip irrigation system. This could be supported with the findings of Ayers et al (1995) and Naimah (1985).

**Table 6.4: Comparison of date production and yield water ratio for three drip pipe types under Surface Drip Irrigation System**

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Date Palm Trees</th>
<th>Water used Trees m$^3$</th>
<th>Total yield (Kg)</th>
<th>Yield ratio Kg/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Drip</td>
<td>Total</td>
<td>In Production</td>
<td>Total</td>
<td>In Production</td>
</tr>
<tr>
<td>Medium Flexible Pipe</td>
<td>66</td>
<td>37</td>
<td>651</td>
<td>365</td>
</tr>
<tr>
<td>Low Flexible Pipe</td>
<td>43</td>
<td>39</td>
<td>328</td>
<td>297</td>
</tr>
<tr>
<td>High Flexible Pipe</td>
<td>61</td>
<td>39</td>
<td>677</td>
<td>433</td>
</tr>
</tbody>
</table>

**Figure 6.3 Comparison of date production for three drip pipe types under surface drip irrigation system**
Table 6.5: Comparison of date production and yield water ratio for three drip pipe types under Subsurface Drip Irrigation System

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Date Palm Trees</th>
<th>Water used Trees m³</th>
<th>Total yield (Kg)</th>
<th>Yield ratio Kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface Drip</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Flexible Pipe</td>
<td>66</td>
<td>37</td>
<td>451</td>
<td>2573</td>
</tr>
<tr>
<td>Low Flexible Pipe</td>
<td>43</td>
<td>39</td>
<td>229</td>
<td>4466</td>
</tr>
<tr>
<td>High Flexible Pipe</td>
<td>61</td>
<td>39</td>
<td>485</td>
<td>2272</td>
</tr>
</tbody>
</table>

Figure 6.4: Comparison of date production for three drip pipe types under subsurface drip irrigation system
6.2.4 Fruit Yield to Water Ratio

The comparison of date yield for each type of drip pipe under one cubic meter of water was also carried out under both surface and subsurface drip irrigation methods.

The results shows that under surface drip irrigation method, The water use efficiency was found as; 17 kg/m$^3$, 7 kg/m$^3$ and 6 kg/m$^3$ for low, medium and high flexible drip pipes respectively as presented in Table 6.4 and shown in Figure 6.6. Quantitative analysis shows that the dates water use efficiency in low flexible drip pipe type is 59% and 65% more than in comparison with medium and high flexible drip pipe types respectively.

Under surface drip irrigation method, the study results shows that water use efficiency was observed as; 22 kg/m$^3$, 10 kg/m$^3$ and 7 kg/m$^3$ for low, medium and high flexible drip pipe types respectively as presented in Table 6.5 and shown in Figure 6.7. Quantitative analysis shows that dates, water use efficiency in low flexible pipe type is 55 % and 68 % more than that for under medium and high flexible drip pipe types respectively.

The both studies results shows that yield to water ratio is almost same or near to same under both surface and subsurface drip irrigation by using low flexible drip pipe followed by medium flexible drip pipe. Although least water used in low flexible drip pipe type under both surface
and subsurface drip irrigation methods but performance wise subsurface drip irrigation method was found better than surface drip irrigation method. As it has been discussed earlier that this might be due to improved water use efficiency and minimized evaporative losses through sub-surface and water delivery directly to the rootzone as compared to surface drip irrigation method (Bajracharya and Sharma, 2005).

![Figure 6.6](image1)

**Figure 6.6: Comparison of dates production per tree per m³ of water consumption under three drip pipe types and under Surface drip irrigation system**

![Figure 6.7](image2)

**Figure 6.7: Comparison of dates production per tree per m³ of water consumption under three drip pipe types and under Subsurface drip irrigation system**
6.2.5 Cost Analysis

The cost analysis of the irrigation system depends on many factors such as price of the irrigation system component, energy requirements, fuel and labor costs. Cost analysis was carried out by using dealer prices of the irrigation system and installation according to 2006 price levels, and date production costs, which was determined according to agricultural census issues of the Ministry of Agriculture in 2006. A simple cost analysis has been carried out to evaluate the gross margin of date palm cultivated in open field under surface and subsurface drip irrigation method using varying flexible self fabricated emitter’s drip pipes. Both fixed and variable costs were calculated for each irrigation system in US$/ha/season and the gross margin of the product under the tested irrigation systems were derived to compare among these systems. The fixed costs included the treatments’ share of digging the well, purchasing the pump and engine, main control unit, sub-main control unit and lateral control unit, main and sub-main lines, manifold, laterals, emitters, gathering the system, design and installation of the irrigation system costs and excluded rent of land. Seasonal total cost and Gross Margin in US$/ha/season of tomatoes under two tested irrigation systems is presented in Table No. 6.6.

The cost analysis showed that capital cost under surface drip irrigation system was 2048.34 US$/ha, while 2072.45US$/ha, in case of subsurface drip irrigation system. The fixed costs which includes depreciation, interest, taxes and insurance for surface drip irrigation was 441.09 US$/ha/season, and 444.36 US$/ha/season, for subsurface drip irrigation system respectively. The operating cost which includes fuel, maintenance and repairing, labours, total annual irrigation cost and total agricultural costs were 1965.67 US$/ha/season, and 1823.34 US$/ha/season, for surface and subsurface drip irrigation system. Total revenue was 2501.06 US$/ha/season, and 2728.4 US$/ha/season, under surface and subsurface drip irrigation system respectively. Gross margin in US$/ha/season under surface and subsurface drip irrigation was 535.93, and 905.06, respectively. The analysis showed that subsurface system was more viable economically. Some scientists could be supported with the findings of Al-Amoud, et. al, 2000 and Dhuyvetter, et. al, 1995.
Table 6.6: Seasonal total cost and gross margin in (US$/ha/season) of Date Palm under the two tested irrigation systems of water application.

<table>
<thead>
<tr>
<th>Cost items</th>
<th>Microirrigation systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface drip</td>
<td>Subsurface drip</td>
</tr>
<tr>
<td>Capital cost (US$/ha)</td>
<td>2048.34</td>
<td>2072.45</td>
</tr>
<tr>
<td>Fixed costs (US$/ha/season, 12 month)</td>
<td>164.58</td>
<td>164.58</td>
</tr>
<tr>
<td>1- Depreciation</td>
<td>245.79</td>
<td>248.7</td>
</tr>
<tr>
<td>2- Interest</td>
<td>30.72</td>
<td>31.08</td>
</tr>
<tr>
<td>Sub-total</td>
<td>441.09</td>
<td>444.36</td>
</tr>
<tr>
<td>Operating costs (US$/ha/season, 12 month)</td>
<td>105.48</td>
<td>104.46</td>
</tr>
<tr>
<td>1- Fuel</td>
<td>61.44</td>
<td>62.16</td>
</tr>
<tr>
<td>2- Maintenance and Repairing</td>
<td>8.46</td>
<td>8.46</td>
</tr>
<tr>
<td>Sub-total</td>
<td>175.38</td>
<td>175.08</td>
</tr>
<tr>
<td>Total annual irrigation cost (US$/ha/season, 12 month)</td>
<td>948.85</td>
<td>806.52</td>
</tr>
<tr>
<td>Total agricultural Costs</td>
<td>1016.82</td>
<td>1016.82</td>
</tr>
<tr>
<td>Total costs (US$/ha/season, 12 month)</td>
<td>1965.67</td>
<td>1823.34</td>
</tr>
<tr>
<td>Yield , (Mg/ha)</td>
<td>11.03</td>
<td>12.03</td>
</tr>
<tr>
<td>Price, (US$/ha)</td>
<td>75.6</td>
<td>75.6</td>
</tr>
<tr>
<td>Total revenue (US$/ha/season, 12 month)</td>
<td>2501.6</td>
<td>2728.4</td>
</tr>
<tr>
<td>Gross Margin, (US$/ha/season, 12 month)</td>
<td>535.93</td>
<td>905.06</td>
</tr>
</tbody>
</table>
6.3 SUMMARY

The irrigation water was applied as per irrigation scheduling to all blocks (Table 6.2 and 6.3 and Figures 6.1 and 6.2) for surface and sub-surface drip irrigation methods. It has been seen that the quantity of water applied for low flexible drip pipe is the least than rest of two drip pipe types. Although the irrigation schedule was same for all blocks but discharge rates were different due to variable used drip pipes hydraulic characteristics.

Least total quantity of water were consumed in low flexible drip pipe type for both drip irrigation system either it was subsurface or surface drip as compared with medium and high flexible drip pipes. The better water use efficiency was observed in low flexible drip pipe type due to its free from maintenance. Per tree per day quantity of water used under low flexible pipe type for the peak period, i.e. for July and August was very less in subsurface as compared with surface drip irrigation method.

The maintenance was negligible in low flexible pipes either used for subsurface or surface drip irrigation system as compared with other two pipes of medium and high flexibility used. Mechanical operations would be possible under subsurface drip irrigation method as compared with surface drip irrigation system as the pipes were installed at some depth, as per advised by the manufacturer, from ground surface. It is concluded from this research experiments that high flexible pipe type was least efficient under subsurface as well as surface drip irrigation system due to its wall thickness, blockage of their built-in emitters and non-bearance of overburden soil weight particularly under subsurface irrigation method.

The yield of dates per tree for the area under low flexible pipe type was found more either of subsurface or surface drip irrigation methods, as compared to medium and high flexible drip pipe type. The comparison of date yield for each type of drip pipe under subsurface and surface drip irrigation system with one cubic meter of water was observed more under low flexible pipes used as compared with other two pipes used. Similarly, the water use efficiency for low flexible pipes was found more in both subsurface and surface drip irrigation methods, in comparison with other two medium and high flexible drip pipe type.
The cost analysis of all three pipes was also done. The price for low flexible pipe type was more than that for medium and high flexible pipes. Although the use of low flexible pipe will enhance the initial cost of the system yet it has negligible maintenance cost and has long-life. A cost analysis has been carried out to evaluate the gross margin of date palm cultivated in the open field under surface and subsurface drip irrigation methods with variable drip pipes containing fabricated emitters on it. The cost analysis of these two system showed that revenue collected and gross margin in US$/ha/season under subsurface drip irrigation system was more as compared with surface drip irrigation system, although fixed and capital cost of subsurface drip irrigation system was more.

Economical analysis studies have shown the superiority of the subsurface drip irrigation over center pivot sprinkler irrigation system. It was found that the total cost for the subsurface drip irrigation system per hectare (including; investment management, operation, etc.) is less than 30% compared to the center pivot system, as also supported by other studies as Dhuyvetter, et. al, 1995.
7.1 GENERAL

The present study was carried out to evaluate performance assessment of surface and subsurface drip irrigation methods, suitable for crops and fruit trees. Experiment base studies were carried out to evaluate the performance of the most advanced techniques of high efficiency irrigation system. Three field experiments were design under surface and subsurface drip irrigation system. One experiment was conducted on tomatoes vegetable crop, while the other two were on date palm trees. In both studies the latest self compensating emitter’s pipes were used. Irrigation schedule was prepared in accordance with crop water requirement of respective crop/fruit tree for these experiments.

A comparison has been made to see, which drip irrigation method, surface or subsurface, are the most effective and suitable method in respect of water consumption, yield, water use efficiency and cost analysis and applicable to crop as well as for fruit trees under different soil and climatic conditions. The study has been carried out on two different locations in the same hydrological region.

7.2 CONCLUSIONS

In the following paragraphs the main conclusion of the two experiments of fruit tree, date palm and one experiment on vegetable crop, tomato are presented separately and an attempt is made to generalize the findings of these experiments.

7.2.1 Findings of Drip Irrigation Experiment under Crop

The main conclusions of the study under vegetable crop are:

This study examined the performance of a surface and subsurface drip irrigation system using drip pipes of low flexibility. Based on the experimental results, the following conclusions can be drawn from this investigation:

1. Low flexible drip pipe, having continues self-cleaning mechanism performed well under subsurface drip irrigation system due to their physical and hydraulic characteristics.
2 Formation of bigger wetted volume of soil in the root zone was observed, in the case of subsurface drip irrigation method and smaller wetted volume of soil was found, in the case of surface drip irrigation method, which means that all volume of water consumed in subsurface drip irrigation system and also saved irrigation water due to non evaporation and wind effects.

3 Higher yield and yield to water ratio was obtained in subsurface drip irrigation method, regardless of their verities used under both drip irrigation methods, it is only due better water use efficiency of subsurface drip irrigation method.

4 Subsurface drip irrigation method proved, a feasible option for vegetable crop production under water limiting conditions.

5 Although fixed and capital costs of subsurface drip irrigation method was more but returns collected and gross margin in US$/ha/season under subsurface drip irrigation system was more as compared with surface drip irrigation system.

7.2.2 Findings of Drip Irrigation Experiment under Fruit Trees.

The main conclusions of the study under fruit trees are:

This study aimed to examine the performance of a surface and subsurface drip irrigation methods, by using drip pipes of varying flexibility, under surface and subsurface drip irrigation system. Based on the experimental results, the following conclusions can be drawn from these investigations:

1 Low flexible drip pipe performed well under subsurface drip irrigation system due to its better physical and hydraulic characteristics as compared to other medium and high flexible drip pipe types used. In addition to that low flexible drip pipes were equally efficient and better for surface drip irrigation system, than the other two, medium and high flexible drip pipe types.

2 Total quantity of water used in subsurface drip irrigation method was less as compared to surface drip irrigation method, under varying flexible drip pipe types used due to efficient utilization of all water applied. Low flexible drip pipe type consumed least water in peak period; for July and August due to its efficient working performance under subsurface.
3 Under subsurface drip irrigation method, the yield of the fruit per tree for the area having low flexible drip pipe type was more, in comparison with surface drip irrigation system containing low flexible drip pipe type due to better physical and hydraulic properties of these drip pipe type, non evaporation and non wind effects.

4 The water use efficiency for low flexible drip pipes under subsurface drip irrigation method was more than surface drip irrigation method due to bigger wetted volume of soil in root zone and climatic factors.

5 Subsurface drip irrigation system eliminates the weed growth around the tree and prevents salt accumulation on the soil surface which was not in the case of surface drip irrigation system.

6 Subsurface irrigation facilitated the ease of mechanical field operation for fruit orchard, as all pipes were underground at recommended depth.

7 Fixed and capital costs of subsurface drip irrigation method was more but outcomes in the shape of revenue and gross margin in US$/ha/season under subsurface drip irrigation method was more as compared with the surface drip irrigation method.

7.3 OVERALL CONCLUSIONS
1 Hydraulic performance of the subsurface drip irrigation method was much better than that of surface drip irrigation method, because of non evaporation and wind effects.

2 The yield under crop and fruit trees from the subsurface drip irrigation method area was found to be more than that from the surface drip irrigation method area.

3 The water use efficiency of subsurface drip irrigation method is much more than that of surface drips irrigation method. As all water utilized by the plants, in case of subsurface drip irrigation method, while as for the surface drip irrigation method partly utilized by plants and partially evaporated.
4. Bigger wetted volume of soil in root the zone was observed in the case of subsurface drip irrigation method, while it is smaller wetted volume of soil under surface drip irrigation method.

5. The analysis showed that subsurface drip irrigation method was more viable economically for both vegetable crop and fruit trees.

### 7.4 RECOMMENDATIONS

Following recommendations are suggested.

1. Further investigation of subsurface drip irrigation method by using low flexible drip pipe type (self compensating dripper pipe type) needs to be undertaken for other crops and fruit trees to confirm the benefits of the use of low flexible drip pipe type under this irrigation method.

2. For efficient and successful system working performance, maintenance schedule as per recommended by the company/manufacturer must be followed, to get the optimum results for crop and fruit trees under this drip irrigation system.

### 7.5 REFERRED FUTURE STUDIES

On the basis of experimental study’s findings, under crop and fruit tree, following recommendations are suggested which can be made for future studies:

1. Further investigation of subsurface drip irrigation method, needs to be undertaken for other fruit trees like citrus to confirm the benefits of the use of low flexible drip pipe type under this irrigation system.

2. Further investigation of subsurface drip irrigation method, needs to be conducted for greenhouses planting of other vegetable crops to verify the features of the use of low flexible drip pipe type under this irrigation system.


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