SUITABILITY OF DRIP AUTOMATION SYSTEMS FOR OPTIMAL IRRIGATION SCHEDULING

by

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THESIS

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2015

DECLARATION

I hereby declare that this thesis entitled **"Suitability of Drip Automation Systems for Optimal Irrigation Scheduling"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Suitability of Drip Automation Systems for Optimal Irrigation Scheduling"** is a record of research work done independently by **Miss. K. Manasa (2013 - 18 - 109)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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SYMBOLS AND ABBREVIATIONS

°C	: Degree Celsius
&	: And
%	: Per cent
>	: Greater than
<	: Less than
+	: Plus
–	: Minus
atm	: Atmospheres
AMC	: Available Moisture Content
AWD	: Available Water Depletion
B:C	: Benefit Cost Ratio
Cm	: Centimeter
Cm^3	: Cubic centimeter
Cond.	: Condition
CoH	: College of Horticulture
CRD	: Completely Randomized Design
DC	: Direct Current
DAP	: Days after planting
dS/m	: Deci Siemens per meter
et al.,	: And co workers

:

E		East
EC	:	Electrical conductivity
ESC	:	Escape
ET	:	Evapotranspiration
FC	:	Field Capacity
g/cc	:	Gram per cubic centi metre
g/m^2	:	Gram per square meter
GI	:	Galvanized Iron
Ha	:	Hactare
HP	:	Horse power
H	:	Hour(s)
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji college of Agricultural engineering & Technology
Kg	:	Kilogram
Kg/m^3	:	Kilogram per cubic meter
Kg/ha	:	Kilogram per hectare
Kg/ham^3	:	Kilogram per hectare per cubic meter
Kg/hamm	:	Kilogram per hectare millimeter
Kpa	:	Kilopascal
L	:	Liter

	:	
LCD	:	Liquid Crystal Display
Lph	:	Liter per hour
l/day		Liter per day
MDL	:	Moisture Depletion Level
Min.	:	Minimum
Max.	:	Maximum
MCU	:	Microcontroller Unit
mg/kg	:	Milligram per kilogram
mg/l	:	Milligram per liter
M Ha	:	Million Hectares
ml/l	:	Milliliter per liter
mm	:	Millimeter
mm/day	:	Millimeter per day
N	:	North
NPN	:	Negative Positive Negative
NWTC	:	Nodal water technology center
PE	:	Pan Evaporation
PCB	:	Printed Circuit Board
pH	:	Negative logarithm of hydrogen ion
PWP	:	Permanent Wilting Point
RS	:	Rain Sensor

	:
Rs.	: Rupees
S	: Second(s)
SLW	Specific Leaf Weight
SMS	: Soil Moisture Sensor
SWP	: Soil water potential
TDR	: Time Domain Reflectometer
t/ha	: Tonnes per hectare
V	: Volt(s)
viz.,	: Namely
WCR	: Water Content Reflectometer
WORS	: With Out Rain Sensor
WUE	: Water Use Efficiency

CHAPTER I

INTRODUCTION

Water and nutrients are two important inputs to agriculture which are determining the whole gamut of agricultural productivity and production in India in addition to the soil and seeds. Water is essential for human civilization, living organisms, and natural habitat. It is also used for drinking, cleaning, transportation, industry, recreation, animal husbandry and for producing electricity. Due to the multiple benefits of water and the problems created by its excesses, shortages and quality deterioration, water as a resource requires special attention. The present and future status of water resources in many regions is closely monitored due to the pressures of climate, land cover and population changes (Murray *et al.*, 2012).

Current water resource constraints in India, in terms of both quality and quantity, can be expected to manifest themselves even more rapidly in the coming years. Now as the gap between the availability of water resources and the demands on such resources narrows, the past approach to water management pursued in India is no longer tenable. Competition for water between urban and agricultural sectors will be a major challenge in the forthcoming century. Advanced scientific methods of irrigation like drip and sprinkler irrigation systems and real time sensor based scheduling with electronic gadgets or sensors can be used to enhance water use efficiency (WUE) and fertilizer use efficiency in India.

Surface irrigation is the oldest and most used method of irrigation. Farmers in Egypt, China, India and countries of Middle East are known to have irrigated lands at least 4000 years ago, most likely using surface irrigation methods. The overall efficiency of surface irrigation is only 20-50%. The drawbacks of surface irrigation include erosion, salinization, waterlogging problems, seepage losses, deep percolation, and runoff. Two necessary aspects to be considered are uniform water distribution in the field and accurate amount of water application by permitting accurate delivery control. These requirements are accomplished only by adopting micro irrigation techniques.

Micro-irrigation is an irrigation method that applies water slowly to the roots of plants, by delivering the water either on the soil surface or directly to the root zone, through a network of valves, pipes, tubing, and emitters.

Drip irrigation is mostly done manually or automatically by using timer devices. The timer devices will regulate the fields at regular intervals. But timers will not have a control on climate and it will work constantly both in rain and summer seasons. So this is not an efficient system since large amount of water will be wasted in rainy season. Hence, in the present study automation by measuring moisture levels are considered and irrigating the field based on different moisture status is studied.

Irrigation scheduling technically means applying water to the effective root zone of a crop at the right time and in required quantities. The purpose of Irrigation scheduling is applying the moisture along with the nutrients to meet the evapotranspiration and metabolic water requirements of the crop. Soil moisture deficit within the domain of the available water holding capacity of the effective root zone plays a crucial role in scheduling irrigation.

In recent years, different types of soil moisture sensors are available for application in the lab as well as in the field. However, the sensors need to be appraised for their performance and economic viability with particular reference to micro irrigation systems. In field conditions, in addition to soil moisture, nutrients and salts present in the rhizosphere may also influence the performance of the sensors. Hence the sensors are to be evaluated for their compatibility to the corresponding environment of irrigation.

Many new opportunities and choices are brought before farmers every day. The goal of the farmer is to choose proper choice to increase farm profitability and reduce risk. The recent irrigation techniques introduce automated irrigation using sophisticated equipment to supply water to the plant as soon as they need it. Automated irrigation systems can increase crop yields, save water usage, energy and labour costs and reduces human errors as compared with manual systems.

Automation in irrigation management refers to those innovations which partially or fully replace manual intervention from watering operations. Automized irrigation includes automation at regional level or farm level. Large number of experiments have been carried out on automation in irrigation at various levels during last two decades. However, the concept of automation in irrigation water management is relatively newer and is gaining momentum slowly in India.In the last two decades, the proliferation of powerful low cost microprocessors and the impressive growth of computer performances mechanized the irrigation and harnessed the power of computerized controllers to improve water use. This increase in the sophistication of automation rationalized the utilization of inputs, increased production, reduced losses and man power and finally increases farmer's net income.

The present study aims to automate drip irrigation by measuring moisture levels in the field using moisture sensors and irrigating the field based on the moisture status, so as to reduce the wastage through excess use of water for irrigation. In order to get wider adoption and popularity of automated irrigation system, it is imperative to bring out a cost effective system in this irrigation technique.

The specific objectives are:

1) To evaluate the performance of sensor based automated drip irrigation systems.
2) Scheduling irrigation for tomato based on the best performing drip automation system.
3) To evaluate the cost economics of drip automation system with optimal irrigation scheduling.

CHAPTER II
REVIEW OF LITERATURE

In this chapter, review on various research activities carried out at different locations by different researchers on automation of drip irrigation system, crop water requirements, soil moisture sensors, response of different crops under different methods of automation in drip irrigation were reported.

2.1. AUTOMATION IN DRIP IRRIGATION SYSTEM

Luthra *et al.* (1997) developed a system in which soil water tension is sensed through a modified manometer type tensiometer. The design provides control of irrigation at the pre-decided soil water tensions and pre-programmed timer. The circuit could be operated with a 12 V DC storage battery for a long period.

Dukes *et al*. (2003) conducted experiment on bell pepper based on three levels of sensor based high frequency irrigation treatments and four levels of twice daily irrigation treatments in 2002 to test the effect on yield and seasonal irrigation volume, water use efficiency, and soil moisture content in the root zone. Sensor based treatments used a soil moisture sensor buried at 10 cm depth within the crop root zone to maintain soil moisture at a set level. The two sensor based irrigation treatments resulted in yields similar to the two daily irrigation treatments but used approximately 50% less seasonal irrigation water. This resulted in irrigation water use efficiencies of 1209-2316 kg/ha/m^3 for the sensor based treatments while those of daily treatments ranged from 703 to 1612 kg/ha/m^3. The results indicate that high frequency irrigation events based on soil moisture sensor control can maintain crop yields while reducing irrigation water requirements.

Miranda *et al.* (2005) developed and tested a distributed irrigation control system, which proved to be reliable, affordable and effective in maintaining the soil water potential (SWP) in the root zone close to a preset value without hard-wire connections between irrigation management units. The system maintained the SWP in the root zone less negative than −18 kPa (the threshold value) for 100% of the time during the study.

Nemali and Iersel (2006) suggested an automated irrigation system which results in little or no wastage of water. The system required little maintenance during the study. Regardless of the time of the day, the system irrigated the plants when the substrate moisture fell below the target level. This irrigation approach can easily be scaled up for use in green houses or nurseries, where it would likely result in significant decreases in water use, leaching and run-off. The controller also has potential for use in drought stress studies, since it is possible to control the amount of water available in the soil.

Dukes *et al.* (2007) conducted study on soil water controlled irrigation on tomato and pepper which resulted in a reduction of about 34-60% of irrigation water applied compared to a fixed time based treatment similar to typical grower scheduled irrigation. In addition, yields of tomato were 78% and 54% higher on the two SMS treatments compared to the fixed time treatment, in 2005 and 2006 respectively. Pepper yields on soil moisture sensor controlled treatments were similar to the fixed time treatment.

Vellidis *et al*. (2008) described real potential for reliably monitoring soil water status in crops. The system was able to successfully monitor soil water status and soil and air temperatures within the canopy for the entire growing season with few technical difficulties. Equipment modifications to overcome the encountered problems resulted in a more robust system that can be installed at the beginning of the season and left in the field. The smart sensor array reliably recorded and transmitted the readings of the Watermark sensors and allowed to successfully implement irrigation scheduling protocol. The relatively low cost of the sensor nodes allows for installation of a dense population of soil moisture sensors that can adequately represent the inherent soil variability present in any field. Hameed and Agarwala (2009) proposed a novel approach to determine the water requirement of agricultural fields for farming in a most scientific and cost effective manner. They designed an ultra- low cost moisture sensor using computer to manage the water resources more appropriately in agricultural farms. The results reveal that the capacitance response characteristics make it possible to maintain soil moisture at the desired level as per the crop. In this experiment an effort has been made to use a sensor to estimate the PWP and FC. They concluded that sensor may provide a new insight to irrigation automation and will be a boon to unskilled farmers to optimize their crop yield by saving water and electricity.

Javadi *et al*. (2009) developed a Fuzzy Logic Controller prototype based on a Mamedani controller built on MATLAB software. The developed fuzzy logic controller can effectively estimate amount of water uptake of plants in distinct depth using the reliable irrigation model, evapotranspiration functions, environmental conditions of greenhouse, soil type, type of plant and other factors affecting the irrigation of greenhouse. Consequently fuzzy controller system had more ability as compared with another system. It is important to note that such systems can save a lot of water and is very cheap to implement.

Romero *et al*. (2012) and Fernandez *et al.,* (2008b) installed and tested an irrigation controller, using a combination of feed-forward and feedback strategies based on weather and soil moisture measurements. This controller has been evaluated in an almond orchard, demonstrating to reduce water losses by drainage, evaporation and runoff.

Migliaccio *et al*. (2010) conducted evaluation of papaya irrigation by including key physiological and production characteristics for Papaya irrigation. Irrigation water savings of about 65% were obtained with either of these methods compared to a set schedule of irrigation. Crop water use efficiency was significantly greater for soil water based and historic ET based management than set schedule irrigation treatments.

Dursun and Ozden (2011) described an application of a wireless sensor network for low-cost wireless controller irrigation solution and real time monitoring of water content of soil using cherry trees in Central Anatolia. Data acquisition is performed by using solar powered wireless acquisition stations for the purpose of control of valves for irrigation. The designed system has 3 units namely: base station unit, valve unit and sensor unit. The obtained irrigation system not only prevents the moisture stress of trees but also provides an efficient use of fresh water resource. In addition, the developed irrigation method removes the need for workmanship for flooding irrigation.

Yildirim and Demirel (2011**)** conducted study of a drip irrigation system which automatically governed irrigation in accordance with water consumption of the soil plant system. The pic1684 functioned as a controller, which decided when and how much water to apply; hence, the pumps ran and stopped according to the irrigation strategy defined by the microcontroller. The pump operation time corresponded to the time to increase soil moisture up to field capacity in the full treatment whenever 30% of the available water in the substrate was depleted by the pepper plant (*Capsicum annuum* L.) in the experiment. The automated system applied four different water applications; one treatment was full and the other three were deficit treatments. Even though yield value was high in treatment I1.0, the best quality parameters were obtained from I0.75. In the deficit treatments I0.50 and I0.25, yield and quality parameters decreased since plants in those treatments were under stress.

Casadesús *et al*. (2012) proposed an approach for automated irrigation scheduling which combines a feed-forward estimation of irrigation needs by water balance method with a tuning mechanism based on feedback from soil or plant sensors.

Ingale and Kasat (2012) prepared a circuit which is cheap and reliable to develop an automated irrigation system. The system provides several benefits and can operate with less manpower. The system supplies water only when the humidity in the soil goes below the reference. Due to the direct transfer of water to the roots water conservation takes place and also helps to maintain the moisture to soil ratio at the root zone constant to some extent. Thus the system is efficient and compatible to the changing environment. Also the system saves water and improves the growth of plants.

Kiran (2012) applied simple electronic circuit principles in irrigation and agricultural drainage and developed a low cost auto irrigation and drainage unit based on soil moisture for paddy field. The circuit works by using integrated circuit CD 4011. The circuit is simple, compact and economical. It works on a 12 V DC power supply and it is given through a step down transformer and consumes very little power.

Prathyusha and Chaitanya (2012) developed microcontroller based drip irrigation system which proves to be a real time feedback control system which monitors and controls all the activities of drip irrigation system efficiently. The system is a model to modernize the agriculture industries at a mass scale with optimum expenditure, which can provide irrigation to larger areas of plants with less water consumption and lower pressure. Using this system, one can save manpower and water to improve production and ultimately profit.

Singh and Sharma (2012) reported that, though conventional flood type methods consume large amount of water, the area between crop rows remains dry and receives moisture only from the incidental rainfall whereas the drip irrigation technique slowly applies a small amount of water to the plant's root zone. So by using the fuzzy based algorithm in wireless sensor drip irrigation technique, we can control the wastage of water and eliminate labour requirement for irrigation.

Sweety and Vijaya (2012) developed a soil moisture sensor using basic property that the resistance of the soil between two points decreases with increase of water content in it. G reater the amount of electrolytes in the soil, greater will be the conductivity of soil. This means the resistance of soil decreases. A relation was developed between soil moisture resistance and voltage and was presented.

Chandrasekhar and Chakravarthi (2013) developed an automatic drip irrigation system using low cost sensors and simple circuitry. Irrigation system uses valves to turn irrigation ON and OFF. These valves may be easily automated by using controllers and solenoids. The humidity sensors are constructed using aluminum sheets and housed in easily available materials. The aim is to use the readily available material to construct low cost sensors. Five relays are controlled by the microcontroller through the high current driver ICULN2003. Four relays are provided for controlling four solenoid valves, which controls the flow of water to four different parts of the field. One relay is used to shut-off the main motor which is used to pump the water to the field.

Divya and Umamakeswari (2013) proposed a system which provides the farmers an option to ease their work of irrigation with the help of available technology of cell phones. The farmer just needs to speak the commands through the cell phone to activate the system in the field. This can greatly save their time needed to travel to the fields in order to switch on/off the motor. Also the system could be used to save water used for irrigation by including the moisture sensor to sense the level of water and automatically switch off the motor.

Guerbaoui *etal*. (2013) proposed a solution which involves the development of an integrated system to automate the drip fertigation in greenhouse. The solution adopted involves a data acquisition card PCL-812PG controlled by PC. The irrigation is provided by a hydraulic circuit based on an electric pump. Water needs are evaluated by measuring soil water status by soil humidity sensor. A PC-based automated system has been developed to manage the drip irrigation/fertigation. The process of irrigation consists of introducing water into part of the soil profile that serves as the root zone, for the subsequent use of the crops. A well-managed irrigation system is one that optimizes the spatial and temporal distribution of water, so as to promote crop growth and yield, and to enhance the economic efficiency of crop production.

Kumar *et al.* (2013) discussed the prototype design of microcontroller based Intelligent irrigation system which will allow irrigation to take place in zones where watering is required, while bypassing zones where adequate soil moisture is indicated. The dielectric constant of soil increases as the water content of the soil increases. This response is due to the fact that the dielectric constant of water is much larger than the other soil components, including air. A soil moisture probe is made up of multiple soil moisture sensors. One of the common types of soil moisture sensors in commercial use is a frequency domain sensor such as a capacitance sensor. Another sensor, the neutron moisture gauge, utilize the moderator properties of water for neutrons. Cheaper sensors often for home use are based on two electrodes measuring the resistance of the soil. Sometimes this simply consists of two bare (galvanized) wires, but there are also probes with wires embedded in gypsum.

Luciana *et al*. (2013) used temperature sensor and soil moisture sensor to measure the soil and weather conditions of the field. The temperature and moisture values from the sensors are sensed to the microcontroller and thus current temperature and moisture are compared with predefined values. According to the temperature and moisture value, required amount of water is supplied to the crops. The sensed temperature and moisture were displayed in the liquid crystal display.

Razali *et al*. (2013) developed open loop control systems which has the advantages like low cost, readily available and many variations of the devices are manufactured with different degrees of flexibility related to the number of stations and schedule specification. However, they do not respond automatically to changing conditions in the environment and require frequent resetting to achieve high levels of irrigation efficiency.

Sanjukumar and Krishnaiah (2013) developed soil moisture sensor based automatic drip irrigation system that checks the moisture content in the soil, based on that pumping motor will automatically pump the water into the field. By using this sensor, we can find whether the soil is wet or dry. In this system, the main controlling device is microcontroller. Here soil sensor will give the status of the soil to the microcontroller, based on that microcontroller will display the status of the soil on the liquid crystal display (LCD) and switch on or off the pumping motor through relay. The pumping motor will pump the water into the field by using drip water system until the field is wet which is continuously monitored by the microcontroller. This saves the water at the same time and on the other hand the plant can get optimum level of water, thereby increasing productivity of crop.

Thakur *et al*. (2013) found that the combination of hardware and software provides an automatic irrigation system that can be implemented at relatively low cost and is extremely user friendly with the use of ZigBee network. We can eliminate the complication of wiring in case of wired irrigation and ZigBee based automation system provides operating range much higher as compared to Bluetooth or other wireless standard. With the use of ZigBee based automation circuit considerable amount of power saving is possible and it is flexible and compatible with future technologies so it can be easily customized for individual requirements.

Agarwal *et al.* (2014) developed a soil moisture sensor based on the conductivity of water. Water sensor is nothing but a series of very close printed circuit boards (PCB) tracks. In normal mode these tracks are not conducting, but when some water fall on these tracks these line slightly start conducting and some positive voltage is available at the base of transistor. So negative positive negative (NPN) transistor is on and NPN transistor provide a negative voltage as a pulse to the microcontroller. The output voltage of a sensor is amplified by an operational amplifier, and is inputted into the base of transistor.

Miller *et al*. (2014) conducted three years field experiments for automated high frequency drip irrigation in watermelon [Citrullus lanatus] production and to determine irrigation set points as percent soil water content depletion. Irrigation water treatments of 15% available water depletion (AWD), 50% AWD and No water application (fertigation only) were tested in sandy coastal plain soils in South Carolina. During peak crop water use and on hot days, four to seven irrigation events per day were necessary to meet crop water needs and minimize leaching in the sandy fields. The 15% AWD irrigation water treatment showed a significant yield increase of 44% and 18.4% during 2008 and 45% and 40% during 2010 compared to no water application and 50% AWD irrigation water treatments respectively. The standard deviation of the root zone VMC was significantly less under the 15% AWD treatment in all years including the very wet 2009 season.

Sun *et al*. (2014) described technical performance of the electromagnetic mobile sensor for dynamically observing the horizontal soil water content distribution at the depth of installation. In general, this novel sensing approach provides previously unavailable measurements for ‘‘imaging’’ horizontal soil water dynamics in the root zone, along crop rows and drip irrigation systems that can be used for assessing the effectiveness of irrigation systems or for evaluating soil water flow and transport models associated with applicable initial and boundary conditions. Beyond this, it facilitates combined use of vertical and horizontal (or other orientation) access tube sensors for investigating soil water dynamics in the field. The system described here or a modified version has tremendous potential to address a variety of agricultural, environmental or ecological problems where water content assessment/monitoring is required in difficult to access conditions.

Steidle Neto *et al*. (2014) developed a fertigation system for real time preparation and application of nutrient solution for soilless tomato production. The performance of the fertigation system was evaluated during tomato cultivation in sand substrate under greenhouse conditions. The commercial crop yield was 4.74 kg/ m2 and the average total soluble solids of tomato fruits were 4.50 Brix. Water use efficiency for tomato crop cultivated using the developed control system was 17.94 kg/ m3. To produce 1 kg of tomato fruits, 44.42 L of nutrient solution was necessary. The proposed system was efficient in adjusting the frequency of fertigation cycles and controlling the prepared nutrient solution concentration, minimizing environmental problems related to effluent disposal and contributing to economy of fertilizer and water resources. Developed control system reduced unnecessary nutrient solution applications during cloudy days, minimizing environmental problems related to effluent disposal and hereby contributing to the economy of fertilizer and water resources. This additionally reduced the plant water stress under high atmospheric demand.

2.2 DIFFERENT TYPES OF SOIL MOISTURE SENSORS

Specific soil moisture sensors based on the principles of dielectric properties and soil suction pressure are used for sensing the soil moisture.

Tensiometers used for measuring soil moisture potential is comprised of a tube filled with water, attached to ceramic cup on one end and a vacuum gauge on the other. During installation, the ceramic tip or cup must make firm contact with the soil at the desired depth. To ensure good contact between the tensiometer and soil, water or soil slurry can be used during insertion into the soil. This includes pushing the device right to the bottom of the hole prepared for it. The maximum pressure range is from 0-75 kPa, and pressures reading are then converted to volumetric soil moisture through the soil characteristic curve. The same principle is used with Water Mark equipment data reading, expressed in centibars (McCann *et al.,* 1992).

An electrical resistance device is housed in a gypsum block or other granular matrix material. Usually an auger is used to place these sensors at multiple depths throughout the soil profile and slurry or water is used to ensure firm contact with surrounding soil. The moisture data is transmitted to and stored in a data logger. These sensors read centibars of soil tension, ranging from 0-200 kPa, and this is then converted to volumetric soil moisture content (McCann *et al*., 1992; Spaans and Baker, 1992).

Shinn *et al.* (1997) developed a cone penetration testing (CPT) probe that measures both electrical resistance and volumetric soil moisture. The design of sensors consists of four concentric rings spaced along the penetration rod with insulators in between. The outer two rings determine the soil resistance; the inner two rings measure the capacitance with use of a modified Clapp high frequency transistor oscillator operating at 100 MHz. The CPT-measured volumetric soil moisture can be used to back-calculate other properties such as dielectric constant and for saturated soil, the dry and wet density.

Neutron probe or neutron moisture meter (NMM) is another way of measuring volumetric soil moisture. It is considered to be among the most robust and accurate method of soil water content measurement (Charlesworth, 2005). The principle is that fast moving neutrons arising from a small radioactive source collide with hydrogen ions in the soil and are slowed down. The higher the water content the higher the extent of collisions (George, 1999). However, due to perceptions of radiation safety threat, its use has declined.

Abraham *et al.* (1999) developed and tested two automated drip irrigation systems one based on soil electrical conductivity and other based on the leaf temperature differential. Different sensors were evaluated for monitoring the soil moisture content based on the electrical resistance variation with moisture content. The sensor with washed sand as porous medium was found to be most efficient one for the study area. A low cost, commercially available button type is thermistor was used as the leaf and air temperature sensors. The amount of water applied per day, leaf air temperature and soil moisture were monitored during study period.

Shock *et al.* (1999) tested watermark soil moisture sensors (model 200 SS, Irrometer Co. Riverside, CA) with a hand held meter or with a programmed data logger. The sensor resistance was converted to water potential through a calibration equation that includes compensation for soil temperature. Calibration equations of Ag Tech readings to soil water potential and sensor resistance were developed.

Cardenas *et al*. (2001) quantified irrigation water use and evaluated turf quality difference between a time based scheduling system with and without a rain sensor (RS), a time based scheduling and soil moisture sensor (SMS) based irrigation system and different commercially available SMS systems.

Yoon *et al*. (2002) described the relationship between electrical resistance and physical property of unsaturated subsurface. For three different tested soils, the electrical resistance of soil exponentially decreased as moisture density increased. The adding of leachate having various ions decreased the electrical resistance.

Pathan *et al.* (2003) evaluated water application rates, leaching and quality of couch grass under a soil moisture sensor controlled irrigation system. They compared with plots under conventional irrigation scheduling recommended for domestic lawns. The cumulative volume of water applied during summer to the field plots of turfgrass with the sensor controlled system was 25% less than that applied to plots with conventional irrigation scheduling. The soil moisture sensor controlled irrigation system enabled automatic implementation of irrigation events to match turfgrass water requirements

Mathew and Senthilvel (2004) developed and tested an automatic furrow irrigation system based on soil moisture sensing to assess its field performance. An electronic tensiometer monitored the prevailing soil moisture status and switched on a solenoid valve commencing irrigation. Once irrigation started the instrument kept on monitoring the soil moisture level and when it reached zero tension, it switched off irrigation. Conventional furrow irrigation method was kept as a control. The system performed well and it could save nearly 20% of water compared to conventional furrow irrigation.

A scatter-plot of measurements *vs* gravimetric data showed close correspondence even in sandy soils (< 10% clay). Studies have shown that the manufacture's WCR sensor calibrations can be used for measurements in sandy soils and in clay soils of low electrical conductivity (Seyfried and Murdock, 2001; Kelleners *et al;* 2005). Results from four year of studies on soils with < 10% clay showed WCR reading to provide a precise and reliable range of soil moisture content (Chandler *et al.*, 2004), however, WCR overestimated the volumetric soil moisture content in soils of high clay content. In such condition in-situ calibrations would improve the quality of results (Chandler *et al*; 2004).Similarly, when the EC is greater than 0.1 Sm-1, field calibration of the WCR is required. The CS 625 model was used with the standard calibration provided by the manufacture (Seyfried and Murock, 2001), which was stated to be accurate for soils having an EC < 0.5 dS/m, a bulk density < 1.55 Mg/ m3 and a clay content < 30% (Campbell Scintific, 2006). Variations in these parameters affect the soil electrical conductivity and at low frequencies, also affect soils electrical properties (Chandler *et al;* 2004).

The Theta probe is another capacitance-based instrument, but does not require an access tube for installation. It consists of steel pin that act as a transmission line, these pins work by monitoring soil moisture changes, using the properties of radio frequency energy when transmitted into and reflected by the soil. The probe head houses an internal circuitry and a sensor which can be used for point measurements or continuous monitoring. The output is in volts and can be converted to soil moisture based on a linear calibration equation (Charlesworth,2005).

An Echo probe operates on the principle of capacitance and it measures the dielectric constant of soil. It is made up of copper electrodes further sealed in epoxy-impregnated fiberglass (Fares and Polyakov, 2006). Manufactured by Decagon Device, Inc., (Pullman, WA, USA), these are several lengths available. Typically enho probes are permanently installed throughout the growing season and connected to either a data logger or telemetry system through which soil moisture content reading may be transmitted. The Echo probe measures soil moisture content in volts, by measuring the change time of a capacitor placed in the soil (Czarnomski *et al*., 2005). Although the Echo probe displays reading in volts, it is easiest to interpret these reading as a trend line for the purposes of scheduling irrigation.

Time domain reflectometer based sensors have different designs, of which the Field Scout (TDR 300, Spectrum Technologies Inc; 2007) is portable. The TDR300 calculates permittivity based on the propagation time of electromagnet ic wave, typically within 0.1 nano second. While for water permittivity (€) is 80 (depending on temperature) for other soil constituents, such as minerals 2< € < 5. Therefore the bulk permittivity of the soil is directly related to the soil moisture content. This property makes the TDR 300 efficient for in situ determination of volumetric soil moisture content. The attached probes function as wave guides, with the standard TDR signal being transformed into square wave output with a frequency to volumetric soil moisture content (Spectrum Technologies Inc; 2007).

The equipment used in obtaining soil moisture content using neutron probe technology consists of a probe and an electron counting scaler connected by an electronic cable. High energy, fast moving neutrons are released into the soil by a radioactive source. The neutrons are slowed down by collisions with the nuclei of hydrogen atoms present in the molecules of water in the soil (Chanasyk and Naeth, 1996). Neutron probes are of two types: depth probes, which can be lowered to the soil depth at which the moisture content is to be measured and surface probes which can be used to measure the moisture content in the uppermost layer of soil (Schmugge *et al.,* 1980). Neutron probes yield accurate results and are non-destructive. They may be used irrespective of the state of the water. The output from the neutron probe can be directly related to the soil moisture content (Chanasyk and Naeth, 1996). The measurement is related to the physico-chemical properties of the soil. The instrument requires a trained operator due to the use of the radioactive source and is potentially hazardous to health and the environment (Tarantino *et al.,*2008). The equipment is expensive and requires extensive soil specific calibrations, which limits its use.

Resistance blocks operates on the principle that the electrical resistance of a porous block is proportional to its water content. Ceramic thermal dissipation blocks are available which measure the rate of heat dissipation in the soil, which correlates to soil moisture content. The method is quick, repeatable and relatively inexpensive. Kolev (2005) evaluated the soil moisture content by using electrical resistance methods and soil moisture meter with gypsum blocks housed in the soil profile.

Thompson *et al*. (2007) determined thresholds of soil matric potential (SMP) and available soil water content (AMC) required to prevent water limitation between irrigations for bell pepper, melon and spring and winter tomato grown in Mediterranean type greenhouses on the south-eastern coast of Spain. For the four crops studied, AMC thresholds calculated at 0- 40 cm were 13-15% higher than those calculated at 0-20 cm. Each AWC threshold for 0-20 cm depth was 20-29% lower when AMC was based on the laboratory rather than field determinations of field capacity and permanent wilting point. The results of this study demonstrated the uncertainty of using recommended fixed AWC threshold values for irrigation management using SWC sensors, measurement of FC and PWP, sensor calibration and sensor accuracy across the relevant range of water contents.

Hignett and Evett (2008) studied electrical resistance sensors. The sensor with brass plate as electrode and washed sand as porous medium showed nearly a constant trend in the relationship between resistance and soil moisture content in all trials. The automated system based on the soil resistance was found to be efficient without frequency supervision and maintained the pre-set moisture content in the root zone. They found that results were specific to soil type and soil salinity. Similar comparisons conducted under different conditions had different results. Reasons for the different response were not clear, but it might be the factors such as clay type and soil salinity.

2.3 COMPARISON AND CALIBRATION OF SENSORS

Bell *et al.* (1986) discussed the comparison of the capacitance method with established methods of defining and determining water content using the neutron probe and the gravimetric technique. The relationship between the capacitance probe readings and water content was not linear and influenced by the type of soil. White *et al*. (1994) predicted the influence of dielectric losses on TDR determinations of water content in porous materials and compared predictions with measurements. A three phase effective medium model was modified to show how dielectric constant and water content were related bound water. This equation was tested using graphite sand mixture in which electrical conductivity varied systematically.

Shock *et al*. (2001) compared six soil moisture sensors as to their performance in producing soil moisture data. The sensors were Aquaflex, Gro Point, Moisture Point, Neutron Probe, Tensiometer and Watermark. All sensors showed correlations ($r^2 > 0.7$) to the neutron and correlations ($r^2 > 0.5$) to the tensiometer except the moisture point sensors. The moisture point estimates of soil water were substantially lower than the neutron probe data. The tensiometer and Watermark sensor responded to the wetting and drying cycles of the soil. The neutron probe and Aquaflex sensors were less responsive to the soil drying between irrigations than Gro point sensor.

Adamchuk *et al*. (2003) attempted to develop on-the-go soil sensors to measure mechanical, physical and chemical soil properties. The sensors have been used based on electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical measurement concepts. They presented reviews which may be suitable to improve the quality of soil related information in the near future.

Heng (2003) carried out numerous comparisons on a wide range of sensors viz, soil moisture neutron probe, Time Domain Reflectometer and capacitance probes. The devices were tested under a wide range of soil types, vegetation and experimental sites, under both irrigated and rain fed conditions in agricultural field environments and in the laboratory. In some of these studies, the effects of soil temperature and salinity were also evaluated. After comparative study, the consultants affirmed their conclusion that all the devices required soil specific calibration except for the conventional TDR systems which can be used reasonably accurately without calibration.

Chandler *et al*. (2004) evaluated the effectiveness of using TDR to calibrate the Campbell Scientific water content reflectometer (WCR) or CS-615, an example of a newly developed sensor. They found that there was a strong, linear correlation between the WCR measured period and TDR measured volumetric soil water content (VWC), the WCR calibration varied. Soil types and calibration of individual sensors resulted in excellent agreement between TDR and the WCR. The site provided ideal field condition for sensor performance, both coarse loamy but differed appreciably in sand and clay content. The soil at the upper site was a sandy loam and contained an average of 75% sand and 8% clay, as compared with the loam soil at the lower site which contained an average of 49 and 16% sand and clay measurements.

Plauborg *et al*. (2004) studied the comparative performance of the CS616 (Campbell scientific, Ltd., Shepsed, UK) sensor and the Aquaflex sensor with TDR using both vertical and horizontally installed sensors. It was found that the CS616 manufacturer's standard calibration needed to be linearly transformed to obtain accurate measurements in a sandy soil with horizontally installed probe. In two different soils, the standard calibration performed better and smaller corrections were found for a sandy loam with larger clay content respectively. The CS616 sensor was most likely affected by electrical conductivity at 1.6 dS m-1 in the soil solution. The dynamic response of the vertical installed sensors to the change in soil water content was shown to be good and the sensor may be useful for assessing threshold values in water content for the start and end of irrigation. The performance of the Aqua flex sensor was investigated in the sandy soil only, and the sensor was found to reflect the dynamics of soil water content well.

Walker *et al*. (2004) inter-compared the virribw, Campbell Scientific CS615 reflectometer, soil moisture Equipment Corporation TRASEW buriable and connector-type time domain reflectometer (TDR) soil moisture and a comparison of the connector type TDR sensor with thermo gravimetric measurements for data collected during a 2 year field study. Both qualitative and quantitative comparisons between the techniques were made and comparisons made with results from a simple water balance 'bucket' model and a Richards's equation based model. This study suggests that connector type TDR sensors give the most accurate measurements of soil moisture content out of the sensor types tested.

Campbell *et al*. (2005) compared Watermark soil moisture sensors and Crop sense soil moisture probes in a drip irrigated carrot seed field to determine whether one type of sensor was more useful than other. Watermark sensors reflect soil water potential. Crop sense probe measure the volumetric water content of the soil. Crop sense was continuously monitoring soil moisture at four depths; 4, 8, 12, and 20 inches. Both types of sensors appear to provide similar wetting and drying pattern data.

Nemali *et al*. (2006) calibrated ECH20-10 and Theta probe for measuring water content of greenhouse substrates and studied the effect of substrate EC and temperature on probe measurements. Reliable and affordable moisture sensors for measuring the water content in soilless substrates were limited. In this study, they examined the efficiency of two moisture sensors (ECH20-10 and Theta probe ML2X) for measuring water content in soilless substrates and developed calibration equation and analyzed the effect of increasing electrical conductivity (EC) and substrate temperature on the voltage output of probes.

2.4 EFFECT OF DRIP IRRIGATION ON GROWTH AND YIELD OF CROPS

Bernear (1971) carried out experiments on tomato crop and reported that with drip irrigation system there was about 50 per cent water saving over furrow irrigation. There was a significant increase in yield under drip irrigation system

Yield response to irrigation was significant only if water stress was severe enough to affect normal plant growth. If the rainfall was inadequate, more frequent irrigation at lower soil moisture tension significantly increased marketable yield (Batal and Smittle, 1981). The effect of water quantities of 2, 4 or 6 mm/day and drip irrigation frequencies of every 1, 2 or 3 days on the fruit production in bell pepper was positively correlated with the amount of water and negatively with percentage of dry matter. Fruit mean weight and the incidence of injured fruit did not differ between treatments, but fruit wall thickness increased with amount of water and greater irrigation frequency and decreased with raising water quality and reduced irrigation frequency (Caixeta *et al*., 1981).

Lin and Hubbles (1983) studied the effectiveness of different amounts of water applied through drip irrigation on yield and quality of tomato. Four levels of moisture maintaining above 25, 50, 65 and 80 per cent available water were used. Such treatments produced 20-40 per cent more marketable yield than the treatment with monthly furrow irrigation.

According to Sivanappan *et al*. (1987) different methods of moisture controls provided yield of 11000 to 14000 kg/ha, whereas water requirement ranged from 20.6 cm to 69 cm. Similarly, different systems of drip required 13.5 cm of water besides 40 cm of rainfall, whereas control plot required 60 cm of water along with a 40 cm of rainfall. Such a water application provided yields of 12000 to 14200 kg/ha as against the control plot of 12500 kg/ha.

Locascio and Smajstria (1996) studied the effect of amount of water application and mulches for 3 years on irrigated tomatoes by applying water at 0.00, 0.25, 0.5, 0.75 and 1.00 times pan evaporation in one application per day. They found that fruit yield gets doubled with drip irrigation. The total yield was found highest with quantities of 0.75, 0.5 and 1.00 times pan evaporation and significantly lower with 0.25 and 0.5 times pan evaporation values. Singh *et al.* (2000) made an attempt to study the effect of drip irrigation compared to conventional irrigation on growth and yield of Apricot, to work out its irrigation requirement. Drip irrigation at 80 per cent evapotranspiration of water gave significantly higher growth and fruit yield of 8.6 tonnes per hectare compared to that of surface irrigation. Plastic mulch plus drip irrigation further raised the fruit yield to 10.9 tonnes per hectare. Drip irrigation besides giving a saving of 98 percent irrigation resulted in 3.3 metric tonnes per hectare higher fruit yield.

Singh *et al*. (2000) studied the yield, water requirement and economics of drip irrigation in litchi orchard at farmer's field in Uttar Pradesh. It was found that good quality marketable yield of litchi varied from 12.5 to 16 metric tonnes per hectare for drip system. The total volume of water applied was 282 mm for drip irrigation during four months of system operation. The benefit cost ratio was found to be 3.91 for drip irrigated litchi orchard compared to 3.05 for surface irrigated litchi.

Jain *et al.* (2001) conducted experiments on the response of potato under drip irrigation and plastic mulching. The highest water use efficiency was found to be 3.24 t/ha-cm for the treatment irrigated with drip system at 80 per cent level with mulch as compared with to 2.17 t/ha-cm control treatment.

Singh *et al.* (2001) carried out experiments to study the effect of different irrigation regimes of 100 percent potential ET (V), 0.8V, 0.6V, 0.4V, 0.2V at four fertility levels on cauliflower yield with and without mulch under drip system and its comparison with the surface irrigation system. The highest curd yield was obtained under 100 percent recommended dose of fertilizer with volume of water applied equal to 22 cm through drip irrigation without mulch.

Singh *et al.* (2001) conducted studies on drip irrigation resulting in significant increase in production and water use efficiency of potato. At Udaipur it was reported that besides saving in water, the yield of potato tubers was high and weed growth was least in drip irrigation compared to surface irrigation.

Singhandhupe *et al.* (2003) conducted a study to determine the response to urea fertilizer with drip irrigation and compared with conventional furrow irrigation for two years. Application of nitrogen through the drip irrigation in ten equal splits at eight days interval saved 20 to 40 percent nitrogen as compared to the furrow irrigation when nitrogen was applied in two equal split. Similarly, 3.7 to 12.5 percent higher fruit yield with 31 to 37 percent saving of water was obtained in the drip system. Water use efficiency in drip irrigation, on an average nitrogen level was 68 and 77 percent higher over surface irrigation in 1995 and 1996, respectively. At a nitrogen application rate of 120 kg/ha, maximum tomato fruit yield of 27.4 and 35.2 tonnes per hectare in two years was recorded.

Yuan *et al*. (2006) studied the effects of different amounts of irrigation water on the growth and yield of cucumber under a rain shelter for two seasons in Yamaguchi University, Japan. For spring experiment, the amount of irrigation water applied was 0.50, 0.75, and 1.00 times of water surface evaporation (Ep) and regimes were denoted as Ep0.50, Ep0.75, and Ep1.00. Same method for autumn experiment, regimes were denoted as Ep0.75, Ep1.00, Ep1.25, Ep1.50, and Ep1.75. The results showed that amount of irrigation water significantly affected plant growth and fruit production. Plant height and biomass increased, but specific leaf weight (SLW, g/m2) decreased with increasing amount of irrigation water.

Stanislaw and Jacek (2008) carried out a study on the influence of surface and subsurface drip irrigation on the yield and quality of roots of parsley grown on ridges and on flat ground. Irrigation water was supplied via drip lines, which in subsurface irrigation were placed at a depth of 50 mm below the surface of the ridges, along the center line between two rows of plants. In the case of surface irrigation, the drip lines were placed on the surface of the ridges between two rows of plants. Irrigation started when soil water potential was between -30 and -40 k Pa. Nitrogen fertilizers (100 kgha-1) were applied in two doses. The first dose was applied pre-plant, while the second one was delivered by fertigation. In the control treatment without irrigation, the second dose of nitrogen was applied by broadcasting. Both surface and subsurface irrigation used in the cultivation on ridges and on flat ground had a significant effect on the marketable yield of parsley roots. However, no significant differences in the yield between surface and sub- surface drip irrigation were found. The yield of non-marketable parsley roots in flat cultivation was twice as high as that in ridge cultivation. Parsley plants cultivated on ridges produced significantly longer, better-shaped storage roots compared to those cultivated on flat ground. Surface and subsurface drip irrigation significantly decreased the total N and K content in parsley roots.

Sefer *et al.* (2009) conducted study to investigate the effects of drip irrigation methods and different irrigation levels on yield, quality and water use characteristics of lettuce cultivated in solar green house. The result showed that the highest yield was obtained from subsurface drip irrigation at 10 cm drip line depth and 100 percent of Class A pan evaporation rate treatment. The water use efficiency and irrigation use efficiency increased as the irrigation was reduced.

Deepa *et al*. (2010) conducted a study to standardize the irrigation requirement of salad cucumber grown in poly house. The experiment had five irrigation treatments with six replications. Two types of irrigation basin and drip were practiced. The irrigation treatments include drip irrigation with 1, 1.5, 2 and 2.5 l/day of water. From the study it was found that drip irrigation has a positive effect on growth and yield of crop. Crops drip irrigated with 1.5 l/plant/day performed well with a water use efficiency of 121 kg/ha-mm. Drip irrigation in comparison with the surface irrigation has given higher yield throughout the crop period. And also drip irrigation has shown larger soil moisture content a day after irrigation, while the conventional surface irrigation has least soil moisture content.

Zhang *et al*. (2011) studied the effect of drip irrigation scheduling on the yield and quality of cucumber fruits. The irrigation water amounts were determined based on the 20 cm diameter pan (*Ep*) placed over the crop canopy, and cucumber plant was subjected to three irrigation water levels (I1, 0.6 *Ep*; I2, 0.8 *Ep*; and I3, 1.0 *Ep*). The results showed that the cucumber fruit yield increased with the improvement of irrigation water. Irrigation water increased yields by increasing the mean weight of the fruits and also by increasing fruit number.

Ghaderi *et al*. (2012) conducted a study to determine the effects of deficit irrigation after the onset of flowering on lint yield and seed quality of cotton (*Gossypium hirsutum* L.) with a drip irrigation system during 2006 and 2007 in the northern Iran. After the onset of flowering, four irrigation regimes (0, 40, 70 and 100% of Class A pan evaporation (%PE)) were applied when the cumulative evaporation amount from class A pan reached approximately 40-50 mm. Lint yield showed a quadratic response to %PE and maximum lint yields were achieved with 82 and 91% PE irrigation regimes in 2006 and 2007, respectively and seed quality (based on standard germination and seed vigor tests) increased with a decrease in deficit irrigation. Thus when the amount of applied water was reduced by 30 (70% PE) and 60% (40% PE), decrease in lint yield was about 4 and 14%, respectively. The results of this study showed that irrigation treatments of 40-70% PE would be optimum for lint yield and seed quality production under drip irrigation.

2.5 SOIL MOISTURE DISTRIBUTION PATTERN UNDER DRIP IRRIGATION SYSTEM

Dhanpal *et al*. (1998) reported that vertical and horizontal movement of water and volume of active root zone in coconut basin wetted in laterite soils were directly related to the quantity of water applied. The percentage volume of active root zone wetted was 13.6 and 18.2 respectively under surface and subsurface placed emitters. The subsurface placement wetted 35 per cent more volume than surface placed emitter.

Through drip irrigation the soil water status was maintained at optimum level in the root zone of the crop (0-50cm) which extended up to 30 cm horizontally from the plant. In the surface layer the soil (< 20 cm) the soil water content was reduced to 15 per cent by volume approximately in the 0-5 cm layer before irrigation, but 20 per cent in the surface layer up to a distance of 45 cm from the emitting point (Anil *et al*., 2001)

Shirahatti *et al.* (2001) made comparison of drip and furrow irrigated cotton on a red soil. The soil moisture was measured in between two irrigation intervals. In vertical distribution, maximum soil moisture content increased along the depth but in lateral distribution, maximum soil moisture was found just below the drip source (0- 10 cm) and decreased as the distance from the water source increased.

Reddy *et al.* (2001) conducted experiment on water, nutrient and root distribution of sweet orange by drip irrigation and micro nutrient management. When soil moisture was taken three days after basin irrigation, soil moisture was13.28 per cent in surface layer while it was 9.79 per cent with drip irrigation. Similar trend was observed at lower depths of soil. From profile taken 1 m away from drip line to a depth of 1 m, it was found that soil moisture was 10.5 per cent.

Lailhacar *et al.* (2008) noticed that the new technologies could improve irrigation efficiency of turf grass, promoting water conservation and reducing environmental impacts. The objectives of thier research was to quantify irrigation water use and to evaluate turf quality differences between (1) Time–based scheduling with and without a rain sensor (RS); (2) A time-based schedule compared to a soil moisture sensor (SMS) based irrigation system; and (3) Different commercially available SMS systems. SMS- based treatments consisted of irrigating one, two, or seven days a week, each with four different commercial SMS brands. Time-based treatments with or without RS and a non-irrigated treatment were also implemented. Significant differences in turf grass quality among treatments were not detected due to the sustained wet weather conditions during the testing periods. The treatment with the rain sensor resulted in 34% less water applied than that without the rain sensor (2-WORS) treatment. Most SMS brands recorded irrigation water savings compared to 2-WORS, ranging from 69 to 92% for three of four SMSs tested, depending on the irrigation frequency. Therefore, SMS systems represent a promising technology because of the water savings that they can achieve during wet weather conditions while maintaining acceptable turf grass quality.

Dukes *et al.* (2003) studied three levels of sensor based high frequency irrigation treatments and four levels of twice daily irrigation treatments to bell pepper (*Capsicum annuum* L.) in 2002 to test the effect on yield and seasonal irrigation volume, water use efficiency, and soil moisture content in the root zone. Sensor based treatments used a soil moisture sensor buried 10 cm deep within the crop root zone to maintain soil moisture at a set level. The two sensor based irrigation treatments with the largest seasonal irrigation volume resulted in yields similar to the two largest seasonal volume daily irrigation treatments (marketable yields ranged between 17,000 and 20,000 kg/ha for these treatments), but used approximately 50% less seasonal irrigation water. This resulted in irrigation water use efficiencies of 1209-2316 kg/ha/m^3 for the sensor based treatments while those of daily treatments ranged from 703 to 1612 kg/ha/m^3. Sensor based irrigation treatments resulted in significantly higher soil volumetric moisture levels at the 15 and 30 cm depths. The results indicate that high frequency irrigation events based on soil moisture sensor control can maintain crop yields while reducing irrigation water requirements.

CHAPTER III

MATERIALS AND METHODS

This chapter describes the experimental setup, working of the automated drip system, and lab experiment methods. Investigations on working of the automated drip system by using sensors for tomato crop were conducted in rain shelter in the research plot of the Nodal Water Technology Centre, Department of Agricultural Engineering, College of Horticulture, Vellanikkara.

3.1 LOCATION OF THE SITE

The experiment was conducted in the rain shelter located near to the Department of Agricultural Engineering, CoH, Vellanikkara. Geographically the experimental site is located at 10°32'53"N latitude and 76°16'57"E longitude. The site is 5 m above the mean sea level.

3.2 WEATHER AND CLIMATE

The area has humid sub-tropical climate with more than 80 per cent of the rainfall distributed through south-west and north-east monsoon showers. The experimental site lies in humid sub-tropical area. The summers are dry and hot, whereas winter is cool. The experimental site consists of laterite soil. The daily readings of important meteorological parameters like maximum and minimum temperature and relative humidity were observed inside the rain shelter. The data on sunshine hours were taken from the Department of Meteorology, COH, Vellanikkara during the crop period.

3.3 DRIP AUTOMATION UNIT

Different automation systems like sensor based automation system and volume based automation system were utilized to provide required amount of water to a crop whenever needed. Tests were done with sensors at different moisture levels to ensure the conservation of water by providing right amount of water at the right time.

3.3.1 Components of Drip Automation System

Components of the unit are:

a) Soil moisture sensor (Resistivity type)

b) User keypad

c) Microcontroller unit

d) LCD display

3.3.1.1 Soil Moisture Sensor

Metallic probes are used for detecting the soil moisture. The conductance of soil is measured and soil moisture content is calculated. The sensors are used to determine the amount of moisture content in the soil. This is determined with the help of the probes that is placed in the soil which form a voltage divider arrangement with pull up resistors. Two conductivity type probes are used in the system, which measures the moisture content with the help of varying conductivity. The conductivity between the probes would vary directly with the moisture content of the soil. This signal from the voltage divider arrangement is further amplified and then transferred to the microcontroller. Plate 3.1 gives the view of the soil moisture sensor.

Plate 3.1 View of soil moisture sensor

3.3.1.2 Keyboard

A keyboard is interfaced to the system. It is used by the user to set the higher and lower limit of the moisture level and also to operate entire system. The view of the keyboard in the system is shown in plate 3.2. The keys and their functions are explained below:

Numeric: To enter values, quantities. Acts as shortcut to selections.

+/- Key: Toggles between positive and negative values and marks check boxes for option selection.

Arrows: Scroll up, down, left and right to select menus.

MENU: To main menu, also acts as "ESC" and "BACK" keys.

DE LETE: Erases typing mistake.

ZONE LOG IN: Access Mode.

Plate 3.2 Keyboard

3.1.1.3 Microcontroller Unit

The microcontroller unit (MCU) controls all the functions of other blocks of the circuit. MCU reads data from the keypad and the soil moisture sensors and controls all the functions of the system by manipulating these data. The microcontroller detects the moisture level of the soil with the help of sensors and then determines the average moisture level. If this average moisture level is below the lower limit of manually set value, the microcontroller automatically turns ON the motor. On the other hand, when the average moisture level increases above the high limit, the motor is turned OFF. A display unit is interfaced with the MCU for user information and displaying the measured moisture content of the soil. MCU operates the motor a ccording to the average moisture level through the interfacing circuits. The microcontroller also stores the recorded value for every 1 minute. Open view and front view of microcontroller unit are shown in Plate 3.3 and Plate 3.4 respectively.

Plate 3.3 Open view of MCU Plate 3.4 Front view of MCU

3.3.1.4 LCD Display

LCD display is used for displaying the state of the unit. It displays the sensor outputs, its average value and the state of the motor. LCD module is a dot matrix liquid crystal display unit that displays alphanumeric, kana (Japanese character) and symbols. The built in controller and driver LSI, provide convectional connection between LCD and either 4 or 8 bit microcontroller

3.4 OPERATION OF AUTOMATION SYSTEM

3.4.1 Main Menu Icons:

When the system is ON, the display will be visible. Then first MENU icon on the keypad should be clicked. The display shows certain main menu icons as shown in Plate 3.5.

The functions of the icons are given below in detail:

1. **Program:** It is used to set the Irrigation regimen, dosing recipe, filter flushing for operating entire program in different valves according to requirement.
2. **Manual:** Used to conduct manual irrigation process, filter flush and system pause whenever repair occurs in the automation system.

3. **Alarm:** To set alarm threshold and reset for some important updates.
4. **History:** Used to get details of data log, irrigation log, water meter and system event log.
5. **Test:** used to set all the manually tested field devices, sensor values, pH, EC values etc., that are calculated for field requirements.
6. **Setup:** System set-up, time/date, sensors calibration, unit measurements.
7. **Configuration:** For professional technical use only.
8. **Install:** For professional technical use only.

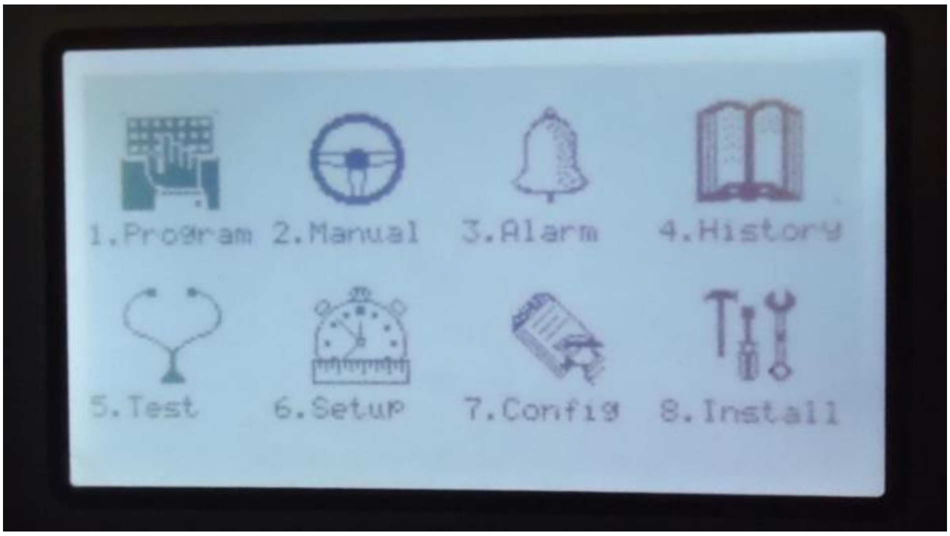


Plate 3.5 Main menu icons

3.4.2 To set Program

In the Main Menu screen, cursor should be placed on the program icon and press ENTER, or press '1' to enter program menu. Plate 3.6 shows the program menu

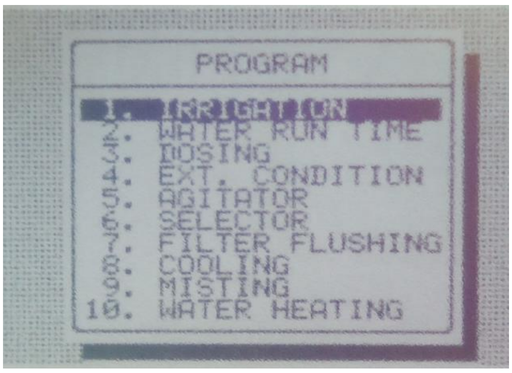
.

Plate 3.6 Program menu

3.4.2.1 Irrigation

The irrigation program screen includes all the settings for configuring automatic irrigation start. It depends mainly on water run time, therefore it is recommended to configure these screens before irrigation takes place. The setting of the irrigation program is shown in Plate 3.7.

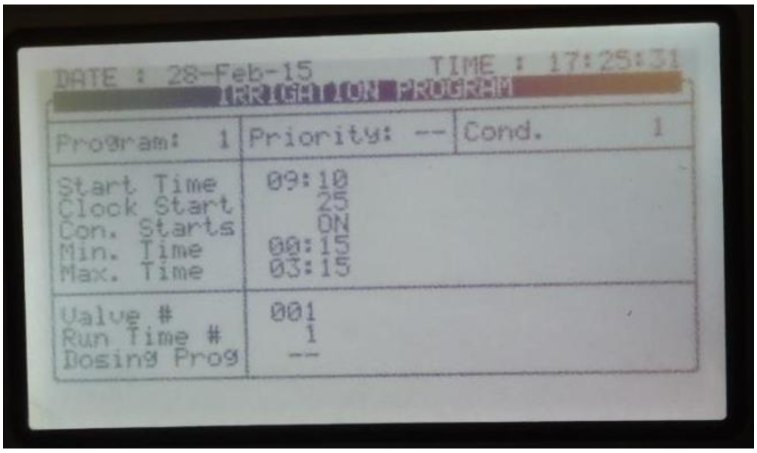


Plate 3.7 Irrigation program

Program: Select the program by entering the program and confirm by entering ENTER.

Priority: It determines the order in which programs will take place. If start time is the same, higher priority programs come first. Higher priority programs do not stop currently operative programs.

Cond: Specify whether the condition program can trigger irrigations, and choose a condition program to start/stop irrigations. Irrigations will be started and stopped according to the settings of the relevant condition program.

Start time: 6 start times can be entered per day for each program

Clock start: Set the number of time based irrigation cycles that will be performed in the cycle. The first cycle starts at the specified start time, subsequent cycles will start after specified interval.

Cond. Starts: On/off

On: Irrigations can be triggered by the condition program, when the specified condition program settings are met.

Off: Irrigations will not be triggered by the condition program, regardless of the condition program status.

Min. time: In condition mode, this determine the minimum time allowed between irrigations. Even if the condition limit has been reached irrigation will not be performed until that time has passed. In clock starts the minimum time is the delay between start of a cycle until start of the next cycle.

Max. time: The maximum time between two subsequent cycles. This value is used to limit the time between two cycles.

Valve: We can operate valves in any required order. Set the valve number and press enter. Several valves can set to work together, as a group. Each irrigation program can include maximum of 100 valves in any required order.

Run time**:** Attach a run time program to a valve or group of valves. When setting valves to work individually, run time program should be set for each program.

3.4.2.2 External Condition

The condition program allows starting and/or stopping according to dry contacts. In addition, it is possible to define an output called condition. This output will be active whenever the condition program settings are met. This enables using the condition program to start any external device. Set the start and end time of the condition program. The condition program will only be operational in the defined time window. Each condition program can be operational for different hours.

3.4.3 History

The history menu provides extensive information regarding measurements and processes performed by system like quantity of water required for irrigation, duration of the flow, working of the valve etc.

3.4.3.1 Irrigation Log

The irrigation log table includes up to 200 rows of the last irrigations data. Each row includes information regarding a specific irrigation. To view additional information, use left/right arrow keys. The details of irrigation log are shown in Plate 3.8.

Date: Shows date in which irrigation started.

Time: Time in which irrigation started.

Valve: Leading valve, the first valve set for group of valves.

Reason**:** Specification of irrigation triggers, time, condition, quantity etc.

Water: Irrigation quantity or irrigation time.

Duration: Irrigation duration (h:m:s).

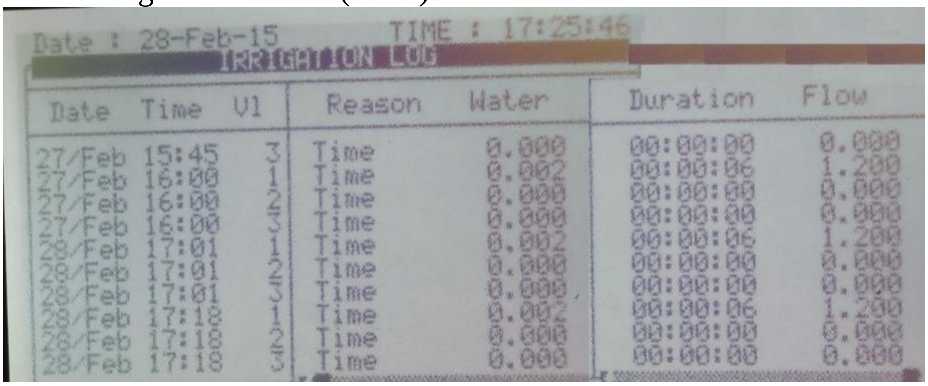


Plate 3.8 Irrigation log

3.4.3.2 Uncompleted Irrigation

The uncompleted irrigation table provides information of irrigations that were started but could not be completed due to failure. The uncompleted irrigation table consists of up to 200 lines. Each line includes information regarding when irrigation was stopped and added to uncompleted irrigation table.

3.4.3.3 Uncompleted Programs

This table provides information on programs that could not be completed. The difference between this table and uncompleted irrigations table is that it contains only irrigation cycles that have not started and could not be completed during the current day. This can happen due to wrong system setup or as the system was not active for a long period of time due to power failure and could not complete its tasks.

3.5 DRIP IRRIGATION UNIT

Water source: Open well

Main pipe: A PVC pipe of 50 mm diameter was used to convey water from source to the experimental site through sub mains.

Sub main: A PVC pipe of 50 mm diameter was used as sub main pipe to convey water from main lines to laterals. Sub main and lateral arrangements are shown in Plate 3.9.

Lateral pipe: An LLDPE pipe was used to supply water directly to the plant root zone from sub main pipes. The laterals are of inline type with the following specifications.

Outer diameter – 16 mm Wall thickness - 0.80 mm Flow rate - 2.00 lph

Spacing of drippers - 40 cm

Bypass valve provision: Since the discharge of pumping water is high, a bypass valve was fixed on the supply main line to divert part of water to open well located nearby.

Water meter: It was used to measure flow of water. A top view of water meter is shown in Plate 3.10.

Start connector: These were used to connect the lateral to the sub main. **Rubber grommet:** These were placed in holes made to the sub main for connecting lateral lines.

Pressure regulator: For regulating pressure when the water passes through the irrigation system.

Pressure gauge: To measure pressure in the system, a pressure gauge is used.

Air release valve: Air release valve was fitted for the purpose of removal of entrapped air when filling pipe lines with water and to remove air pockets at high points in the system.

Flush-out: It was connected at the end of main and sub main pipes for flushing out sediment and debris from them.

End caps: Eight shaped caps were kept at the end of all lateral lines which were connected to stop the flow of water further.

Disc filter: It was used to filter foreign materials and thus prevents the clogging of drippers. Plate 3.5 shows the view of the disc filter. The technical data of the disc filter is given in Table 3.1. The disc filter is shown in Plate 3.11. The control head components are shown in Plate 3.12.

Solenoid valve: Used to turn on and off the system to control irrigation whenever required. Solenoid valves are shown in Plate 3.13 and Plate 3.14.

Plate 3.9 Sub main and lateral arrangement

Plate 3.10 Water meter

Plate 3.11 Disc filter

Plate 3.12 Control head components

Plate 3.13 Series of solenoid valves

Plate 3.14 Solenoid valve

Table 3.1 Technical data of disc filter

Inlet/outlet diameter	40 mm nominal diameter
	48.2 mm pipe diameter
Maximum pressure	10 atm
Maximum flow rate	2.22 l/s
General filtration area	316 cm^3
Filtration volume	379 cm^3
Filter length	250 mm
Filter width	130 mm
Distance between end	200 mm
Weight	1.3 kg
Maximum temperature	70^oC
pH of water	5 -11

3.6 SOIL PHYSICAL CHARACTERISTICS

The physical properties of the soil at the site were determined. Soil data includes bulk density, particle density, field capacity, wilting point and porosity. The data were determined by using standard procedures as explained below.

3.6.1 Soil Moisture Constants

The pressure plate apparatus which was developed by Richards (1949, 1954) was used to determine soil moisture constant in laboratory. The apparatus consists of ceramic pressure plate of high air entry values contained in airtight metallic chambers strong enough to withstand high pressure (15 bars or more).The apparatus enables the determination of two important soil moisture constants viz. field capacity and permanent wilting point. The procedure for determining soil moisture constants using pressure plate apparatus requires saturated porous plates and the soil (undisturbed or disturbed), were placed on these plates. The soil samples were filled in the ring of the respective pressure plates and soaked in water. The samples were kept overnight for complete saturation and then the plates were transferred to the metallic chambers. The chamber was closed with wrenches to tighten the nuts and bolts with the required torque for ceiling it. It was ensured that there was no leakage from the chamber. Pressure was applied from a compressor through control which helps in maintaining the desired two pressures 1/3 atm & 15 atm which were applied to get field capacity and permanent wilting point. Water starts to flow out from saturated soil samples through the outlet and continues to trickle till equilibrium against the applied pressure is achieved. After that the soil samples were taken out and oven dried for determining moisture content by gravimetric method. The setup of the experiment was given in Plate 3.15.

Plate 3.15 Pressure plate apparatus

3.6.2 Determination of Different Soil Physical Properties

Different physical properties like bulk density, particle density and porosity were determined by using standard procedures and their formulas were given below.

3.6.2.1 Bulk Density

$$\text{Dry bulk density, } D_b = \frac{\text{mass of dry soil solid particle}}{\text{volume of soil}} = \frac{W3-W1}{V} \text{ (g/cc)}$$

$$\text{Wet bulk density, } D_w = \frac{\text{mass of wet soil}}{\text{volume of soil}} = \frac{W2-W1}{V} \text{ (g/cc)}$$

V = Volume of the core (cm^3)

W1 = Weight of the core (g)

W2 = Weight of the core + wet field soil (g)

W3 = Weight of the core + dry soil after placing in oven (g)

3.6.2.2 Particle Density

$$\text{Particle density Dp} = \frac{\text{mass of solid particle}}{\text{volume of soil}} = \frac{W2-W1}{V} \text{ g/cc}$$

$$\text{Volume of soil (V)} = (W_4 - W_1) - (W_3 - W_2)$$

W1 = Weight of volumetric flask (g)

W2 = Weight of the flask + soil (g)

W3 = Weight of the flask + soil + water (g)

W4 = Weight of the flask + water (g)

V =Total volume = 1000 (ml)

3.6.2.3 Porosity

Porosity (%) = {1-(Db / Dp)} * 100

Where,

Db = Dry bulk density, g/cc

Dp = Particle density, g/cc

3.6.3 Soil Chemical Characteristics

The soil of the experimental site was tested for its nutrient status in the lab using standard procedures. The soil of the site was laterite soil and was acidic in reaction with pH of 5.1. The chemical characteristics of the soil of the experimental field are presented in section 4.1.2.

3.7 WATER QUALITY PARAMETERS

Open well water was used for irrigation and the water was pumped near to the experimental plot. Water was pumped from an open well of 8 m depth. The quality of irrigation water was tested in lab before conducting the field experiments. The physical and chemical properties were analyzed by using standard procedures.

3.8 EXPERIMENTAL SETUP

3.8.1 Rain Shelter

Rain shelter is a less expensive naturally ventilated tent, similar to the greenhouse, usually made using GI pipes or wooden or bamboo poles. The roofing is provided with a transparent UV stabilized low density polyethylene film of 200 micron thickness, which will create a micro climate inside the tent by regulating temperature, relative humidity and partially cutting Ultra Violet rays. Rain shelters are often used in high rainfall areas to produce sensitive crops such as tomatoes, cherries, blue berries etc., which are susceptible to cracking. The specification of the rain shelter used for the study are as given in Table 3.2. The side view and front view of the rain shelter are shown in Plate 3.16 and Plate 3.17 respectively.

Table 3.2 Specifications of rain shelter

Particulars	**Specification**
Rain shelter height (center)	3 m
Area inside	72 m^2
GI pipe posts	2 inch diameter
Cement blocks	3 layers (12x8x4 mm^3)
Roofing	200 micron thickness UV stabilized LDPE

Plate 3.16 Front view of rain shelter

Plate 3.17 Side view of rain shelter

3.8.2 Crop and variety

Tomato (*Solanum lycopersicum*) variety *Akshaya*, semi determinate variety released from Kerala Agricultural University was used for the experiment. It is a high yielding variety and most suited for rain shelter cultivation.

3.8.3 Scheme of the Experiment

The plot was prepared by adding the required farm yard manure as per the recommended dose to plant the tomato crop. The plot having area of 36 m^2, was divided into four beds each having area of 4.8m^2. The inline drip has uniform emitter spacing of 40 cm and the spacing of 40 cm is maintained from plant to plant. To study the effect of different treatments and also to compare the economics of treatments, three replications were taken from each bed. The treatments are as below:

Treatment 1: Irrigation at 40% moisture depletion level

Treatment 2: Irrigation at 50% moisture depletion level

Treatment 3: Irrigation at 60% moisture depletion level

Treatment 4: control (volume based system – 2 l/day per plant)

Experimental Design: CRD

Treatments: 4

Replications: 3

3.8.4 Layout

The field was prepared clean by removal of weeds and levelled for preparing beds. Soil improvement using manures were done during land preparation for the early nourishment of the plant. Farm yard manure was mixed to the soil at the rate of 20 t/ha. Beds of 6 m length and 0.80 m width were prepared. The bed was raised to a height of 0.2 m. Each plot was leveled manually and ridges and furrows were made. The complete drip system was installed for irrigation. Plate 3.18 shows the prepared crop beds before experiment starts.

Plate 3.18 Prepared crop beds in rain shelter

3.8.5 Planting Material

Tomato (*Solanum lycopersicum)* seeds were sown in a protray containing mixture of vermi compost and sand in 1:1 ratio to a depth of 0.5 cm. These seedlings were transplanted to the field 25 days after sowing. Plate 3.19 shows the seedlings in the protray before transplanting in the plot.

Plate 3.19 Seedlings in protray before transplanting

3.8.6 Irrigation

After transplanting of tomato crop, irrigation was done manually for a week till the plants attained steady growth conditions to that environment. After that irrigation was given according to the scheduled treatment for the crop.

For proper irrigation scheduling of different irrigation treatments, the upper and lower limit of the operation of the sensors were calculated. The inline drippers were fixed at 40 cm along lateral line and plants were at 60 x 40 cm. The 2 lph capacity inline drippers were used for a plot size of 36 m^2. There were 4 laterals with 10 emitters each.

Field capacity and permanent wilting point were determined to calculate water requirement of the crop. The upper and lower limit of the soil moisture were calculated by using available moisture content in the soil to set the values for working of the sensor.

Available moisture content = [(FC – PWP)/100] x Root zone depth x Sp. gravity of soil

Where,

FC = field capacity (%)

PWP = Permanent wilting point (%) Root zone depth (cm)

Available moisture content present in the soil was considered as the upper limit for all the treatments. The amount of moisture depleted from the available moisture content according to the requirements in different treatments were taken as lower limit. Soil moisture sensor was kept at a proper depth within the active root zone of the crop. As the soil gets dried, resistance increased and conductivity decreases which is in proportion with soil moisture content. The sensor senses the change in moisture and irrigation starts whenever required. There is also manual operation (ON/OFF) for the motor in any case of requirement.

For treatment T_1, lower limit of the sensor value was set to 40 per cent of the moisture depletion of available moisture content at which the motor becomes automatically ON. The sensor was placed in the bed at depth near to the healthy plant for accurate measurement of water at a depth of 20 cm. The sensor senses the moisture content in the bed and if the moisture content is below the lower limit then resistance value increases so that motor starts pumping water automatically whenever required and it stops after reaching upper limit of the set moisture content.

For treatment T2, lower limit of the sensor value was set to 50 per cent of the moisture depletion of available moisture content at which the motor becomes automatically ON. The sensor was placed in the bed near the healthy plant for accurate measurement of water. The sensor senses the moisture content in the bed and if the moisture content is below the lower limit then resistance value increases so that motor is ON automatically whenever required and it will be OFF after reaching the upper limit of the moisture content.

For treatment T3, lower limit of the sensor value was set to 60 per cent of the moisture depletion of available moisture content at which the motor becomes automatically ON. The sensor was placed in the bed near the healthy plant for accurate measurement of water. The sensor senses the moisture content in the bed and if the moisture content is below the lower limit then resistance value increases so that motor is ON automatically whenever required and it will be OFF after reaching the upper limit of the moisture content.

For treatment T4 automation unit was set based on volume. In this treatment, a total of 2 l/day per plant was given at different triggers four times daily at 2 hour time intervals.

3.8.7 Manual Fertilizer Application

Well dried farm yard manure at the rate of 20 t/ha was applied at the time of land preparation and mixed well with the soil. A fertilizer dose of 75:40:25 kg N: P_2O_5 : K_2O per ha was given. Half the dose of nitrogen, full phosphorus and half of potash were applied as basal before transplanting. One fourth of nitrogen and half of potash were applied after 20- 30 days after planting. The remaining quantity was applied in the next month as per recommendation in the package of practices, Kerala Agricultural University. The details of the fertilizer application scheduling for 36 m^2 area are shown in Table 3.3

Table 3.3 Fertilizer application schedule

Dosag	Urea (g)	Phosphorus (g)	Murate of potash (g)
Basal	650	1750	160
35DAT	325	-	160
80DAT	325	-	-
Total	1300	1750	320

* DAT – Days after transplanting

3.8.8 Pest and Disease Management

Crops vary in their tolerance to insect pests and disease attack depending on the type of damage and stage of growth. Seedlings have little tolerance to insect attack and relatively small numbers can cause economic damage. Most crops can withstand considerable insect pressure in the vegetative stage but considerably less damage at critical growth stages such as establishment, flowering and fruit development. Monitoring and management during these high risk periods is essential to minimize economic loss.

Tomato leaf curl virus was observed during early stages of the crop. As a control measure against leaf curl, Asataaf (1.5 g/l) was sprayed on the plant during early stages.

Leaf miner feeding results in heavily mined leaflets having large whitish blotches. It occurs early in the fruiting period, reduces yield and fruit size and expose fruit to sunburn. The symptoms of leaf miner is shown in Plate 3.20.

As a control measure against leaf miner, Confidor (2 ml/10 l) was applied to the plants. Initially weeds were removed by using hand tools, spade and rake. Gradually the weed growth reduced as the water was supplied at the root zone which was required to the plant itself. Then manual weeding was effectively done once in a week during the crop growth period.

Plate 3.20 Leaf miner

3.9 FIELD DATA COLLECTION

3.9.1 Biometric Observations

For analyzing the growth pattern of the crop, three plants were selected randomly from the net plot area in each treatment and were tagged to record the various observations. The main crop growth parameters like height of the plant, days to first flowering, days to initial budding, days to first harvest, root length and root mass were measured.

3.9.1.1 Height of the Plant

Plant height was measured from ground level to tip of top most (youngest) leaf. It was recorded at weekly intervals from the three sample plants. The average was worked out for each plant.

3.9.1.2 Days to First Flowering

The tomato crop was transplanted on 29th October 2014. The time taken for different irrigation levels to start initial flowering stage from date of transplanting was observed. The number of days were recorded for each treatment.

3.9.1.3 Days to Initial Budding

The tomato crop was transplanted on 29th October 2014. The time taken for different irrigation levels to start initial budding stage from flowering stage from date of transplanting was observed. The number of days were recorded and for each treatment.

3.9.1.4 Days to First harvest

The tomato crop was transplanted on 29th October 2014. The number of days taken for different irrigation levels to reach final fruiting stage and starting of first harvest was recorded.

3.9.1.5 Root Length

After the crop period the roots were collected from selected plants under each treatment. Then length of these roots were measured from end portion of stem to the edge of roots.

3.9.1.6 Root Dry Weight

After the crop period the roots were collected from selected plants under each treatment. These roots were washed thoroughly free from soil particles. Then these roots were dried at 65°C for 4 hours and afterwards the weight was noted

3.9.2 Yield Parameters

3.9.2.1 No. of Fruits/plant

Three plants were selected randomly from each bed. The total number of fruits per plant were recorded at each harvest and the total number was calculated. Different moisture levels affect the total number of fruits in all treatments.

3.9.2.2 Yield (kg/ha)

Harvesting of the crop was done treatment wise after attaining maturity. After the first harvest, other harvests were done at an interval of minimum 2 days. The first yield was taken 50 days after transplanting. The total of 14 harvests for irrigation trial gave the total yield. Fruit weight in each treatment was taken.

3.10 Water Use Efficiency

Water use efficiency was calculated by using the following formula and expressed in kg/ha mm.

$$\text{Water use efficiency (kg/ha-mm)} = \frac{yield\ (kg/ha)}{water\ utilized\ (mm)}$$

The changes in moisture content leads to variation in water use efficiency.

3.11 Moisture Distribution Pattern in Drip Automation System

For effectiveness of drip irrigation system, both horizontal and vertical distribution of the wetting fronts are important and a two dimensional moisture regime in the soil profile must be considered. In order to analyze the variation in soil moisture at different depths, the gravimetric method of moisture content determination was made. The size of this wetted area is a function of irrigation and surface infiltration rates. The samples were taken from the desired depths of 0, 10,
20 and 30 cm at particular distance of 0, 15 and 30 cm laterally away from the emitter. Moisture patterns for the treatments were observed 2 hours and 6 hours after the irrigation starts. The soil moisture contours were plotted using computer software *'teraplot1.3.01'* version.

3.12 Statistical Analysis

The data were analyzed using the standard program SPSS for CRD design. Whenever the treatment differences were found significant critical differences were worked out at 5 per cent probability level. Based on these tests, the significance of one treatment over the other could be ascertained.

3.13 Economics

Net income per ha and benefit - cost ratio were calculated based on cultivation, cost of input and sale of produce. The cost incurred in different stages of crop growth were computed and compared for different treatments taking into account the difference in yield using Net Present worth method.

CHAPTER IV

RESULTS AND DISCUSSION

The study was conducted during the months of October 2014 - March 2015 in rain shelter in the research plot of the Nodal Water Technology Centre, College of Horticulture, Vellanikkara. The work was done to assess the water requirement of tomato crop grown in rain shelter at various moisture depletion levels and to compare the performance of the crop with respect to growth and yield parameters. The study also involved the analysis of the effect of different levels of drip irrigation on water use efficiencies and cost economics. The results of the study are presented in this chapter.

4.1 EVALUATION OF SOIL AND WATER CHARACTERISTICS

4.1.1 Soil Physical Properties

The soil physical properties such as bulk density, particle density, field capacity and permanent wilting point of the experimental field were studied and used for determining the water requirement of the crop. The results are presented in Table 4.1.

Table 4.1 Physical properties of the soil of experimental field

Sl. No.	Soil Property	Values
1	Bulk density	1.94 g/cc
2	Particle density	2.34 g/cc
3	Field capacity	15.89%
4	Permanent wilting point	9.6%

4.1.2 Soil Chemical Properties

The chemical characteristics of the soil in the experimental field were tested in the laboratory by using standard procedures and the values are presented in Table 4.2.

Table 4.2 Chemical properties of the soil of experimental field

Parameters	Quantity/ Value	Remarks
pH	5.1	Strongly acidic
Electrical Conductivity (dS/m)	0.04	Normal
Organic carbon (%)	0.76	Medium
Available phosphorus (kg/ha)	16.12	Medium
Available potassium (kg/ha)	133.28	Medium
Available Calcium (mg/kg)	553.75	Sufficient
Available Magnesium (mg/kg)	104.25	Deficient
Available Sulphur (mg/kg)	9.37	Sufficient
Micro nutrients		
Copper (mg/kg)	6.93	Sufficient
Iron (mg/kg)	58.24	Sufficient
Zinc (mg/kg)	0.62	Deficient
Manganese (mg/kg)	22.25	Sufficient
Boron (mg/kg)	0.03	Deficient

From the Table 4.2 it is observed that the soil pH is highly acidic with a value 5.1. EC was found to be 0.04 dS/m which shows that salinity effect is negligible and can be used for cultivation. Almost all the micro and macro nutrients are seen sufficient.

4.1.3 Water Quality Analysis

The quality of irrigation water was tested in laboratory before conducting the field experiments. The physical and chemical properties were analyzed by using standard procedures and the values are presented in Table 4.3. In most irrigation situations, the primary water quality concern is salinity levels, since salts can affect both the soil structure and crop yield. However, a number of trace elements are found in water which can limit its use for irrigation. Numerous parameters are used to define irrigation water quality, to assess salinity hazards, and to determine appropriate management strategies. A complete water quality analysis will include the determination of the total concentration of soluble salts, the relative proportion of sodium to the other cations and the bicarbonate concentration as related to the concentration of calcium and magnesium.

Table 4.3 Water quality parameters

Sl. No.	Parameters	Quantity	Remarks
01	pH	6.3	Slightly acidic
02	Electrical conductivity (dS/m)	0.05	Normal
03	Carbonates (me/l)	Nil	Safe
04	Bicarbonates (me/l)	0.60	Safe
05	Copper (mg/l)	ND	Safe
06	Zinc (mg/l)	0.002	Safe
07	Iron (mg/l)	0.42	Safe
08	Manganese (mg/l)	0.01	Safe
10	Magnesium (mg/l)	0.67	Safe
11	Sodium (mg/l)	3.90	Safe
12	Potassium (mg/l)	0.40	Safe
13	SAR	0.73	Safe
14	RSC (me/l)	0.49	Safe
15	Boron (mg/l)	ND	Safe

Aluminium can cause non-productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity. Boron is essential for plant growth, with optimum yields obtained for many trails when added in mg/l in nutrient solutions, but toxic to many sensitive plants (e.g., citrus) at 1 mg/l. In this case it is safe as Boron is not detected in the soil. Copper is also not detected and it is toxic to a number of plants even at 0.1 to 1.0 mg/l in nutrient solution. So the quality in this aspect is safe. Iron is found to be 0.42 mg/l which is not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum (Rowe and Abdel-Magid, 1995). Considering the above values it is safe to use the source water for the cultivation.

4.1.4 Irrigation Scheduling Computation

The upper limit of moisture was fixed as the available moisture in the soil and the lower limit was fixed at 40%, 50% and 60% depletion from available moisture. Accordingly the net irrigation depth in mm, was computed and fixed as the net depth of irrigation. The values are given below in Table 4.4. Calculations are given in Appendix I

Table 4.4 Upper and lower limits of the moisture depletion levels

Treatments	Upper limit of MDL (mm)	Lower limit of MDL (mm)	Net depth of irrigation, (mm)
T1	24.4	9.7	14.7
T2	24.4	12.2	12.2
T3	24.4	14.7	9.7

*MDL – Moisture Depletion Levels

4.2 MICROCLIMATE INSIDE THE RAIN SHELTER

The climatic parameters such as maximum temperature, minimum temperature and relative humidity inside the rain shelter were observed at 9 AM every day. The data on sunshine hours were taken from the Department of meteorology, College of Horticulture, Vellanikkara for the crop period. The values are given in Appendix II. Figure 4.1 shows variation of maximum and minimum temperature at 9 AM inside the rain shelter during crop period. The maximum temperature ranges from 38.8^{o}C to 28.8^{o}C and the maximum value was recorded during the final days of harvesting period of crop. The minimum temperature ranges from 25.8^{o}C to 17.5^{o}C. The least value of minimum temperature recorded was 17.5^{o}C during the middle stage of crop development. The rise in atmospheric temperature inside the rain shelter ranges from 1°C to 2.2°C than that of outside. These results agree with findings of Parvej *et al.* (2010) and Farguesa *et al*. (2005). It indicates that there is considerable increase in the inside temperature of the rain shelter. The temperature shows lower value during rainy season and a high temperature is observed in non-rainy days. Rainfall during the crop duration has a major role in the soil and atmospheric temperature. Hence crop water requirement depends on the rate of evaporation which in turn depends on the temperature. At high rainfall periods, the inside and outside temperature was almost the same value.

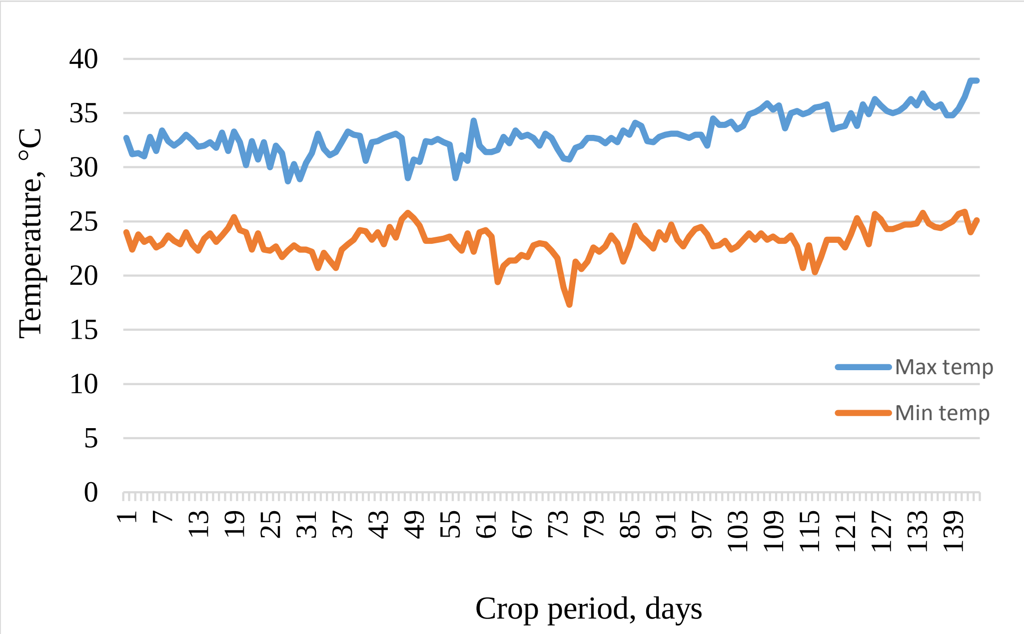


Figure 4.1 Daily variation of maximum and minimum temperature inside the rain shelter

Variation of relative humidity during the crop period were observed and shown in Figure 4.2. From the figure it is seen that the average relative humidity ranges from 98% to 65%. The maximum value was 98% and minimum was noted as 55%. The higher value was noted during the initial stage of crop development. Similar results were observed by Nimje and Shyam (1993). The relative humidity was higher inside the structure than in the open field which positively influenced tomato growth and yield. The relative humidity inside rain shelter was also slightly higher than that in open field conditions and similar readings were reported (Rajasekar *et al.*, 2013).

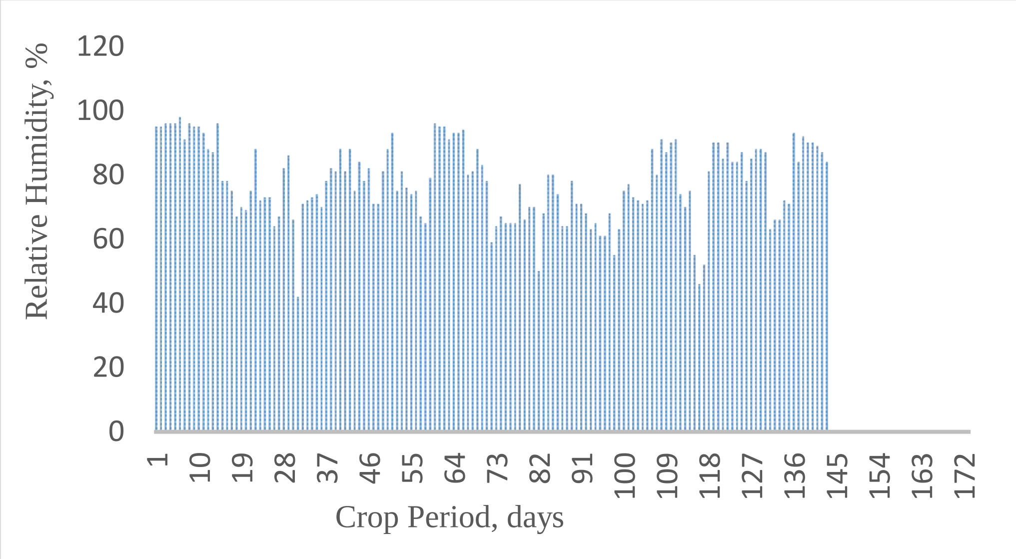


Figure 4.2 Daily variation of relative humidity at 9 AM inside the rain shelter

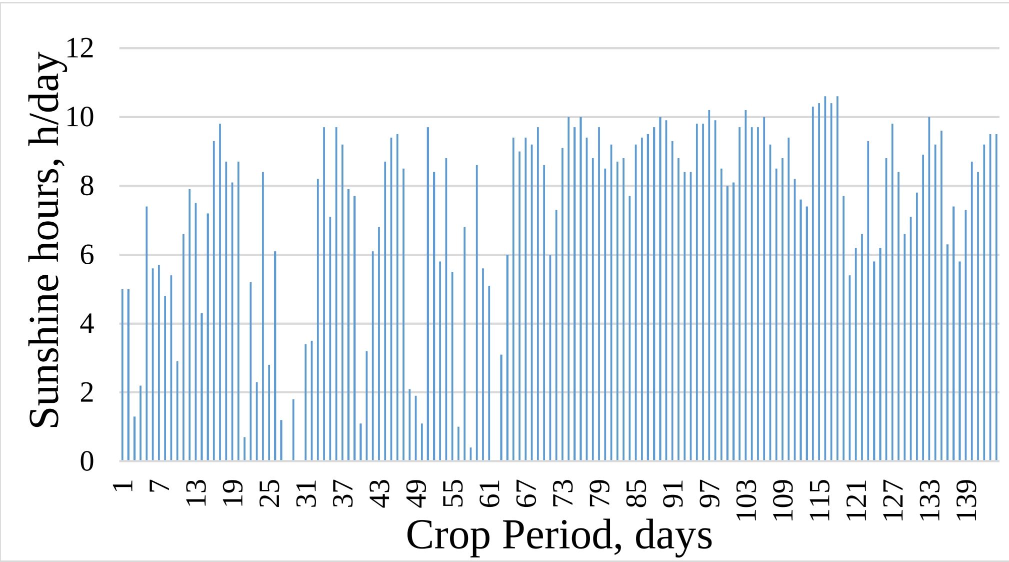


Figure 4.3 Daily variation of sun shine hours during the crop period

4.3 CROP GROWTH AND YIELD PARAMETERS

Crop growth parameters such as height of the plant, days to first flowering, days to initial budding, days to first harvest, number of fruits per plant, yield, length of the root and dry root mass for each treatment were observed during the experiment. The influence of irrigation at different soil moisture depletion levels on these crop growth parameters are discussed below.

4.3.1 Height of the Plant

The data on height of the plant at different stages of crop growth from transplanting to harvest were measured at 30, 60, 90 and 120 days as influenced by different irrigation treatments are presented in the Table 4.5 and Figure 4.4. Plant heights at initial and final stages are shown in Plate 4.1 (A) and (B).

Table 4.5 Effect of irrigation at different moisture depletion levels on plant height

Treatments	**Height of the plant (cm)**			
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**
T1	37.3^{a}	86.43^{ab}	113.3^{a}	127.6^{a}
T2	36.9^{a}	84.86^{b}	109.8^{b}	119^{b}
T3	36.6^{a}	82.63^{c}	107.7^{c}	118.43^{b}
T4	37.1^{a}	88^{a}	114.13^{a}	127.78^{a}

(In each column, mean values followed by the same letter do not differ significantly and a, b, c represents that values are significantly different from each other at *P* = 0.05 according to the Post hoc tests) *DAT – Days after transplanting

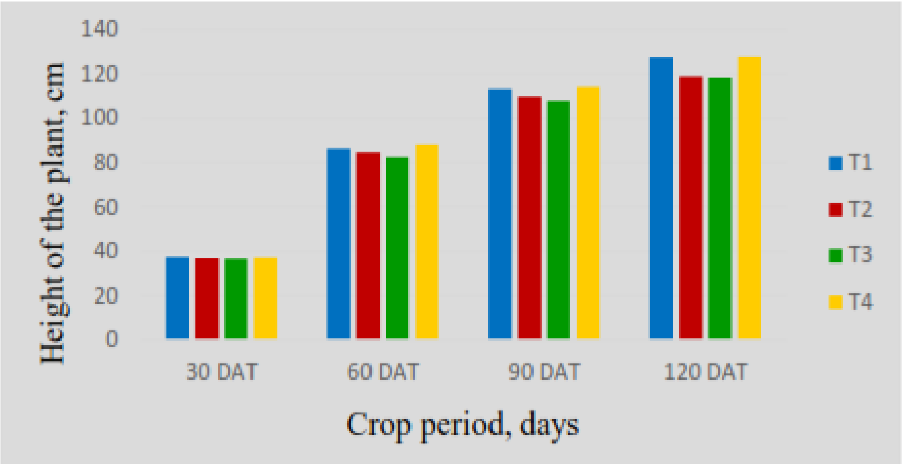


Figure 4.4 Effect of treatment parameters on plant height at various stages of growth

(A) (B)

Plate 4.1 Plant growth stages at: (A) Initial stage (B) Final stage

Data on height of the plant was recorded at thirty days interval from the days after transplanting. As shown in Table 4.5 it is seen that average height of the plants at the initial stage were same with highest 37.3 cm at 30 days. The statistical analysis showed that all the treatments have no significant difference in the initial stage. The height increases with crop growth and reached a maximum height of 127.78 cm in T_4 and with a minimum value of 118.43 cm in T_3. T_1 has high frequency of irrigation at 40 per cent moisture depletion with height of 127.6 cm. Hence vegetative growth might have increased in T_1. Increasing soil moisture under drip irrigation might have led to effective absorption resulting in quick growth. At the final stage the difference in the height of the plant slightly decreased because irrigation did not affect height of plant any longer. The statistical results indicate that treatments were found to be significantly different in later stages at 5% level of significance.

4.3.2 Number of Days to First Flowering

The data on number of days taken by the plant for first flowering was recorded and is given in Table 4.6 and depicted in Figure 4.5.

Table 4.6 Effect of irrigation at different moisture depletion levels on days to first flowering

Treatments	Days to first flowering
T_1	22^a
T_2	25^{bc}
T_3	27^c
T_4	23^{ab}

From Table 4.6 it is seen that early flowering was started in T_1 with less number of days (22). Statistically two treatments T_2 and T_4 are on par with 5 per cent level of significance. T_3 is significantly different (27) from others as flowering stage was delayed by few days than that of other treatments.

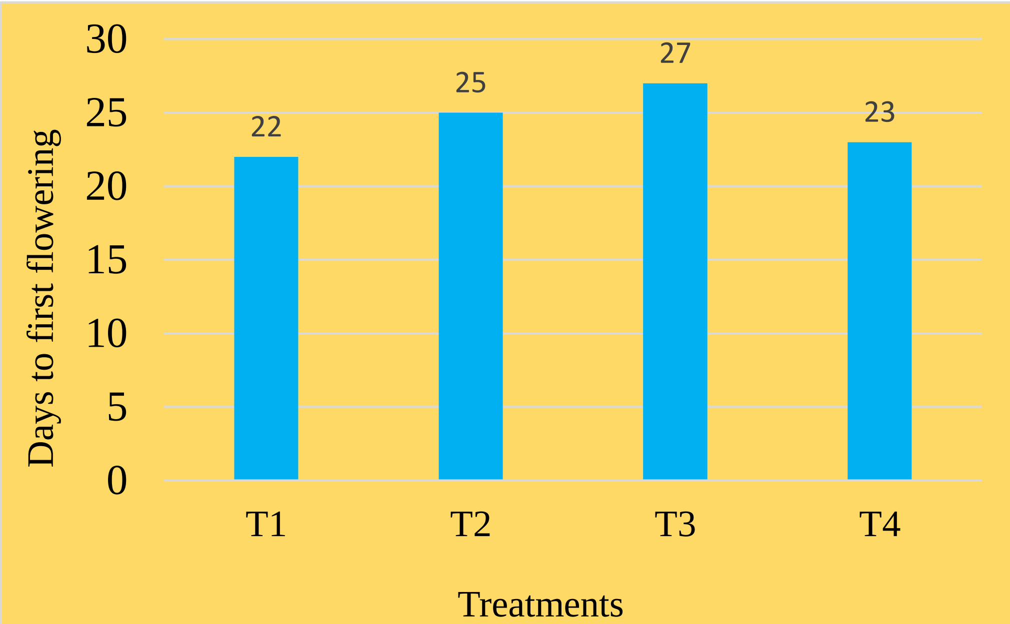


Figure 4.5 Effect of irrigation at different moisture depletion levels on days to first flowering

4.3.3 Days to Initial Budding

The number of days taken by the plant to initiate budding from flowering stage was recorded. The data is given in Table 4.7 and shown in Figure 4.6.

Table 4.7 Effect of irrigation at different moisture levels on days to initial budding

Treatments	Days to initial budding
T_1	54^a
T_2	57^a
T_3	62^b
T_4	54^a

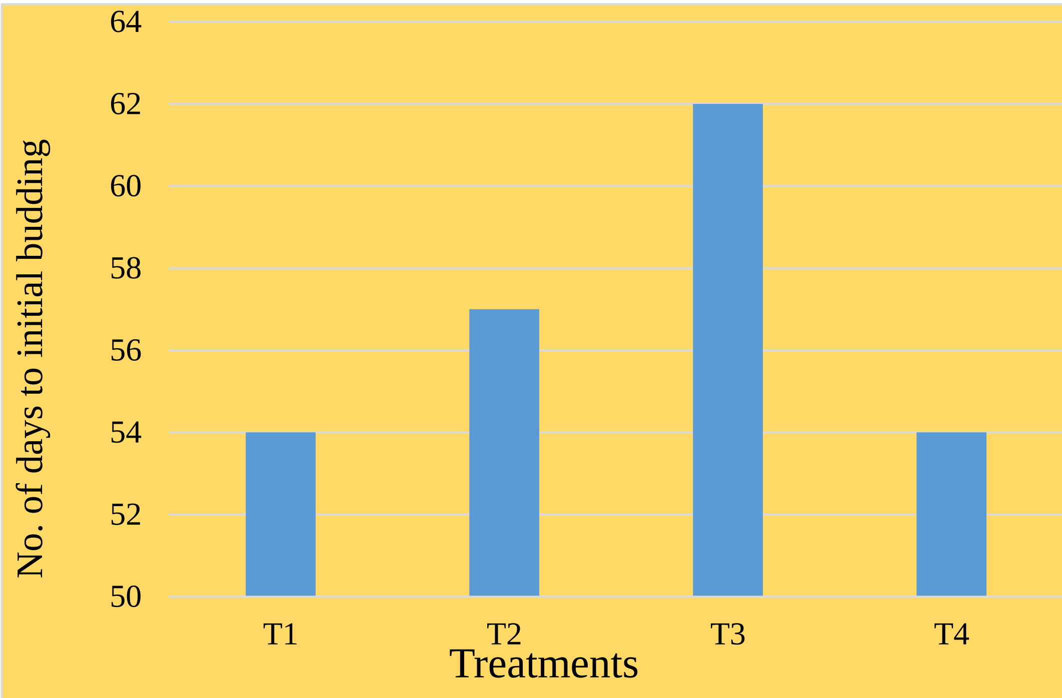


Figure 4.6 Effect of irrigation at different moisture depletion levels on days to initial budding

From Table 4.7, minimum number of days taken for initial budding is seen in T_1 and T_4 at 54 days. From the statistical analysis it was clear that the three treatments T_1, T_2, T_4 are on par and irrigation levels did not affect the initial budding. The maximum number of days were observed in T_3 with 62 days. The reason might be that less amount of water was applied for the plant.

4.3.4 Days to First Harvest

The number of days taken for the maturity of the fruit to first harvest was recorded. The data is given in Table 4.8 and shown in Figure 4.7.

From the Table 4.8, it is obvious that the number of days for the first harvest are less in T_2 and T_4. They are on par at 5 per cent level of significance. The minimum number of days taken for T_2 and T_4 are 77 and 76 days respectively, whereas the maximum number of days for the first harvest are observed in T_3 with 87 days. The reason might be that due to less application of water.

Table 4.8 Effect of irrigation at different moisture depletion levels on number of days to first harvest

Treatments	Days to first harvest
T_1	80^a
T_2	77^a
T_3	87^b
T_4	76^a

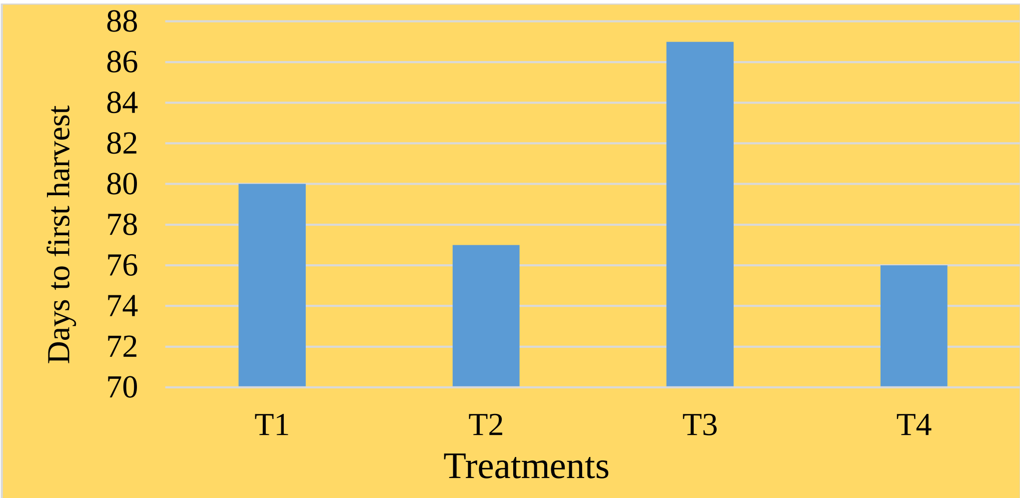


Figure 4.7 Effect of irrigation at different moisture depletion levels on number of days to first harvest

From the Table 4.8, it is obvious that the number of days for the first harvest are less in T_2 and T_4. They are on par at 5 per cent level of significance. The minimum number of days taken for T_2 and T_4 are 77 and 76 days respectively, whereas the maximum number of days for the first harvest are observed in T_3 with 87 days. The reason might be that due to less application of water.

4.3.5 Number of Fruits/Plant

At the time of harvesting, the number of fruits per plant were also recorded. The harvests were done at 4 days interval. The details and variation of the mean value of fruit numbers per plant for a single harvest were given in Table 4.9 and depicted in Figure 4.8. Plate 4.2 shows average number of fruits per plant in single harvest.

Table 4.9 Effect of irrigation at different moisture depletion levels on average value of number of fruits per plant

Treatments	**Number of fruits/plant**
T_1	22^a
T_2	25^a
T_3	24^a
T_4	21^a

It is observed from the Table 4.9 that the highest number of fruits were found in treatment T_2 (25 fruits/plant). It was found that there was no significant difference between the four treatments at 5 per cent level of significance. Alaoui *et al.* (2014) observed that number of fruits was neither affected by the amount of irrigation nor by frequency as irrigation have a greater effect on the average fruit weight than on fruit number because of the limited number of tomato flowers.

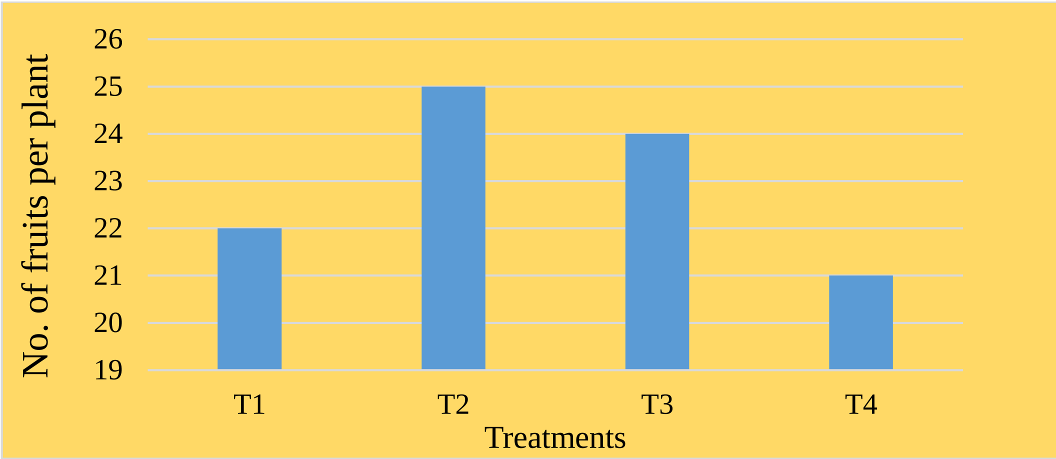


Figure 4.8 Effect of irrigation at different moisture depletion levels on average value of number of fruits per plant

Plate 4.2 View of the crop in harvest stage

4.3.6 Fruit Yield

The data on total yield at 150 days after planting as influenced by different treatments and levels of irrigation are presented in the Table 4.10. The average yield in t/ha as influenced by irrigation at different moisture depletion levels is depicted in Figure 4.9. A view of harvested tomatoes is shown in plate 4.3.

Table 4.10 Effect of irrigation at different moisture depletion levels on yield

Treatments	Yield	
	kg/plant	t/ha
T_1	1.64[c]	34.21[c]
T_2	1.83[a]	37.8[a]
T_3	1.73[b]	36.35[b]
T_4	1.61[c]	33.52[c]

Table 4.10 shows that the maximum yield was observed for the treatment T_2 (37.8 t/ha). The minimum value was seen for the treatment T_4 (33.525 t/ha). The data presented in Table.4.6 revealed that all the treatments showed significant difference. The treatments T_4 (33.525 t/ha) was on par with the treatment T_1. The average total yield was more in the case of treatment T_2. Excessive irrigation results in reduction of yield. This might be a reason for getting lowest yield in treatment T_1 and T_4 as up to certain limit of water application, yield increases with increase in quantity of water but afterwards yield reduces (Mathieu, 2007). In the case of the control treatment the water applied through surface irrigation resulted in less WUE. Singh *et al.* (2001) indicated that the biometric growth of the plants irrigated at 60 percent depletion level through drip system with plastic mulching was good and gave better yield.

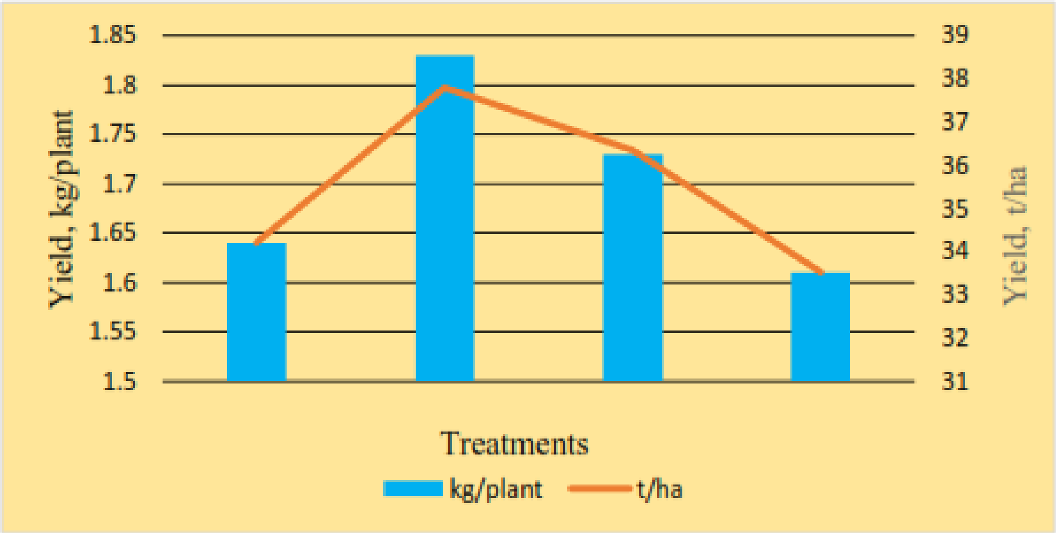


Figure 4.9 Effect of irrigation at different moisture depletion levels on yield

Plate 4.3 A view of harvested tomato

4.3.7 Root length

The roots were measured in the final stage after completing harvesting of the fruits. The data of root length recorded for the plants as influenced by different treatments are presented in the Table 4.11 and Figure 4.10.

Table 4.11 Effect of irrigation at different moisture depletion levels on root length

Treatments	Root length (cm)
T_1	52.7^a
T_2	44.4^b
T_3	42^c
T_4	54.3^a

As shown in Figure 4.10, it is seen that average length of the root was maximum in T_4 with a length of 54.3 cm and minimum value was found in T_3 with a length of 42 cm. Statistical analysis reveals that treatments T_1 and T_4 are on par and there was no significant difference between them. T_1 has less root length comparing to T_4 but the roots were more concentrated near to emitter. Irrigation affected the root depth formation during final stage. Although automation of the drip systems can reduce production costs, the small soil-root volume per plant under drip irrigation can cause plant stress, if application of water or nutrients is delayed for even shorter periods of time (Bar-Yosef et al., 1980). For both surface and sub surface drip irrigation, most of the root system was concentrated within the top 40 cm of the soil profile where root length density reached 0.5–1.5 cm/cm^3 (Rui *et al.,* 2003). Klepper (1991) also observed that when irrigation maintains wet surface soil, most of the root system is found in the upper part of the profile.

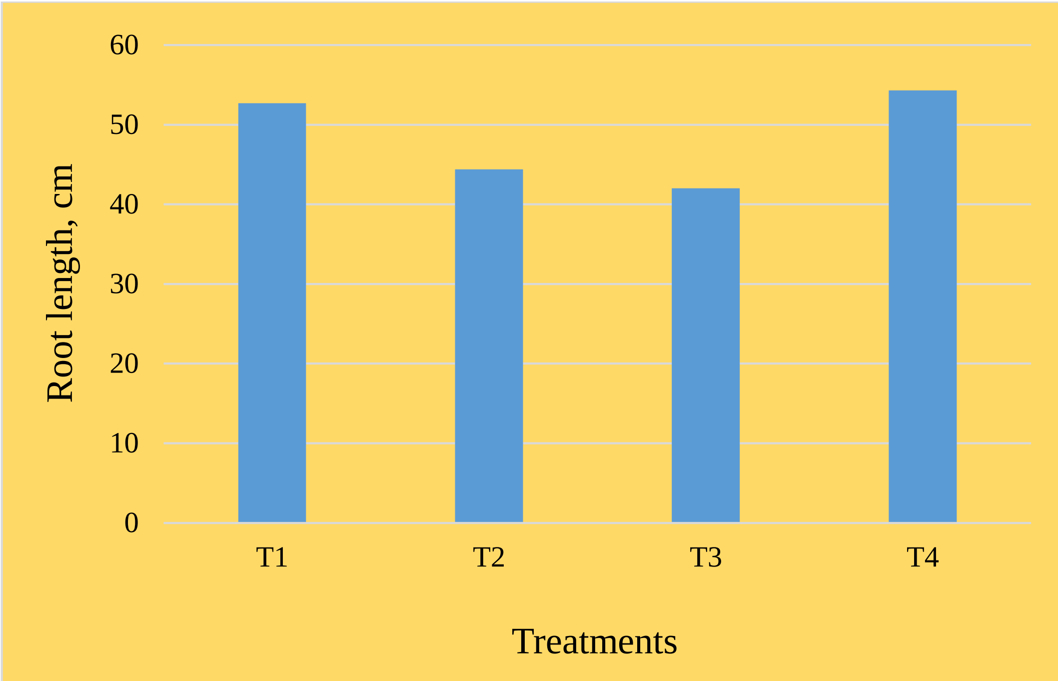


Figure 4.10 Effect of irrigation at different moisture depletion levels on root length

4.3.8 Root dry weight

After final harvesting, these roots were dried in oven and after that weights were noted for different treatments. The data is given in Table 4.12 and Figure 4.11

Table 4.12 Effect of irrigation at different moisture depletion levels on root dry weight

Treatments	Root dry weight (g)
T_1	19.7[a]
T_2	15.3[b]
T_3	13.8[c]
T_4	20.66[a]

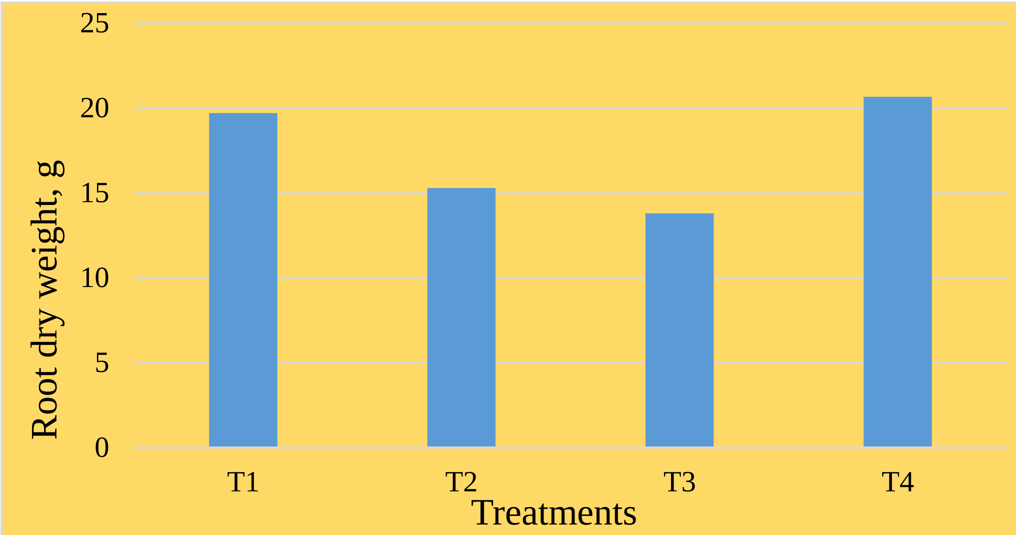


Figure 4.11 Effect of irrigation at different moisture depletion levels on root dry weight

From Table 4.12 and Figure 4.11 it is clear that the weight of the dried root was maximum in T_4 with 20.66 g and was minimum with 13.8 g in T_3. It was recorded as 19.7 and 15.3 g in treatments T_1 and T_2 respectively. It was observed that treatments T_4 and T_1 were on par. T_2 and T_3 significantly differed from other treatments. Alaoui *et al.*, (2014) reported that irrigation frequencies and timings have large effect on root development, tomato yield, water distribution and water use efficiency. Increasing irrigation interval decreases root dry weight. This is the reason for less root dry weight in T_2 and T_3 compared to T_1 and T_4. Decrease in root system due to water stress resulted in a reduction in shoot dry weights. Saleh *et al.* (2007) reported that water stressed conditions encourage tomato plants to develop their root systems in the deeper soil where soil moisture content is high. Increasing irrigation interval saved more water at early growing stage of the plants.

4.4 WATER USE EFFICIENCY

The water use efficiency of the crop was calculated based on the yield and water applied throughout the growth period. The data is presented in the Table 4.13 and Figure 4.12

Table 4.13 Variation of water use efficiency with irrigation at different moisture depletion levels

Treatments	Yield (kg/ha)	Water used (mm)	Water use efficiency (kg/ha-mm)
T_1	34210	291.60	117.3^{b}
T_2	37800	260.41	146.4^{a}
T_3	36350	244.16	148.9^{a}
T_4	33520	322.00	104.0^{c}

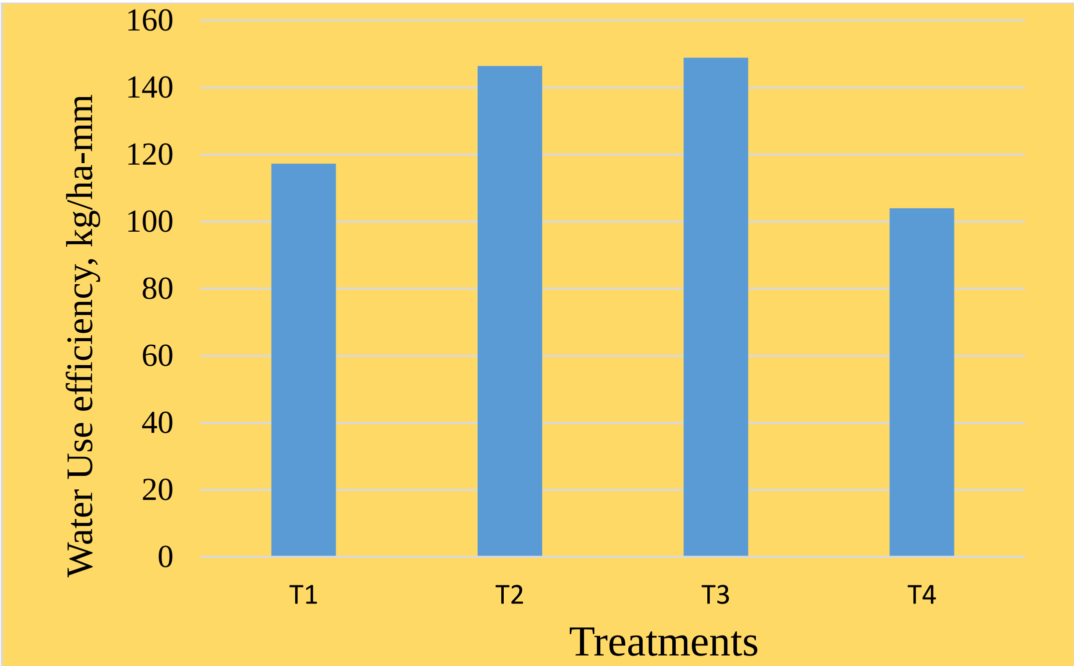


Figure 4.12 Variation of water use efficiency with irrigation at different moisture depletion levels

From the Table 4.13 it is seen that maximum WUE is in T_3 with 148.9 kg/ha- mm. The water use efficiency in 50 per cent moisture depletion level was 146.4 kg/ha- mm. Statistical analysis shows that T_3 and T_2 are on par. The other treatments were significantly different at 5 per cent level of significance. The minimum WUE was observed in T_4 with the value of 104 kg/ha-mm. The reason might be that more amount of water was applied throughout crop period. Regarding WUE both T_3 and T_2 can be considered as acceptable irrigation depletion. As T_2

gives good yield and almost all other parameters are good for T_2, 50 per cent depletion level can be considered ideal for the condition of the study. But for water scarce condition, even 60 per cent depletion can be suggested as yield and WUE are on par with T_2.

4.5 SOIL MOISTURE DISTRIBUTION PATTERNS UNDER DIFFERENT MOISTURE DEPLETION LEVELS

The analysis of the data of soil moisture content at 2 and 6 hours after irrigation was done and soil moisture contour maps for the longitudinal section of the soil were plotted using computer software "Teraplot1.3.02" version. The water distribution pattern for a given soil depends on the rate and duration of water application and the spacing of the laterals. The data of two dimensional distribution of moisture content in percentage on gravimetric basis at distances of 0, 15 and 30 cm from the emitter and at the depths of 0, 10, 20 and 30 cm from the surface for all the treatments are given in Appendix III.

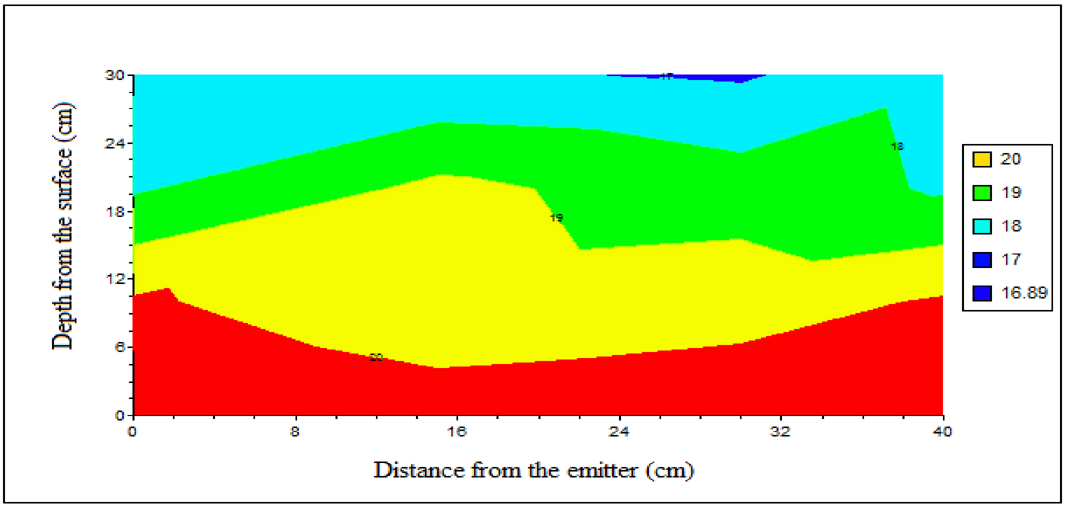
4.5.1 Soil moisture distribution pattern for treatment T_1 two hours after irigation

Soil moisture distribution patterns for the treatment T_1 (40 per cent moisture depletion level) two hours after irrigation is shown in Figure 4.13(A). From figure 4.13(A) the highest and lowest moisture content varies between 20.86 per cent and 16.89 per cent. Surface layer up to depth of 10 cm and emitter positions 0 and 40 cm with more moisture content in the range of 20.86% - 19.6% was seen. There is good moisture distribution laterally between the emitter positions. Redistribution of moisture to deeper layers is indicated and at depth of 20 cm the moisture content is as 17.9% - 18.51%. This indicates that frequent irrigation might happen in this treatment. Moisture contours indicate non uniform distribution in deeper layers.

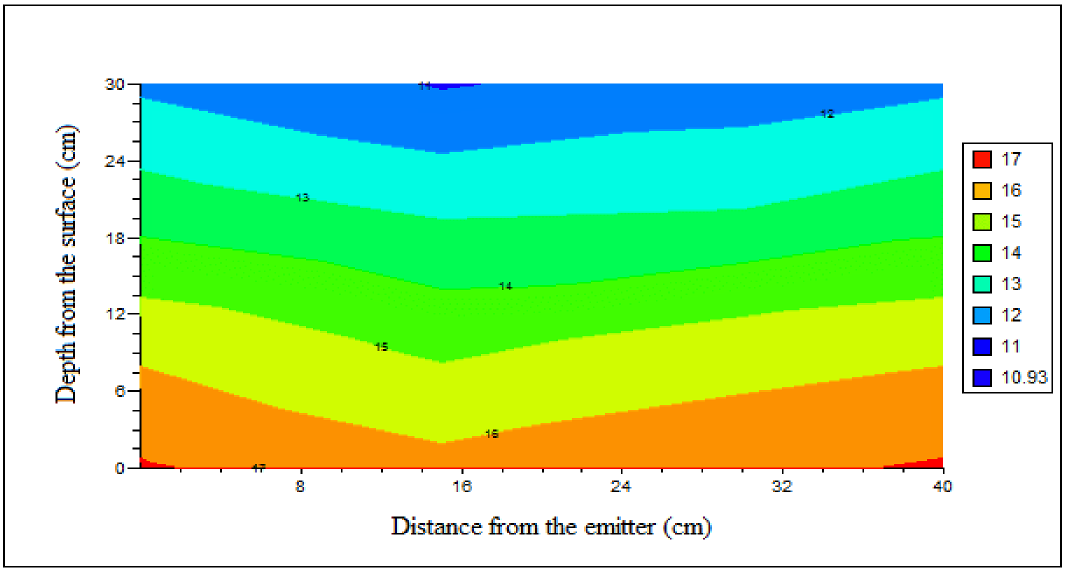
4.5.2 Soil moisture distribution pattern for treatment T_1 six hours after irrigation

Soil moisture distribution patterns for the treatment T_1 (40 per cmoisture depletion level) six hours after irrigation is shown in Figure 4.13(B). From figure

4.13(B), the highest and lowest moisture content varies between 17.1% and 11.47 per cent. Surface layers is having moisture content in the range of 17% - 15.4 %. At a depth of 20 cm, moisture content is between 13% - 14%. Moisture has redistributed to deeper layers and more uniform contours are seen in deeper layers.



(A)



(B)

Figure 4.13 Moisture distribution pattern - T_1 40% moisture depletion level:

(A) Two hours after irrigation (B) Six hours after irrigation

4.5.3 Soil moisture distribution pattern for treatment T_2 two hours after irrigation

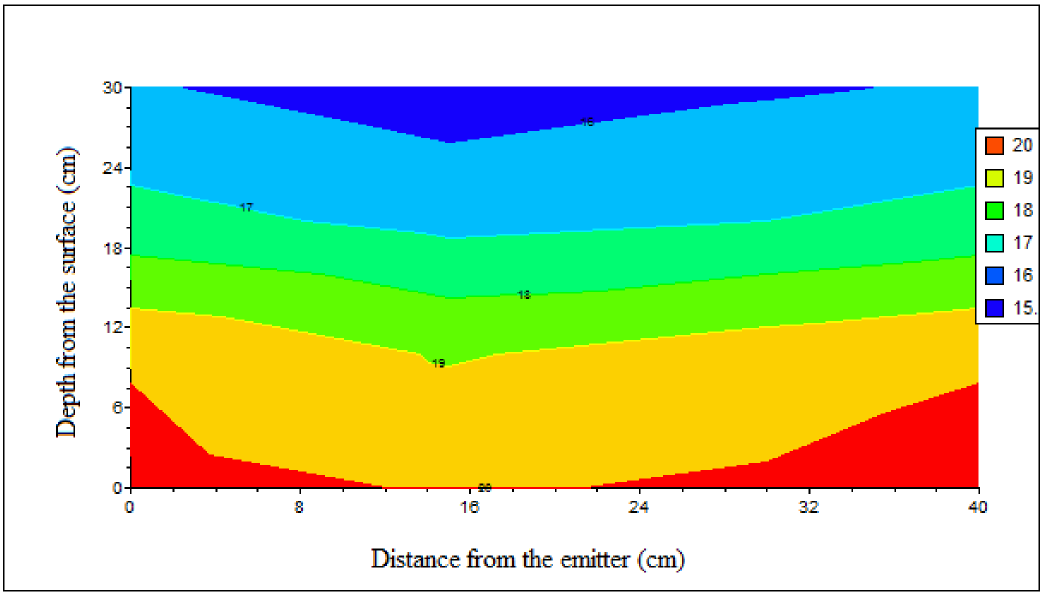
Soil moisture distribution patterns for the treatment T_2 (50 per cent moisture depletion level) two hours after irrigation is shown in Figure 4.14(A).

From the figure 4.14(A), it is seen that moisture content varies from 20.36 % to 15.9%. The overlap effect is less predominant compared to T_1. But moisture content is high near to the emitter and also indicate lateral spreading. Beneath the emitter position at 0 and 40 cm, moisture has penetrated up to depth of 8 cm. More uniform contours indicating uniform moisture distribution is seen in T_2 two hours after irrigation comparing to T_1.

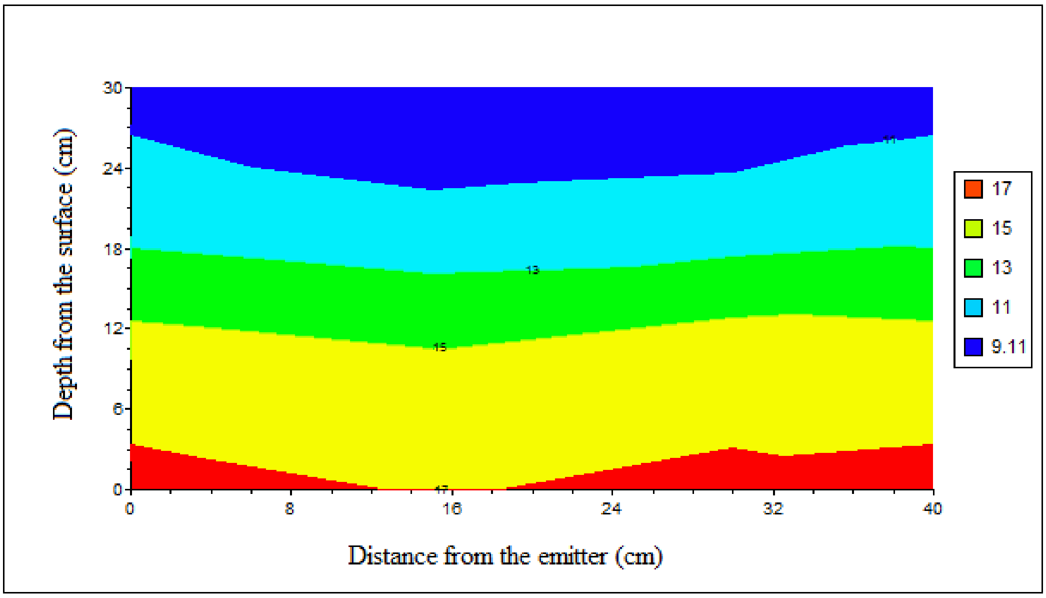
4.5.4 Soil moisture distribution pattern for treatment T_2 six hours after irrigation

Soil moisture distribution patterns for the treatment T_2 (50 per cent moisture depletion level) six hours after irrigation is shown in Figure 4.14(B).

From Figure 4.14(B), it is observed that the moisture content varies between 17.56 % and 9.48 % which indicates no frequent irrigation happened. Moisture content was less compared to two hours after irrigation. Surface layers near to emitter position have moisture content of 17 % and above. Uniform moisture content of 15 % - 17.56 % is seen in the layers up to the depth of 12 cm, 13 % - 15 % moisture content up to depth of 18 cm. This indicates that no further irrigation happened since the moisture content at 20 cm depth is above critical limit.



(A)



(B)

Figure 4.14 Moisture distribution pattern – T_2 50% moisture depletion level: (A) Two hours after irrigation (B) Six hours after irrigation

4.5.5 Soil moisture distribution pattern for treatment T_3 two hours after irrigation

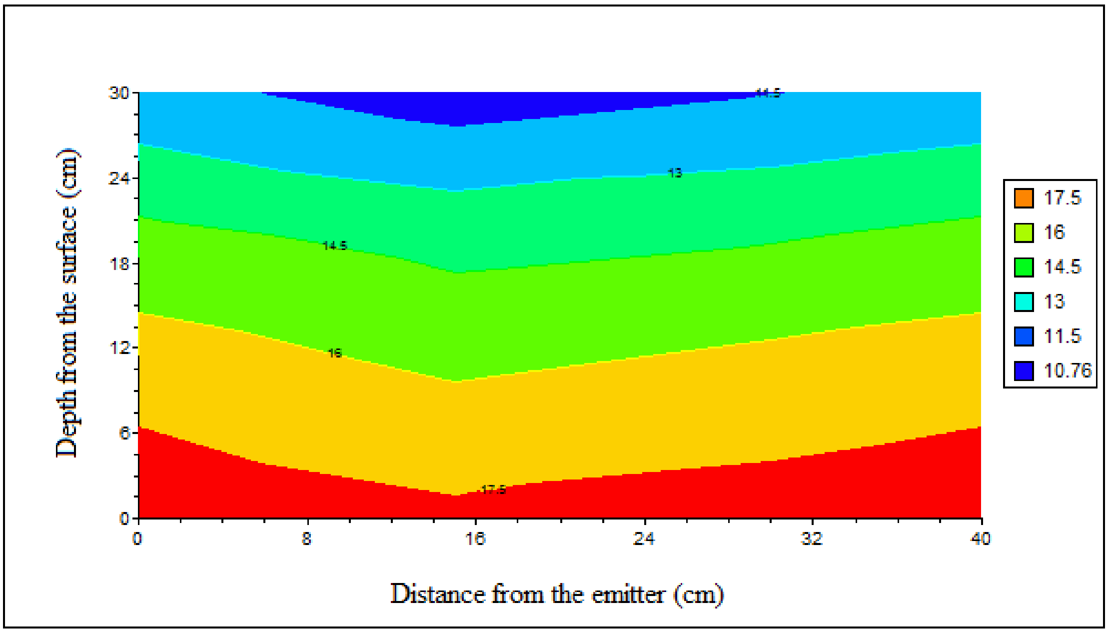
Soil moisture distribution patterns for the treatment T_3 (60 per cent moisture depletion level) two hours after irrigation is shown in Figure 4.15(A).

From figure 4.15(A) the highest and lowest moisture content varies from 18.5 % to 11.47 %. More uniform moisture contours are seen as in T_3. Surface layers near to emitter positions are more moist up to a depth of 6 cm and moisture reduces as it goes away from the emitter. Throughout the section, moisture content of each layer is least at a distance of 16 cm from the emitter. Lateral distribution of moisture is sufficient and moisture is uniform. At depth of 20 cm moisture content is between 15 % and 14.5 %. No irrigation might have happened within this time interval in this treatment.

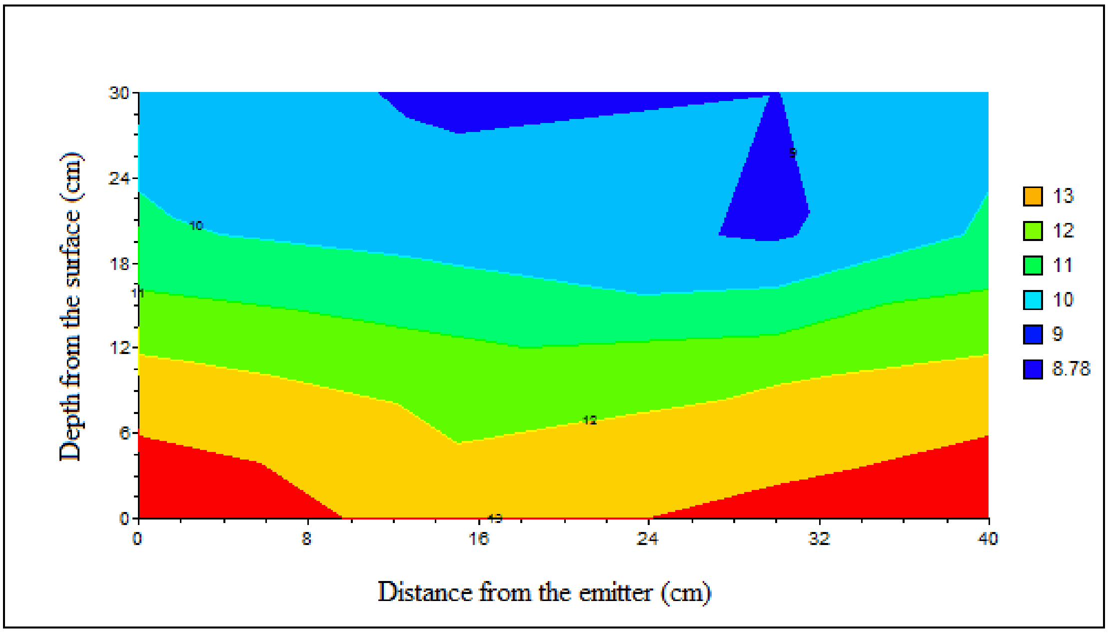
4.5.6 Soil moisture distribution pattern for treatment T_3 six hours after irrigation

Soil moisture distribution patterns for the treatment T_3 (60 per cent moisture depletion level) six hours after irrigation is shown in Figure 4.15(B).

Figure 4.15(B) shows that moisture content varies from 13.89 % to 9.29%. The values are highest near to emitter position up to depth of 6 cm. Moisture content away from emitter position and distance of 16 cm laterally was 13%. At a depth of 20cm, moisture content varies between 10-11%. If moisture at this depth reduces till further irrigation will be initiated. Moisture distribution pattern is not uniform as in earlier case.



(A)



(B)

Figure 4.15 Moisture distribution pattern – T_3 60% moisture depletion level: (A) Two hours after irrigation (B) Six hours after irrigation

4.5.7 Soil moisture distribution pattern for treatment T_4 two hours after irrigation

Soil moisture distribution patterns for the treatment T_4 (volume based irrigation - control) two hours after irrigation is shown in Figure 4.16(A).

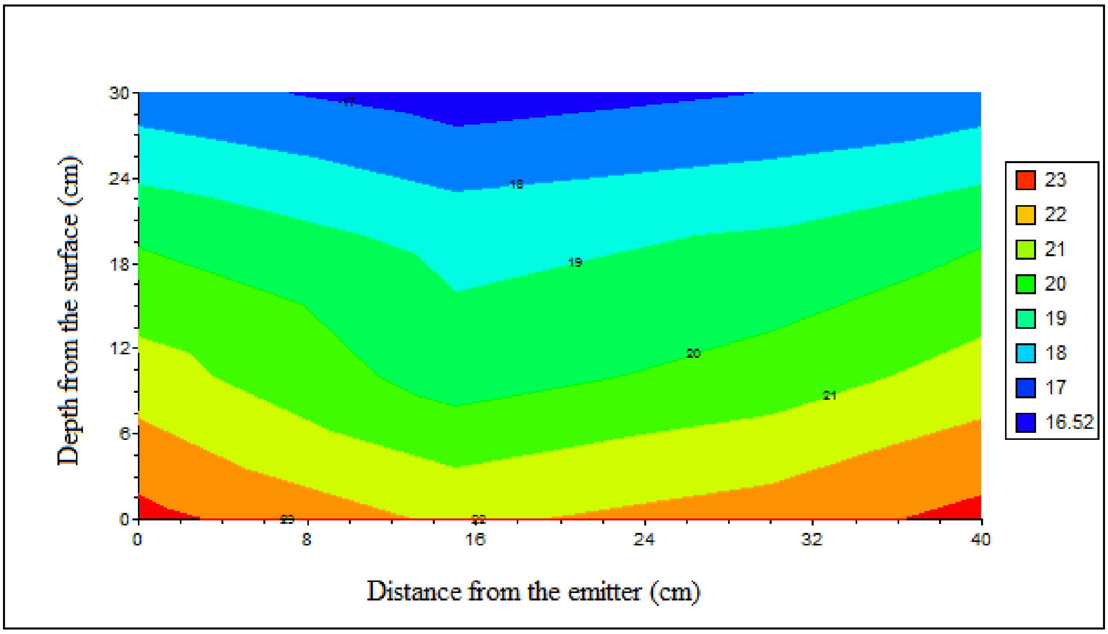
Figure 4.16(B) shows that moisture content throughout the profile is above field capacity and the highest and lowest values ranges from 23.3% to 17%. Near to the emitter position at the depth of 6 to 8 cm the moisture content is 22% and slow lateral spreading is seen. Moisture distribution is uniform but it is more in all layers. At a depth of 20 cm the moisture content is 19%. Volume based irrigation maintains moisture in excess of field capacity in the entire root zone even two hour after irrigation.

4.5.8 Soil moisture distribution pattern for treatment T_4 six hours after irrigation

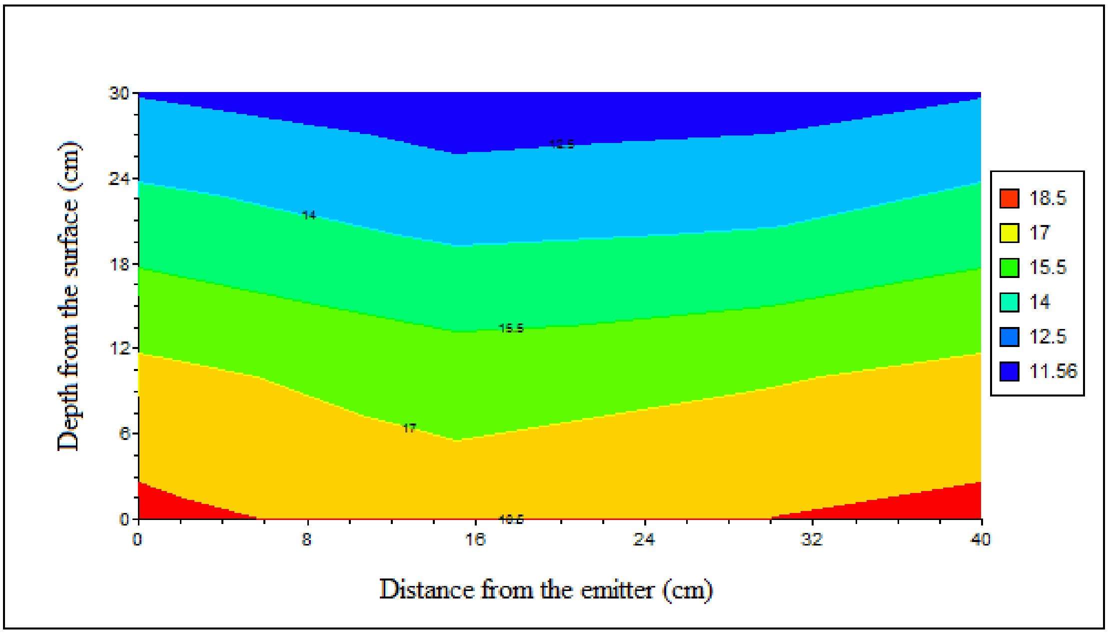
Soil moisture distribution patterns for the treatment T_4 (volume based irrigation - control) six hours after irrigation is shown in Figure 4.16(B).

Figure 4.16(B) shows that moisture content varies from 18.87% to 11.89%. Though uniform patterns are seen, the values are less compared to two hours after irrigation indicating losses of water to deeper layers. T_4 cannot be suggested as moisture content is higher than field capacity throughout all the layers.

Moisture content from all the treatments indicates that T_2 as best treatment regarding uniform distribution and moisture content below field capacity levels. Frequent low volume of irrigation applied through automation systems assures more water saving and good moisture distribution in loamy soil compared to bulk irrigation.



(A)



(B)

Figure 4.16 Moisture distribution pattern – T_4 (control – volume based system):

(A) Two hours after irrigation (B) Six hours after irrigation

4.6 COST ECONOMICS OF AUTOMATION SYSTEM IN RAIN SHELTER

The economic analysis of an automation system in a simple rain shelter was done by making the following assumptions and is tabulated below. It is assumed that 3 crops are cultivated in a year. The assumptions are same for all the treatments and only yield from different treatments differs.

Assumptions

1. Expected life of the drip automation system is 15 years
2. Annual growth rate of costs and benefits is 5%
3. Salvage value is nil
4. The costs and benefits are discounted at 12%
5. Size of rain shelter: 12×5.5 m^2
6. Cost of construction of rain shelter: Rs 100/ m^2
7. Capital cost (cost of construction + cost of irrigation system) : Rs 750/ m^2

4.6.1 Cost economics of treatment T_1

1 Cost of cultivation of Tomato: Rs 60/ m^2
2 Yield of Tomato: 4.8 kg/ m^2
3 Price of Tomato: Rs 30/ m^2

Table 4.14 Economic analysis of tomato cultivation in rain shelter- T_1 (40% MDL)

Year	Capital Cost	O&M Cost	Production Cost	Total Cost	Benefits	Discount Factor	Present worth of Costs	Present worth of Benefits	Cash Flow	Net Present Worth (NPW)
1	64800 0	0	8640	73440	28080	1	73440	28080	-45360	-45360
2			4536	4536	29484	0.893	4050	26325	24948	22275
3		6000	4763	10763	30958.2	0.797	8580	24680	20195	16100
4			5001	5001	32506.11	0.712	3560	23137	27505	19578
5			5251	5251	34131.42	0.636	3337	21691	28880	18354
6			5514	5514	35837.99	0.567	3129	20335	30324	17207
7		6946	5789	12735	37629.89	0.507	6452	19064	24895	12613
8			6079	6079	39511.38	0.452	2750	17873	33433	15123
9		0	6383	6383	41486.95	0.404	2578	16756	35104	14178
10		8041	6702	14742	43561.3	0.361	5316	15709	28819	10392
11			7037	7037	45739.36	0.322	2266	14727	38703	12461
12		0	7389	7389	48026.33	0.287	2124	13806	40638	11682
13		9308	7758	17066	50427.65	0.257	4380	12944	33362	8563
14			8146	11125	52949.03	0.229	2550	12135	41824	9585
15			8553	11682	55596.48	0.205	2390	11376	43914	8986
Total		30294	97539	198741	605926		126901	278638	407185	151737

Discount Rate (%) : 12
Benefit-Cost Ratio : 2.20
Net Present Worth (Rs) : 151737
Internal Rate of Return (%) : 40.8

4.6.2 Cost economics in treatment T_2

1. Cost of cultivation of Tomato: Rs 60/ m^2
2. Yield of Tomato: 6 kg/ m^2
3. Price of Tomato: Rs 30/ m^2

Table 4.15 Economic analysis of tomato cultivation in rain shelter- T_2 (50% MDL)

Year	Capital Cost	O&M Cost	Production Cost	Total Cost	Benefits	Discount Factor	Present worth of Costs	Present worth of Benefits	Cash Flow	Net Present Worth (NPW)
1	64800	0	8640	73440	32832	1	73440	32832	-40608	-40608
2			4536	4536	34473.6	0.893	4050	30780	29938	26730
3		6000	4763	10763	36197.28	0.797	8580	28856	25434	20276
4			5001	5001	38007.14	0.712	3560	27053	33006	23493
5			5251	5251	39907.5	0.636	3337	25362	34657	22025
6			5514	5514	41902.88	0.567	3129	23777	36389	20648
7		6946	5789	12735	43998.02	0.507	6452	22291	31263	15839
8			6079	6079	46197.92	0.452	2750	20898	40119	18148
9		0	6383	6383	48507.82	0.404	2578	19591	42125	17014
10		8041	6702	14742	50933.21	0.361	5316	18367	36191	13051
11			7037	7037	53479.87	0.322	2266	17219	46443	14953
12		0	7389	7389	56153.86	0.287	2124	16143	48765	14019
13		9308	7758	17066	58961.55	0.257	4380	15134	41895	10754
14			8146	11125	61909.63	0.229	2550	14188	50785	11639
15			8553	11682	65005.11	0.205	2390	13301	53323	10911
Total		30294	97539	198741	708467		126901	325792	509726	198891

*MDL – Moisture depletion level

Discount Rate (%) : 12

Benefit-Cost Ratio : 2.57

Net Present Worth (Rs) : 198891

Internal Rate of Return (%) : 40.8

4.6.3 Cost economics in treatment T_3

1. Cost of cultivation of Tomato: Rs 60/ m^2
2. Yield of Tomato: 5.25 kg/ m^2
3. Price of Tomato: Rs 30/ m^2

Table 4.16 Economic analysis of tomato cultivation in rain shelter- T_3 (60% MDL)

Year	Capital Cost	O&M Cost	Production Cost	Total Cost Cost	Benefits	Discount Factor	Present worth of Costs	Present worth of Benefits	Cash Flow	Net Present Worth (NPW)
1	64800	0	8640	73440	31104	1	73440	31104	-42336	-42336
2			4536	4536	32659.2	0.893	4050	29160	28123	25110
3		6000	4763	10763	34292.16	0.797	8580	27338	23529	18757
4			5001	5001	36006.77	0.712	3560	25629	31006	22069
5			5251	5251	37807.11	0.636	3337	24027	32556	20690
6			5514	5514	39697.46	0.567	3129	22525	34184	19397
7		6946	5789	12735	41682.33	0.507	6452	21118	28947	14666
8			6079	6079	43766.45	0.452	2750	19798	37688	17048
9		0	6383	6383	45954.77	0.404	2578	18560	39572	15983
10		8041	6702	14742	48252.51	0.361	5316	17400	33510	12084
11			7037	7037	50665.14	0.322	2266	16313	43628	14047
12		0	7389	7389	53198.4	0.287	2124	15293	45810	13169
13		9308	7758	17066	55858.32	0.257	4380	14337	38792	9957
14			8146	11125	58651.23	0.229	2550	13441	47526	10892
15			8553	11682	61583.79	0.205	2390	12601	49902	10211
Total		30294	97539	198741	671180		126901	308645	472438	181744

Discount Rate (%)	:	12
Benefit-Cost Ratio	:	2.43
Net Present Worth (Rs)	:	181744
Internal Rate of Return (%)	:	40.8

4.6.4 Cost economics in treatment T_4

1. Cost of cultivation of Tomato: Rs 60/ m^2
2. Yield of Tomato: 4kg/ m^2
3. Price of Tomato: Rs 30/ m^2

Table 4.17 Economic analysis of tomato cultivation in rain shelter- T_4 (control)

Year	Capital Cost	O&M Cost	Production Cost	Total Cost	Benefits	Discount Factor	Present worth of Costs	Present worth of Benefits	Cash Flow	Net Present Worth (NPW)
1	64800	0	8640	73440	27216	1	73440	27216	-46224	-46224
2			4536	4536	28576.8	0.893	4050	25515	24041	21465
3		6000	4763	10763	30005.64	0.797	8580	23920	19243	15340
4			5001	5001	31505.92	0.712	3560	22425	26505	18866
5			5251	5251	33081.22	0.636	3337	21024	27830	17687
6			5514	5514	34735.28	0.567	3129	19710	29222	16581
7		6946	5789	12735	36472.04	0.507	6452	18478	23737	12026
8			6079	6079	38295.65	0.452	2750	17323	32217	14573
9		0	6383	6383	40210.43	0.404	2578	16240	33828	13662
10		8041	6702	14742	42220.95	0.361	5316	15225	27479	9909
11			7037	7037	44332	0.322	2266	14274	37295	12008
12		0	7389	7389	46548.6	0.287	2124	13382	39160	11258
13		9308	7758	17066	48876.03	0.257	4380	12545	31810	8165
14			8146	11125	51319.83	0.229	2550	11761	40195	9212
15			8553	11682	53885.82	0.205	2390	11026	42204	8636
Total		30294	97539	198741	587282		126901	270064	388541	143163

Discount Rate (%)	:	12
Benefit-Cost Ratio	:	2.13
Net Present Worth (Rs)	:	143163
Internal Rate of Return (%)	:	40.8

The initial cost for all the treatments is same and the variation takes place only in difference of yield. From observing the above information it was concluded that the Benefit Cost ratio is maximum for T_2 (2.57) with NPW 198891/- as the yield incurred was more in this treatment. T_4 is having minimum benefit Cost ratio with value of 2.13 as the yield was very less in this treatment. The other treatments T_1, T_3 having ratio of 2.20 and 2.43 respectively. Thus it was concluded that T_2 (50% MDL) can be adopted for better yield and profit using automation for tomato (*Akshaya*) under rain shelter.

Regarding WUE aspect, T_3 can also be suggested in water shortage areas. So the study reveals that automation of drip irrigation with 50 % or even 60 % depletion level of water from available moisture can be adopted for tomato (*Akshaya)* variety in rain shelter.

Suggestions for future work

- Comparison of different automation systems like sensor based, time based system and volume based system for various vegetables to optimize the system.
- Studies need to be conducted for various vegetables under different moisture levels using sensors in rain shelter to arrive at appropriate drip automation levels through automation unit for achieving optimum yields and higher net returns.
- Number of trials on tomato crop can be increased for optimizing the irrigation levels that gives best yield with less amount of water.
- Studies need to be conducted for various vegetables in rain shelter to arrive at appropriate nutrient levels including fertigation by using automation unit for achieving optimum yields and higher net returns.

CHAPTER V

SUMMARY AND CONCLUSIONS

The current trend in high-tech horticulture is towards switching from a manual system to automatic operations in micro irrigation systems. Energy savings, reduced labour cost and control in fertilizer application are among some of the major advantages in adopting automated techniques in micro irrigation systems. These systems also provide high crop yield and reduced water usage compared to conventional systems. Automated drip system facilitate high frequency, low volume irrigation and also reduces human errors.

A study was conducted to evaluate the suitability of drip automation systems for optimal irrigation scheduling. The field experiment was done in the rain shelter in the research plot of Nodal Water Technology Centre, College of Horticulture, Vellanikkara, during the months of October 2014-March 2015. The soil physical properties of the site were measured and evaluated. Field capacity and permanent wilting point were evaluated in the lab. Three different moisture depletion levels *viz.*, 40 per cent, 50 per cent and 60 per cent of available moisture were used for scheduling the automation using moisture sensors and volume based irrigation was set as control. The experiment was laid out in completely randomized design with four treatments *viz.*, T_1, T_2, T_3 and T_4 and three replications. The summary and conclusions of the study are presented in this section.

Field capacity and permanent wilting point were determined to calculate the available moisture content of the soil. For proper irrigation scheduling based on the treatments, the upper and lower limit of the operation of the sensors were set according to the available moisture content. The upper limit was fixed as amount of available moisture present in the soil for all the treatments. The lower limit was set based on different depletion levels. Control treatment was volume based irrigation at the rate of 2 l/day per plant applied four times a day.

The study was done to evaluate the effect of optimal irrigation scheduling under drip automation for tomato crop in rain shelter on the growth and yield parameters. Statistical analysis, moisture distribution patterns at two hours and six hours after irrigation was studied and the cost economics of drip automation systems was calculated.

The daily variation of weather parameters such as maximum and minimum temperature and relative humidity were recorded inside the rain shelter in the morning. Sunshine hours observations were taken from the Department of meteorology, KAU, Vellanikkara. The maximum temperature (38.8^0C) was observed inside the rain shelter during harvesting stage in the month of March and minimum temperature (17.5^0C) was recorded during the middle stage of the crop. The maximum relative humidity (98%) was recorded in the initial stage during October inside the rain shelter and the minimum relative humidity (55%) was observed during December inside the rain shelter.

Crop growth parameters such as plant height, days to first flowering, days to initial budding, days to first harvesting, root length and root dry weight were observed for all the treatments.The height of the plant was measured during the crop period at one month interval. At initial stage, height was insignificant in all treatments and after that plant height was high in control in final stage. The number of days to first flowering was significantly higher in T_1 and followed by T_2. All the treatments were significantly different at five percent level. The number of days taken for the initial budding was on par in all treatments except in $T_{3.}$ The number of days for initial budding was significantly lower in T_3 (62 days). The number of days taken for the first harvest was significantly lower in T_3 (87 days) from the transplanting day. It was observed that root length and root dry weight were higher in T_4 and T_1 and the values were on par. But for other treatments the values were significantly different.

Yield parameters such as number of fruits per plant and yield per plant for each treatment were observed during various crop growth stages.The number of fruits per plant for each harvest were on par in all the treatments and it was inferred that irrigation did not affect the number of fruits. The yield was significantly higher in T_2 (1.83 kg/plant) and there was a significant difference in all the treatments. The minimum yield was observed in T_4 (1.61 kg/plant).

The maximum WUE was observed in T_3 with 148.9 kg/ha-mm. Statistically T_3 and T_2 were on par at 5 % level of significance. The other treatments were significantly different at 5 per cent level of significance. The minimum WUE was observed in T_4 with the value of 104 kg/ha-mm.

The analysis of the data of soil moisture content at two hours and six hours after irrigation was done gravimetrically and soil moisture contour maps for the longitudinal section of the soil were plotted using computer software Teraplot1.3.02" version. The pattern obtained was uniform indicating good moisture distribution in 50% moisture depletion level at two hours after irrigation.

Benefit cost (B/C) ratio for each treatment was calculated. The maximum benefit cost ratio of 2.57 was noted in 50 % moisture depletion level and minimum benefit cost ratio was observed as 2.13 in control.

From the study it was obvious that treatment T_2 (50% depletion level) can be chosen as the best irrigation schedule as it gives good yield and almost all other parameters are good for T_2. But for water scarce condition, even 60 per cent depletion can be suggested as good since yield and WUE are on par with T_2. Benefit cost ratio was maximum in T_2. Thus it can be concluded that 50% MDL can be adopted as ideal condition for scheduling automated drip irrigation system to ensure better yield , water saving and profit for tomato variety *Akshaya* grown in rain shelter.

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Appendix I: Upper and lower limits of the moisture depletion levels

Available moisture content = [(FC – PWP)/100] * root zone depth * specific Gravity

= [(15.89-9.6)/100] x 1.94 x 20

= 2.44 cm = 24.4 mm (Upper limit for all the treatments)

The lower limits of different moisture depletion levels are given below:

T_1	=	40 per cent moisture depletion from available moisture
	=	2.44 x (40/100)
	=	9.7 mm
T_2	=	50 per cent moisture depletion from available moisture
	=	2.44 x (50/100)
	=	12.2 mm
T_3	=	50 per cent moisture depletion from available moisture
	=	2.44 x (60/100)
	=	14.7 mm

Appendix II: Micro climate inside the rain shelter

Daily variation of relative humidity inside the rain shelter and sunshine hours

Sl. No.	November		December		January		February		March	
	RH	SSH	RH	SSH	RH	SSH	RH	SSH	RH	SSH
1	95	5.0	42	3.4	95	3.1	63	8.4	85	6.6
2	95	5.0	71	3.5	91	6.0	65	9.8	90	9.3
3	96	1.3	72	8.2	93	9.4	61	9.8	84	5.8
4	96	2.2	73	9.7	93	9.0	61	10.2	84	6.2
5	96	7.4	74	7.1	94	9.4	68	9.9	87	8.8
6	98	5.6	70	9.7	80	9.2	55	8.5	78	9.8
7	91	5.7	78	9.2	81	9.7	63	8.0	85	8.4
8	96	4.8	82	7.9	88	8.6	75	8.1	88	6.6
9	95	5.4	81	7.7	83	6.0	77	9.7	88	7.1
10	95	2.9	88	1.1	78	7.3	73	10.2	87	7.8
11	93	6.6	81	3.2	59	9.1	72	9.7	63	8.9
12	88	7.9	88	6.1	64	10	71	9.7	66	10
13	87	7.5	75	6.8	67	9.7	72	10	66	9.2
14	96	4.3	84	8.7	65	10	88	9.2	72	9.6
15	78	7.2	78	9.4	65	9.4	80	8.5	71	6.3
16	78	9.3	82	9.5	65	8.8	91	8.8	93	7.4
17	75	9.8	71	8.5	77	9.7	87	9.4	84	5.8
18	67	8.7	71	2.1	66	8.5	90	8.2	92	7.3
19	70	8.1	81	1.9	70	9.2	91	7.6	90	8.7
20	69	8.7	88	1.1	70	8.7	74	7.4	90	8.4
21	75	0.7	93	9.7	50	8.8	70	10.3	89	9.2
22	88	5.2	75	8.4	68	7.7	75	10.4	87	9.5
23	72	2.3	81	5.8	80	9.2	55	10.6	84	9.5
24	73	8.4	76	8.8	80	9.4	46	10.4	-	-
25	73	2.8	74	5.5	74	9.5	52	10.6	-	-
26	64	6.1	75	1.0	64	9.7	81	7.7	-	-
27	67	1.2	67	6.8	64	10.0	90	5.4	-	-
28	82	0.0	65	0.4	78	9.9	90	6.2	-	-
29	86	1.8	79	8.6	71	9.3	-	-	-	-
30	66	0.0	96	5.6	71	8.8	-	-	-	-
31	-	-	95	5.1	68	8.4	-	-	-	-

RH: Relative humidity (%)

SSH: Sunshine hours (h/day)

Daily variation of maximum and minimum temperature inside the rain shelter

Sl. No.	November		December		January		February		March	
	Max. temp	Min. temp	Max. temp	Min. temp	Max. temp	Min. temp	Max. temp	Min. temp	Max. temp	Min. temp
1	32.7	24.0	30.4	22.4	31.4	23.6	33.1	23.3	33.8	22.6
2	31.2	22.4	31.3	22.2	31.6	19.4	32.9	22.7	35.0	23.8
3	31.3	23.8	33.1	20.7	32.8	20.9	32.7	23.6	33.8	25.3
4	31.0	23.1	31.7	22.1	32.2	21.4	33.0	24.3	35.8	24.3
5	32.8	23.4	31.1	21.4	33.4	21.4	33.0	24.5	34.9	22.9
6	31.5	22.6	31.4	20.7	32.8	21.9	32.0	23.8	36.3	25.7
7	33.4	22.9	32.3	22.4	33.0	21.7	34.5	22.7	35.7	25.2
8	32.4	23.7	33.3	22.9	32.7	22.8	33.9	22.8	35.2	24.3
9	32.0	23.2	33.0	23.3	32.0	23.0	33.9	23.2	35.0	24.3
10	32.4	22.9	32.9	24.2	33.1	22.9	34.2	22.4	35.2	24.5
11	33.0	24.0	30.6	24.1	32.7	22.3	33.5	22.7	35.6	24.7
12	32.5	22.9	32.3	23.3	31.7	21.6	33.8	23.3	36.3	24.7
13	31.9	22.3	32.4	24.0	30.8	18.9	34.9	23.9	35.7	24.8
14	32.0	23.4	32.7	22.9	30.7	17.3	35.1	23.3	36.8	25.8
15	32.3	23.9	32.9	24.5	31.8	21.3	35.4	23.9	35.9	24.8
16	31.8	23.1	33.1	23.5	32.0	20.6	35.9	23.3	35.5	24.5
17	33.2	23.7	32.7	25.2	32.7	21.3	35.3	23.6	35.8	24.4
18	31.5	24.4	29.0	25.8	32.7	22.6	35.7	23.2	34.8	24.7
19	33.3	25.4	30.7	25.3	32.6	22.2	33.6	23.2	34.8	25.0
20	32.3	24.2	30.5	24.6	32.2	22.7	35.0	23.7	35.4	25.7
21	30.2	24.0	32.4	23.2	32.7	23.7	35.2	22.7	36.5	25.9
22	32.4	22.4	32.3	23.2	32.3	23.0	34.9	20.7	38.0	24.0
23	30.7	23.9	32.6	23.3	33.4	21.3	35.1	22.8	38.0	25.1
24	32.3	22.4	32.3	23.4	33.0	22.7	35.5	20.3	-	-
25	30.0	22.3	32.1	23.6	34.1	24.6	35.6	21.7	-	-
26	32.0	22.7	29.0	22.9	33.8	23.6	35.8	23.3	-	-
27	31.3	21.7	31.1	22.3	32.4	23.1	33.5	23.3	-	-
28	28.7	22.3	30.6	23.9	32.3	22.5	33.7	23.3	-	-
29	30.3	22.8	34.3	22.2	32.8	24.0	-	-	-	-
30	28.9	22.4	32.0	24.0	33.0	23.3	-	-	-	-
31	-	-	31.4	24.2	33.1	24.7	-	-	-	-

Max. temp: Maximum temperature ^{0}C

Min. temp: Manimum temperature ^{0}C

Appendix III: Data on moisture content per cent in different treatments

T_1 - 40 % moisture depletion level

Two hours after irrigation			
	0	15	30
0	20.86	20.4	20.66
10	20.1	19.43	19.60
20	17.9	19.23	18.51
30	17.81	17.14	16.89
Six hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	17.1	16.3	16.8
10	15.72	14.72	15.42
20	13.59	12.9	13.05
30	11.82	10.93	11.47

T_2 - 50 % moisture depletion level

Two hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	20.36	19.91	20.12
10	19.9	18.91	19.5
20	17.33	16.73	17.00
30	16.1	15.5	15.9
Six hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	17.56	16.89	17.36
10	15.91	15.18	16.20
20	12.3	11.62	11.91
30	10.32	9.11	9.48

T_3 – 60 % moisture depletion level

Two hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	18.5	17.8	18.1
10	16.94	15.92	16.58
20	14.86	13.99	14.36
30	11.98	10.76	11.47
Six hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	13.89	12.7	13.57
10	12.33	11.83	12.15
20	10.15	9.81	8.86
30	9.67	8.78	9.29

T_4 – control (volume based automation system)

Two hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	23.03	21.78	22.5
10	21.45	19.54	20.43
20	19.85	18.65	19.11
30	17.44	16.52	17.03
Six hours after irrigation			
Depth	Distance from emitter (cm)		
	0	15	30
0	18.87	17.9	18.51
10	17.43	16.28	16.87
20	14.9	13.81	13.9
30	12.44	11.56	11.89

ABSTRACT

Automation in irrigation management refers to those innovations which partially or fully replace manual intervention from watering operations. Automized irrigation includes automation at regional level or farm level. Recently, technological advances have been made in soil water sensors for efficient and automatic operation of irrigation system by which exact quantity of required water can be supplied to the crop. Automatic soil water sensor-based irrigation seeks to maintain a desired soil water range in the root zone that is optimal for plant growth.The present study was conducted to evaluate the suitability of drip automation systems for optimal irrigation scheduling. The field experiment was done in the rain shelter in the research plot of Nodal Water Technology Centre, College of Horticulture, Vellanikkara, during the months of October 2014–March 2015. The experiment was done for tomato variety *Akshaya* in rain shelter with 4 treatments of irrigation levels. The experiment was laid out in CRD with 3 replications. The main objectives of the study were to evaluate the performance of sensor based automated drip irrigation systems, scheduling irrigation for tomato based on the best performing drip automation system and to evaluate the cost economics of drip automation system with optimal irrigation scheduling. Irrigation was provided using sensors through drip automation system at 40 per cent, 50 per cent and 60 per cent moisture depletion levels (MDL) from the available moisture content. Control was irrigated at the rate of 2 l/plant/day. Crop growth parameters such as height of the plant, number of days to first flowering, number of days to initial budding, number of days to first harvest, root length and root dry weight were observed. During all the stages, plant height significantly varied in all treatments. All the parameters were found to be better in 50 per cent MDL treatment compared to other treatments. Yield parameters such as number of fruits and total yield were recorded. There was no significant difference in number of fruits per plant in all the treatments. Yield was significantly higher in 50 per cent MDL than that of other treatments. Water use efficiency was significantly different in all the treatments. WUE in T_2 and T_3 was on

par which showed better performance than other treatments. The analysis of the data of soil moisture content at 2 and 6 hours after irrigation was monitored at distances of 0, 15 and 30 cm from the emitter laterally and at a depth of 0, 10, 20 and 30 cm from the surface. Soil moisture contour maps for the longitudinal section of the soil were plotted using computer software “Teraplot 1.3.02” version. The pattern was more uniform for T_2 (50 per cent MDL) two hours after irrigation. Benefit cost (B/C) ratio for each treatment was calculated. The maximum benefit cost ratio of 2.57 was noted in T_2. Hence it can be concluded that for tomato (*Akshaya*) grown in rain shelter, 50 per cent MDL can be fixed as the optimum level for scheduling irrigation. As 60 per cent moisture depletion also gave good yield and WUE on par with 50 per cent level, 60 per cent MDL can also be suggested for scheduling irrigation in water scarce areas.