FIELD EVALUATION OF AUTOMATED DRIP IRRIGATION SYSTEM

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BY

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THESIS SUBMITTED TO THE ACHARYA N. G. RANGA AGRICULTURAL UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF

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COLLEGE OF AGRICULTURAL ENGINEERING

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2014

DECLARATION

I, **Mr. CH.APPARAO,** hereby declare that the thesis entitled **"FIELD EVALUATION OF AUTOMATED DRIP IRRIGATION SYSTEM"** submitted to the Acharya N. G. Ranga Agricultural University for the degree of **Master of Technology in Agricultural Engineering** in the major field of **Soil and Water Engineering** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place:

Date: **(CH.APPARAO)**

CERTIFICATE

Mr. **CH.APPARAO** has satisfactorily prosecuted the course of research and that thesis entitled "**FIELD EVALUATION OF AUTOMATED DRIP IRRIGATION SYSTEM**" submitted is the result of original research work of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any University.

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CERTIFICATE

This is to certify that the thesis entitled **''FIELD EVALUATION OF AUTOMATED DRIP IRRIGATION SYSTEM"** submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the major field of **Soil and Water Engineering** of the Acharya N. G. Ranga Agricultural University, Hyderabad is a record of the bonafide research work carried out by Mr**. CH.APPARAO** under my guidance and supervision. The subject of the Thesis has been approved by the Student's Advisory Committee.

No part of the Thesis has been submitted for any degree or diploma or has been published. The published part has been fully acknowledged. All the assistance and help received during the course of the investigation have been duly acknowledged by the author of the thesis.

Thesis is approved by the following Student's Advisory Committee.

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Dedicated to my Parents

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Place: Bapatla
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVATIONS AND SYMBOLS

Unless otherwise stated, the abbreviations and symbols in the text shall have the following meaning

AC	-	Alternate current
ASCE	-	American Society of Civil Engineering
BSU	-	Base Station Unit
CEA	-	Controlled Environmental Conditions
cm	-	Centimeter
Cu	-	Coefficient of uniformity
DAP	-	Days after planting
DC	-	Direct current
EC	-	Electrical conductivity
et al	-	and others
ET	-	Evapotranspiration
ET_o	-	Reference evapotranspiration
FAO	-	Food and Agriculture Organization
g	-	Grams
ha	-	Hectare
IC	-	Integrated circuit
Kg	-	Kilogram
LCD	-	Liquid crystal display
LLDPE	-	Linear Low density poly ethylene
LRWC	-	Leaf relative water content
lt	-	Liter
LVHF	-	Low volume high frequency
min	-	Minutes
ml	-	Milliliter
mm	-	Millimeter
NMC	-	Netafim Micro Controller
NPK	-	Nitrogen, phosphorus, potassium
NPN	-	Negative Positive Negative
PC	-	Pot culture

PCB	-	Printed circuit board
PVC	-	Poly vinyl chloride
SMS	-	Soil Moisture Sensor
SU	-	Sensor Unit
t	-	Tones
USA	-	United States of America
V	-	Volts
VR	-	Variable Resistor
VMC	-	Volumetric Moisture Content
WORS	-	Without the rain sensor
WUE	-	Water Use Efficiency

ABSTRACT

Author	:	**CH. APPARAO**
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The recent irrigation techniques introduce automated irrigation using sophisticated equipments to supply water and nutrients to the plant as soon as they need it. Automated irrigation systems can increase crop yields, save water, energy and labour costs as compared with manual systems.

The automation of the irrigation process is important for three main reasons: scarcity of water, timely irrigation and maximum crop profit. Automatic irrigation systems presently available are costly and are not adopted by most of the Indian farmers. Therefore, appropriate low cost technology has to be developed to facilitate high water use efficiency. As the farm holdings are not large enough in India and also high cost of automation cannot be realized in India, low cost automatic irrigation is suitable to farmers, if developed and can be made as a technology, farmers can feel comfortable in view of the frequent power cuts and less power available in his farm. To apply simple electronic circuit principles in irrigation an attempt has been made to develop low cost automated drip irrigation based on soil moisture.

The experimental field with an area of 600 sq m was selected at field irrigation laboratory, Department of Soil and Water Engineering, College of Agricultural Engineering, Bapatla. The field was divided into five sub plots each with 3 × 20 m size to conduct experiments under drip irrigation with brinjal and tomato crops. The yield response of brinjal and tomato crops for different row to row spacings (50 cm row to row spacing and 30×70 cm paired row spacing) and irrigation application methods (flood irrigation, time based automated drip irrigation, soil moisture sensor based automated drip irrigation)were evaluated.

The results revealed that the the yield response was observed to be best in soil moisture sensor based irrigation with paired row spacing. CRD design is used for statistical analysis of the yield data. The analysis of variance inferred that there is a significant difference in yield response at all treatment plots of brinjal and tomato. Soil moisture sensor was calibrated to switch off the motor when soil moisture reaches field

capacity and switch on the motor when soil moisture reaches 80% of field capacity. Maximum penetration of root depth, well developed distribution of brinjal and tomato crops respectively were observed in soil moisture sensor based irrigation with paired row spacing compared to other treatments in both brinjal and tomato crops.

The linear programming model was formulated to optimize the water supplies and maximize the profit. The maximum profit of Rs.46060/- per acre is obtained when brinjal is irrigated with 546480 liters of water. The cost economics of automated time based irrigation and soil moisture sensor based irrigation was carried out and results revealed that soil moisture sensor based irrigation system is low cost with initial system cost of Rs.786/- when compared with automated time based irrigation with initial system cost of Rs.87153.6 /-

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. In the changing climate scenario, the water resource has become very scarce and also being unscientifically used in the farming fields. India, consuming almost 80% of its total water resources for agriculture sector, needs to reduce the consumption of water and nutrients to substantial levels using advanced scientific methods of irrigation like drip and sprinkler irrigation systems and real time sensor based scheduling with electronic gadgets or sensors to enhance water use efficiency (WUE) and fertilizer efficiency in India.

The recent advances in irrigation sector through APMIP programme in Andhra Pradesh state has brought in more land under drip and sprinkler irrigation systems (0.531 M ha drip irrigation area in Andhra Pradesh & 0.252 M ha sprinkler irrigation area in Andhra Pradesh) in order to supply the water exactly at the root zone of the crops and to save the water and fertilizers thereby. These recent irrigation techniques introduce automated irrigation using sophisticated equipments to supply water and nutrients to the plant as soon as they need it. Automated irrigation systems can increase crop yields, save water, energy and labour costs as compared with manual systems.

Automation of drip/micro irrigation system refers to operation of the system with no or minimum manual interventions. Irrigation automation is well justified where a large area to be irrigated is divided into small segments called irrigation blocks and segments are irrigated in sequence to match the flow or water available from the water source.

Today in India inclination towards automization of drip / micro irrigation is gaining momentum due to:

- Automation eliminates manual operation of opening or closing the valves, especially in intensive irrigation process.

- Possibility to optimise the irrigation and fertigation process.
- Adoption of advanced crop systems and new technologies, especially new crops system that are complex and difficult to operate manually.
- Use of water from different sources and increased water and fertilizer use efficiency.
- System can be operated at night, thus the day time can be utilized for other agricultural activities.
- Pump starts and stops exactly when required, thus optimizing energy requirements

Automated irrigation has a number of advantages including greater precision, more efficient use of water and reduction in human error. It is very useful, particularly in humid areas where unpredictable and unevenly distributed summer rainfall disrupts fixed irrigation schedules. Automated irrigation system also facilitates high frequency and low volume irrigation.

The scientific rationing or scheduling of irrigation water and nutrients to cropping system needs regular sensing of microclimatic, soil and soil moisture parameters. The system which is already having such sensors both for water and nutrient will have its own real-time scheduling of the same. This saves lot of labour, time, water resource and nutrients, eventually leading to adequately reducing recurring costs of crop production.

The automation of the irrigation process is important for three main reasons: scarcity of water, timely irrigation and maximum crop profit. Automatic irrigation systems presently available are costly and are not adopted by most of the Indian farmers. Therefore, appropriate low cost technology has to be developed to facilitate high water use efficiency.

The main components of the auto irrigation system are a soil moisture sensor, control circuitry, gate valve, auto pumping unit, timer and power supply. The auto irrigation system developed monitors soil water stress at the root zone continuously and controls irrigation as per present values of soil water tension and duration of irrigation.

In the light of the above discussion, it is proposed to develop and evaluate the performance and popularization of such automation sensors for drip irrigation systems for various crops to demonstrate to the farming communities and other line department personnel. In this connection, a research work is carried out on automation of drip irrigation system at College of Agricultural Engineering, Bapatla with the following objectives:

Objectives of the investigation

1. To develop a low cost soil moisture sensor for drip system.
2. To evaluate the hydraulic performance of automated drip irrigation systems.
3. To compare the economics of automated drip system with low cost soil moisture sensor.
4. To optimize the water supplies for different crops using automated drip irrigation system.

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. Development of Automation in Drip Irrigation System

Agarwal *et al.* (2014) developed a soil moisture sensor based on the fact that water is not pure water which is non-conductor, but it is impure which is slightly conductor. 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 .The moisture sensitivity adjusting the gain of an operational amplifier by variable resistor (VR).

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 aluminium 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 IC, ULN2003. 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.

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. Most soil moisture sensors are designed to estimate soil volumetric water content based on the dielectric constant (soil bulk permittivity) of the soil. The dielectric constant can be thought of as the soil's ability to transmit electricity. 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. Thus, measurement of the dielectric constant gives a predictable estimation of water content. Soil moisture sensors measure the water content in soil. A soil moisture probe is made up of multiple soil moisture sensors. One common type 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.

Munyaradzi *et al*. (2013) aimed at developing an automatic irrigation controller which is low cost and reliable for a low income farmer. The controller uses signals from the soil to schedule irrigation and was made from cheap and off the shelf components from laboratory stores and local electronic retail shops. The heart of the controller circuit was the PIC Microcontroller 16F872 that uses only 35 instructions for programming in assembly language. Two dielectric capacitance sensors (0.20 m ECH_2O probe, Decagon Devices, Inc. Pullman, Washington (WA), United States of America (USA).) connected to the controller circuit. The sensor was calibrated by developing a relationship between volumetric water content (VMC) and sensor output voltage.

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 pumps the water into the field. By using this sensor, we can find whether the soil is wet or dry. If it is dry, pumping motor will pump the water. 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 monitor by the microcontroller. In irrigation process, most parameter of monitoring is soil, so we have to monitor the soil condition, whether the soil is dry or wet. If it is dry, then by using pumping motor, water has to be pumped automatically. The main aim of our system presenting here is to monitor the moisture content in the soil in cultivating field. Based on soil moisture, pumping motor will be automatically switch on or off through relay. This saves the water at the same time and on the other hand the plant can get optimum level of water, so increasing productivity of crop.

Ingale and Kasat (2012) prepared a circuit which is cheap and reliable to develop an automated irrigation system. The system provides with 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 the 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 VDC power supply and it is given through a step down transformer and consumes very little power.

Sweety and Vijaya (2012) developed a soil moisture sensor using basing basic property, that the resistance of the soil between two points decreases with increase of water content in it. We know that the water is a good conductor of electricity in the presence of ions. So, greater 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.

Dursun and Ozden (2011) described an application of a wireless sensor network for low-cost wireless controlled irrigation solution and real time monitoring of water content of soil. 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 (BSU), valve unit (VU) and sensor unit (SU). The obtained irrigation system not only prevents the moisture stress of trees and salification, but also provides an efficient use of fresh water resource. In addition, the developed irrigation method removes the need for workmanship for flooding irrigation. The designed system was applied to an area of 8 acres in a venue located in central Anatolia for controlling drip irrigation of dwarf cherry trees.

Hameed and Agarwala (2009) proposed a novel approach to determine the efficient water requirement of agricultural fields for farming in a most scientific and cost effective manner and to design a ultra low cost moisture sensor using computer and thereby to manage the water resources more appropriately in agricultural farms for the plants irrigation and its results reveals that the capacitance response characteristics make it possible to maintain soil moisture at the desired level as per the crop requirement and its withstanding capacity from its field capacity level. Due to plant uptake, evapotranspiration, atmospheric temperature, the soil moisture continue to vary and most of the crops can give a better yield at up to 50% decrease in soil moisture content from its field capacity. So in this experiment an effort has been made to use a sensor to estimate the PWP and FC and a comparative study is made using tensiometer concurrently and its being concluded that it may improve a new insight to irrigation automation and will be a boon to unskilled farmers to optimize their crop yield as well as saving water, electricity apart from reducing green house gases emission from agricultural fields which takes place up on full saturation.

Cepuder and Nolz (2007) stated that water is a sensitive and limited resource, mainly in intensively used agricultural areas in Austria, where groundwater is used as drinking water as well as for irrigation purposes. In order to guarantee a sustainable use of irrigation water, soil water measurement devices can be used to optimise irrigation, which means that controlling the soil water content in the entire root system may prevent water stress due to water deficiency on the one hand, and over wetting on the other hand. Furthermore, losses of nutrients due to leaching can be avoided. Sensors in different depths measure the plant water uptake in the root zone under standard irrigation practices on different sites and different soils, respectively.

Abraham *et al.* (2000) used a low cost, commercially available button type thermistor as the leaf and air temperature sensors. The amount of water applied per day, leaf-air temperature and soil moisture content were monitored during the study period. The systems maintained the designed soil moisture content and air-leaf temperature differential throughout the study period.

Luthra *et al.* (1997) developed a system in which soil water tension is sensed through a modified monometer 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 d.c storage battery for a long period.

2.2. Hydraulic Performance of Automated Drip Irrigation System

Nyatume *et al.*(2013) conducted an experiment to study the effect of scheduling irrigation on the water use efficiency and yield of cabbage. It was conducted on a cabbage farm near Ghana Electricity Company's power house of Adaklu road in the Ho Municipality. The weights of harvested cabbage heads were recorded. Four raised beds were prepared with two replication labelled into various treatment (T1, T2, T3, and T4). Completely randomized design with two replications and 4 treatments was used. Treatment 1 was irrigated every day, Treatment 2 irrigated three times in a week, Treatment 3 irrigated only once in a week and Treatment 4 was under control (No irrigation). Treatment 1 (T1) yielded the highest weight(kg) of cabbage head after harvesting and the lowest water use efficiency as compared to yields of treatment 2 and 3 with treatment 4 yielding the least in weight of cabbage heads. The relationship between yield and applied water will allow to improve the management of water resources under water scarcity.

Sharma (2013) studied to evaluate the performance of on – line non pressure compensating drip emmiters of 2,4 and 8 lph discharge ratings. The system was tested for its uniformity coefficient, emission uniformity, manufacturing coefficient of variation and head discharge relationship. Uniformity coefficient of emmiters was tested using the Christiansens formula (1942). It gives the information that how efficiently water is distributed in the field.

$$Cu = 100(1 - \Sigma X / mn)$$

Where Cu = coefficient of uniformity.

m = average value of all observations.

n = total number of observation points.

X = numerical deviation of all observation points from the average application rate.

Sibomana *et al.* (2013) studied the effects of water stress on the growth and yield of tomatoes was carried out at Egerton University, Horticultural Research and Teaching Field between 2009 and 2010. Tomato “Money Maker” was subjected to four soil moisture threshold levels of 100%PC, 80%PC 60%PC and 40%PC under randomized complete block design with four replications. Five weeks old tomato seedlings were transplanted into 10-litre pots put under polyethylene covered tunnels. The measurements taken to quantify the effects of water stress on the crop include flower abortion (%), crop yield, fruit equatorial diameter, plant height, stem diameter, internode length, stomata conductance, leaf relative water content (LRWC) and leaf chlorophyll contents. Water stress resulted in significant decreases in chlorophyll content, leaf relative water content (LRWC) and vegetative growth. Severe water stress (40% of PC) reduced the plant height by 24%, stem diameter by 18% and chlorophyll concentration by 32% compared to the control. The highest yield reduction of 69% was observed in the most stressed plants. The decrease in plant growth and yield as a result of water stress can be attributed to the effects water has on the physiology of the crop.

Mirjat *et al.* (2010) observed that the water movement below the emission point of drip emmiters was more pronounced in the vertical. In most cases, the wetting front followed an axially symmetric pattern. The water laterally moved to about 0.35 m while it moved to a 0.56 m depth. The root zone for many short rooted crops is located in this range hence the percolation losses would practically be negligible under such situations.

Kim *et al.* (2009) stated that automated site-specific sprinkler irrigation system can save water and maximize productivity, but implementing automated irrigation is challenging in system integration and decision making. A controllable irrigation system was integrated into a closed-loop control with a distributed wireless in-field sensor network for automated variable-rate irrigation. An experimental field was configured into five soil zones based on soil electrical conductivity. In-field soil water sensors were installed on each zone of the distributed wireless sensor network and remotely monitored by a base station for decision making. The soil water sensors were calibrated with a neutron probe and individually identified for their response ranges at each zone. Irrigation decisions were site-specifically made based on feedback of soil water conditions from distributed in-field sensor stations. Variable-rate water application was remotely controlled by the base station to actuate solenoids to regulate the amount of time an individual group of sprinkler nozzles was irrigating in a 60-s time period. The performance of the system was evaluated with the measurement of water usage and soil water status throughout the growing season. Variable water distribution collected in catch cans highly matched to the rate assigned by computer with r^2 =0.96. User-friendly software provided real-time wireless irrigation control and monitoring during the irrigation operation without interruptions in wireless radio communication.

Carpena *et al.* (2003) conducted experiments on a low-volume/high frequency (LVHF) soil moisture based drip irrigation system and was tested on a commercial tomato farm in south Florida. Seven irrigation treatments were compared.In the first six treatments, the system was pressurized by means of an electrical pump and a pressure tank, and controlled by an irrigation timer (controller) set to irrigate five times per day. The last treatment consisted of the farm's standard commercial practice where a portable pump was used on a twice weekly manual irrigation schedule. Four of the six LVHF treatments resulted from interfacing in a closed control loop with the irrigation controller two types of soil moisture sensors (switching tensiometers and granular matrix sensors) set at two moisture points (wet: 10 cbar, optimal:15 cbar), i.e., irrigation was allowed to start when the soil moisture measured by the sensor was below the set point. The other two LVHF resulted from the same system with no sensors set with the timer at two irrigation schedules, one to supply 100% of the maximum recommended seasonal crop water needs (12 min per irrigation) and the other to supply 150% of those needs (18 min per irrigation). Results from the six LVHF treatments show that tomato yields were not different from that of the commercial field while conserving water. Switching tensiometers at 15 cbar set point performed the best (up to 73% reduction in water use compared with commercial farm practice, and 50% with respect to the 100% recommended crop water needs treatment).

Reddy *et al.* (2000) conducted field experiments in College of Agricultural Engineering, Bapatla to study the effect of drip irrigation on growth and yield of brinjal. They reported that yield was observed to be 6.47 t/ha for drip method, 5.45 t/ha for bi-wall method and 4.45 t/ha for traditional method.

2.3 Economics of Irrigation Systems

Lailhacar *et al.* (2008) noticed that the new technologies could improve irrigation efficiency of turfgrass, 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 turfgrass 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 turfgrass 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; however, future research is needed to reproduce this first year of results.

2.4 Optimization of Water Supplies for Different Crops using the Automated Drip Irrigation System

Patel (2014) stated that operations research is the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide to those in control of the system with optimum solutions to the problems. The Programming Problems are concerned with optimizing (i.e. maximizing or minimizing) the collection of techniques used for solving such problems is called mathematical programming. Linear programming, a simple and most commonly used technique, is a particular case of mathematical programming, in which best policies are determined under the prescribed restrictions.

Pradhan (2012) analyzed profitability and constraints of mixed cropping pattern (i.e. the production of fruit, vegetable and other non-cereal crop along with the basic rice crop) in the area under study. An attempt has been made with Linear programming Model to compare the profitability of actual and suggested (optimum) production mix farming method considering the primary data collected from 400 sample farm households of three different villages (irrigated, tailed-irrigated and non-irrigated) located in three different blocks of Bargarh district of Orissa. Despite the profitability nature of the mix-cropping pattern the farmers in the area under study are not in a position to adopt this type of cropping, they are highly concentrating on the rice based and biased cropping as evident from the research result; this may be due to certain constraints that discourage them to go for Mix-cropping.

Wavhal and Giri (2013) used linear programming to distribute available water to the crops if and only if there is immense need of water to the crop in order to get maximum profit with minimum cost. Also linear Programming helps in proper management of available water in agriculture fields by using wireless sensor network along with linear programming.

Chapter - III

MATERIALS AND METHODS

This chapter deals with the description of the experimental setup, cultivation details of experimental crops, experimental details, and methods used. Experimental investigations on brinjal and tomato crops have been carried out using the land available in the premises of College of Agricultural Engineering, Bapatla.

3.1. Experimental Setup

The experiment was conducted in the field irrigation laboratory, Department of Soil and Water Engineering, College of Agricultural Engineering, Bapatla. Geographically the experimental site is located at latitude of 15^0 $54^{|}$ N and longitude of 80^0 $30^{|}$ E with an altitude of 4.5 m above mean sea level. The experimental site lies in humid sub tropical area. The summers are dry and hot, where as winter is cool. The experimental site consists of sandy soil with well drained conditions.

3.1.1. Preparation of the field for the experiment

The field was prepared by rotavator for loosening the soil and for removal of weeds prior to plantation of nursery. After one week of applying about 200 kg of farm yard manure throughout the field having area of 600 m^2, once again the plot was tilled with rotavator to mix the dried farm yard manure thoroughly in the soil.

3.1.2. Water source

An existing open well near the experimental site was utilized for the water supply. The quality of water was assessed to know the suitability of water for irrigation and found that EC and pH of water is 4 dS/m and 7.2 respectively.

3.1.3. Irrigation accessories

i. Main pipe: A PVC pipe of 63 mm diameter (Class 2, 4 kgf/cm^2) was used to convey water from source to the experimental site through sub mains.

ii. Sub main: - A PVC pipe of 50 mm diameter (class 3, 6 kgf/cm^2) was used as sub main pipe to convey water from main lines to laterals.

iii. Lateral pipe: - A 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

iv. Pump: - A centrifugal mono block pump of 3 hp capacity is used for pumping water.

v. 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.

3. 1.4. Screen filter

The screen filter normally consists of stainless steel screen of 120 mesh (0.13 mm) size, which is enclosed in a mild steel body. Filtration is achieved by the movement of water through the stainless steel mesh. Specifications are as follows.

Maximum flow capacity	-	27 m^3/hr
Nominal size	-	50 mm
Nominal pressure	-	2 kg/cm^2
Size of aperture	-	120 mesh
Clean pressure drop	-	0.5 kg/cm^2 maximum.

3.1.5. Sand filter

Media filters consist of fine gravel or coarse quartz sand, of selected sizes (usually 1.5 – 4 mm in diameter) free of calcium carbonate placed in a cylindrical tank. These filters are effective in removing light suspended materials, such as algae and other organic materials, fine sand and silt particles. This type of filtration is essential for primary filtration of irrigation water from open water reservoirs, canals or reservoirs in which algae may develop.

3. 1.6. Other accessories on the main line

i. Ball valve : It was located at the upstream end of main line, to provide on - off service to the downstream sub main pipe.

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

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

iv. Plugs : These were kept to holes made to laterals by squirrels, rats etc for controlling wastage of water.

v. Start connector : These were used to connect the lateral to the sub main.

vi. Jointer : These were used to connect the two lateral pipes when the lateral pipe was end in the middle of the crop row.

vii. Rubber grommet : These were placed in holes made to the sub main for connecting lateral lines.

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

ix. Pressure gauge : For measuring pressure in the system, a pressure gauge is used.

x. Air release valve : Air release valve is fitted for the purpose of removal of entrapped air when filling pipe lines with water and remove air pockets at high points in the system. The above water distribution components were shown in Figure 3.1.

Figure 3.1 Water distribution system with sand filter, screen filter and other accessories

3.2. Automation of Irrigation

3.2.1. Scheduling of irrigation

Real time scheduling forms the basis for automation. The automation is possible with electronic circuits. Indirect way of calibrating the scheduling parameters and connecting the circuit to the starter motor forms the concept of the automation.

The automation units range from low cost to high cost (solenoid valves in drip system with central input data fed system). The general basis for automation followed by various researchers is listed below.

1. Timer based automation.
2. Soil moisture depletion based automation.
3. Leaf conductance or resistance based automation (with the help of infrared thermometry parameters).
4. Submergence water levels (like in paddy fields).
5. Water quantity based automation (like solenoid valves etc.)

The method of selection of automation depends on the purpose of crop production, extent of the farm, availability of water and electricity etc. In India, farmers from Gujarat have obtained patents for cell phone operated automation which is now being adopted in the rest of the states of the country.

In the present study NMC-NANO irrigation controller (Figure 3.2) is used for automation of irrigation. The NMC-NANO is a small economical controller designed for supply of water and nutrigation of small sized green houses, open fields and orchards.

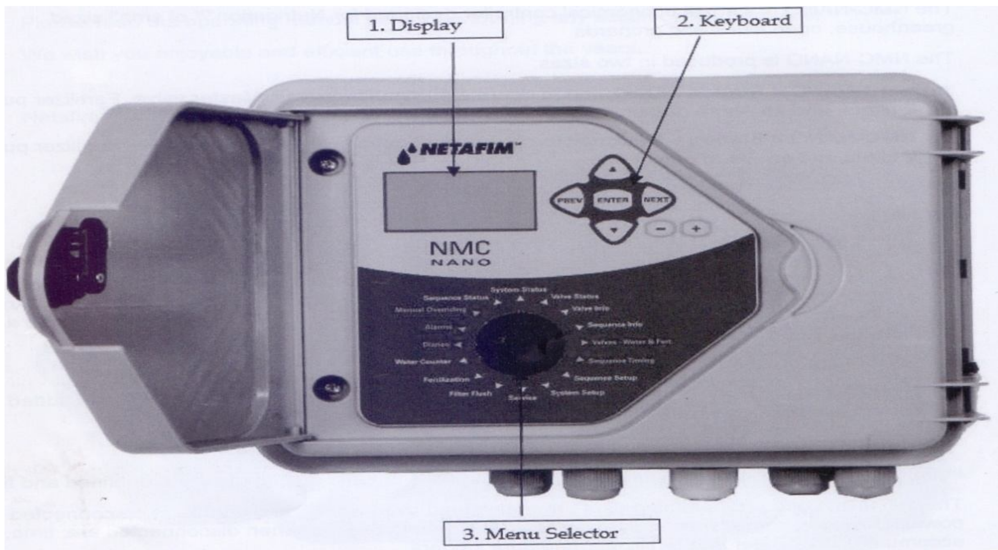

Figure 3.2 NMC NANO Irrigation Controller

The NMC-NANO is produced in two sizes:

i. NMC-NANO 4 Station : Designed to operate 4 irrigation valves, master valve, fertilizer pump, 2 filters, and an Alarm output.

ii. NMC-NANO 8 Station : Designed to operate 8 irrigation valves, master valve, fertilizer pump, 2 filters, and an Alarm output.

The NMC- NANO is manufactured in two configurations:

i. NMC-NANO DC:

The controller operates 2 or 3 wires 12V DC latching solenoids. The controller is operated by 4 * 1.5 volt batteries (installed inside the controller casing) or an external power supply of 12 V DC – disposable dry battery or rechargeable battery of 5-7 Ampere hours. Using the rechargeable battery requires the use of an adequate power supply with an output of 13.8 volts or a solar panel of 5 watts.

ii. NMC-NANO AC:

Operated by standard socket of 220V or 110V. If necessary, protection cards can be added for controller's inputs and outputs. The controller operates solenoids of 24V Alternate Current (AC) type.

In both of the controller configurations, the controller outputs and inputs are predefined and fixed.

The definitions and programming data are maintained even when the controller is disconnected from power. However, some types of data are lost. The data that is lost when disconnected are: time, date, accumulation of water and fertilizer, and data loggers.

In NMC-NANO AC, a 9V battery is connected in order to preserve all the data during power failure.

3.2.2. Description of the controller

The several operations involved in the NMC NANO irrigation controller were shown in Figure 3.3.

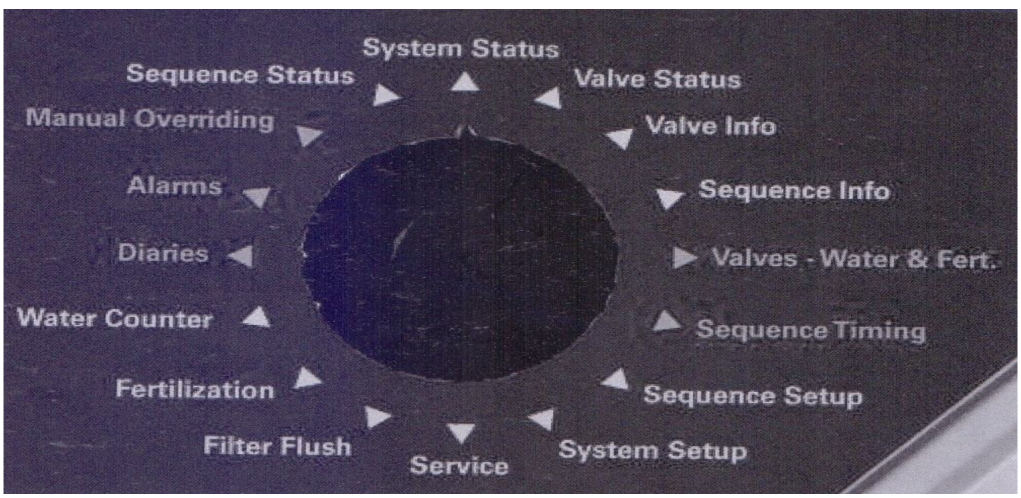

Figure 3.3 Menu selector of NMC NANO Irrigation Controller

1. Display – 5 alphanumeric display rows.

The first row shows the current position of the menu.

The next 4 rows show information and enable programming.

The display is normally off. Pressing any key or turning the "Menu Sector" turn the display on.

When the keys are untouched for more than two minutes, the display turns off.

2. Keyboard (7 keys)

The keyboard provides navigation, information and programming.

3. Menu Selector (16 positions)

The selector enables direct access to all of the controller options. It is possible to turn the selector in both directions.

4. Battery Compartment – 4 * d type 1.5 volt batteries for NMC-NANO DC.

5. Power Supply Connectors – Connect the internal batteries or external power supply.

6. Input Connectors – Connect the water meters, fertilizer meters and conditioned inputs such as pressure stat, differential pressure stat etc.

7. Output Connectors – Connect the system solenoids and alarm outputs.

8. Reset Button on CPU – Pressing this button resets the following parameters : time and date, logs and accumulations. Controller definitions and irrigation programs are not affected by the reset button. This button is to used if severe disruption of the controller activity is experienced.

3.2.3. Programming

3.2.3.1. Principles of irrigation operation

The irrigation valve

The valve is a virtual element that has a physical counterpart that controls the actual valve in the field. It also has a program that specifies the quantities of water and fertilizer. In each valve, define the water counter the valve uses and the condition input if necessary.

Sequences

A sequence is a group of valves that irrigates one after the other according to a predefined order. A sequence includes 1-8 valves. The system has the timetable for the valves it contains.

Programming always includes:

1. Programming water and fertilizer quantities for the valves **– Valves – Water & Fert.** menu.
2. Organizing the valves in the sequence **– Sequence Setup** menu.
3. Making timetable for each sequence **– Sequence Timing** menu.

3.3. Design of Low Cost Soil Moisture Sensor

3.3.1. Working principle of soil moisture sensor

The soil moisture sensor works based on the fact that water is not pure water which is non-conductor, but it is impure which is slightly conductor. As the moisture content of the soil increases, the electrical conductivity of the soil increases. The electrical conductivity of the probes can be related to the soil moisture of the soil. Usually the electrical conductivity is read manually from a multimeter.

3.3.2. Component spares required for making a low cost soil moisture sensor based on – off switch circuit for irrigation

1. Transformer
2. Diode
3. Capacitor
4. Integrated circuit (I.C)
5. Resistors
6. Transistor
7. Electromagnetic Relay
8. Led indicator
9. Pin base
10. Flexible wire
11. Connectors
12. Soldering lead
13. Paste
14. Solder iron
15. Covering box

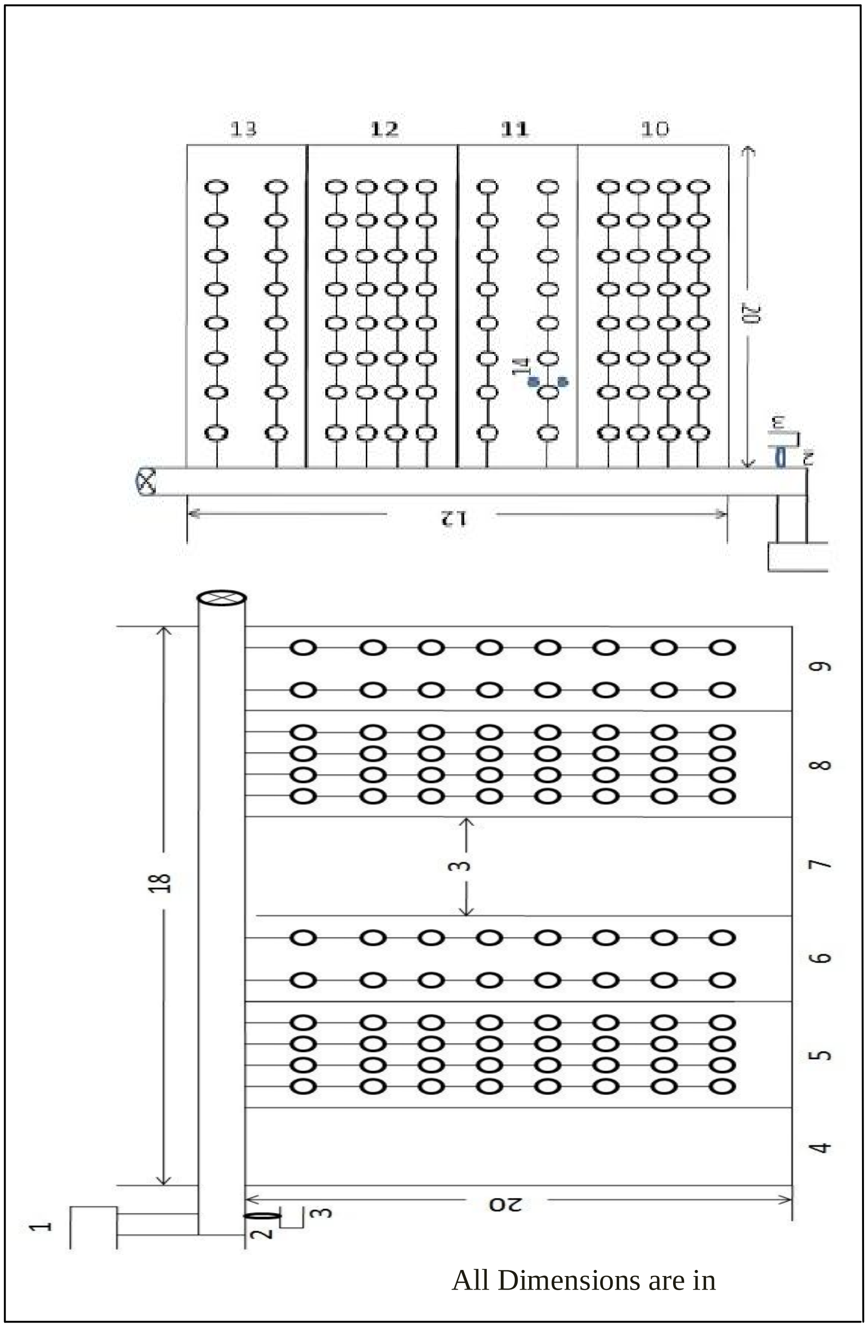

Figure 3.4 Layout of experimental field

1. Main line **2. Sub main** **3. Control valve**

4,5,6,10,11 are sub plots 1, 2, 3, 4, 5 respectively of tomato crop

7,8,9,12,13 are sub plots 1, 2, 3, 4, 5 respectively of brinjal crop

14. Soil moisture sensor

3. 4. Scheme of the experiments

Brinjal and tomato were chosen as the test crops. The plot was kept ready by adding the required farm yard manure as per the recommended dose to plant the brinjal and tomato nursery. The plot having area of 600 sq m, is divided into two main plots each having an area of 300 sq m. The main plot having area of 300 sq m, is divided into five sub plots as 3 × 20 m each to conduct experiments. As the inline drip has uniform emitter spacing at 40 cm, the same 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, each main plot is divided into five sub plots. Each sub plot is allocated to a treatment with areas as indicated above to conduct the following scheme of experiments.

Treatment 1	Crop at 50 cm row to row spacing with flood irrigation.
Treatment 2	Crop at 50 cm row to row spacing with automated drip irrigation system.
Treatment 3	Crop at 30 x 70 cm paired row spacing with automated drip irrigation system.
Treatment 4	Crop at 50 cm row to row spacing with soil moisture sensor based automated drip irrigation system.
Treatment 5	Crop at 30×70 cm paired row spacing with soil moisture sensor based automated drip irrigation system.

The plant to plant spacing is not altered and maintained the spacing of 40 cm from plant to plant as per the standard recommendation in all five sub plots.

3. 4. 1. Layout of the laterals

The inline laterals were taken from the sub main which supplies water to the crop. A distance of 50 cm from row to row was maintained in the 1, 2 & 4 sub plots and paired row spacing of 115 cm was maintained in the 3 & 5 sub plots.

3.4.2. Seedling raising

Brinjal seeds are sown in rows 5 cm apart on 6-12 mm raised nursery beds. The nursery bed is covered with plastic or straw mulch till seeds germinate. The seedlings of 4 to 6 weeks old are transplanted in a well-prepared field of which the surface soil is mixed thoroughly with FYM and a small quantity of super phosphate.

Tomato seeds are sown in well-prepared nursery beds in the month of June- July for the autumn winter crop and in November for the spring summer crop. Nursery is raised in poly house for early germination and protection of seedlings from adverse weather conditions. About 400-500 g seeds are needed for one-hectare area. The suitable height for tomato plant for transplanting is 7.5 cm to 10 cm with a good sturdy stem. Planting of tomato is done after 3-4 weeks of sowing of seeds.

3.4.3. Planting of nursery

Brinjal (bagyamathi) and tomato (marutham) nursery was planted on 12th December 2013 and 8th January 2014 respectively as per the specified spacing (Figure 3.5).

Brinjal is one of the most commonly grown vegetable crop of the country. India produces about 7.676 M t of brinjal from an area of 0.472 M ha with an average productivity of 16.3 t/ha. The brinjal producing states are Orissa, Bihar, Karnataka, West Bengal, Andhra Pradesh, Maharashtra and Uttar Pradesh. It is also a source of vitamins A, C and minerals. The brinjal (*Solanum melongena L.*) plant belongs to the family Solanaceae. Brinjal requires a long warm growing season. Daily mean temperature in the range of 13^0 C to 21^0 C is favourable for its successful production. Special care is required to protect the crop from frost. A well-drained fertile soil is desirable for the brinjal crop. It is a hardy plant and may be grown on different soils. However, it grows best on soils with silt loam and clay loam texture. Sandy or sandy loam soil is preferred for the early crop. The duration of brinjal crop is 130 days. The crop requires adequate moisture during the initial 70 days of its growing season. It can withstand drought in the later part of the growing season. Drip irrigation is ideal for the irrigation of brinjal crop. The daily water requirement of one plant is 0.75 liter at the initial growth stage and 3.25 liters at the peak growth stage.

Tomato is one of the most important protective food crops of India. It is grown in 0.458 M ha area with 7.277 M t production and 15.9 t/ha productivity. The major tomato producing states are Bihar, Karnataka, Uttar Pradesh, Orissa, Andhra Pradesh, Maharashtra, Madhya Pradesh and West Bengal. Tomato (*Lycopersicon esculentum L.*) plant belongs to the family Solanaceae. The tomato crop is cultivated during winter and summer seasons. The crop cannot withstand severe frost. It grows well under an average monthly temperature range of 21^0 C to 23^0 C but commercially it may be grown at temperatures ranging from 18^0 C to 27^0 C. Temperature and light intensity affect the fruit-set, pigmentation and nutritive value of the fruits. The best soil for tomato is a fertile loam soil with more sand in the surface layer, and clay in the sub-surface layers. The most favourable range of soil pH is 6.0–7.0. the duration of tomato crop is 135 days. Tomato plants require adequate moisture throughout their growth period. Drip irrigation is most appropriate to maintain uniform moisture supply. First irrigation is provided soon after the seedlings are transplanted. Daily irrigation is necessary when plants are small. Erratic moisture conditions may cause radial and concentric cracking on fruits. A period of drought followed by a sudden heavy watering during the fruiting period may cause cracking of fruits. The minimum and maximum daily water requirement varies from 0.45 l/plant during the initial growth stage to 1.15 l/plant during the peak growth stage. Irrigation interval of 2 to 3 days is generally recommended with drip irrigation.

Figure 3.5 Manual plantation of nursery

3.5. Preplanting, intercultural and plant protection measures:

Initially at the time of preparation of the field, farm yard manure of 200 kg was applied in the experimental site and rotavated to mix with soil thoroughly. During the crop growth period, fertilizers, insecticides and pesticides were applied according to recommended doses. The fertilizers were applied manually through placement method at the required stages of crop growth at the required stages of crop growth.

Figure 3.6 Manual application of fertilizer

3.5.1. Application of fertilizers

Ammonium Sulphate was applied in two stages viz. development stage and fruit bearing stage at the rate of 2.5 kg per plot (the recommended dose of 104 kg/ha).

Also, for enhancing the crop growth, 20-20-20 (N-P-K granules–water insoluble) fertilizer was manually applied at the stages of 20 days and 40 days after planting at the rate of 2.5 kg per plot (the recommended dose of 104 kg/ha).

During the process of manual application of fertilizer, approximately 3 to 5 g of fertilizer at each plant was placed by dibbling method at a depth of 2 cm below the soil surface and afterwards, it was covered with soil (Figure 3.6). The time interval of 10 days was maintained between the application of different fertilizers used for enhancing the growth of the crop.

To control soil born diseases and to improve growth of the crop, neem cake in powdered form was also applied twice to all the plots at the crop growth stages of 20 and 40 days after sowing at the rate of 2.5 kg per plot (the recommended dose of 104 kg/ha).

3.5.2. Application of insecticides and pesticides

In the first week of January 2013, i.e., after 20 DAP of brinjal crop growth, the plants leaves were observed with some brown patches. It was suggested by a Entomology subject matter specialist to apply Monocrotophos the rate of 3 ml/lt. Accordingly 15 liters of water has been taken and the Monocrotophos at the specified rate was added and applied with a hand sprayer in all the plots (Figure 3.7).

Figure 3.7 Application of pesticide using knapsack sprayer

After 40 DAP, the insect damage was observed and to control the same, Inspector, Chlorpyriphos and Cypermethrin were applied at the rate of 3 ml/lt with a 15 lt capacity hand sprayer on the crop in all the plots at an interval of 5 days. To improve the crop growth, spraying Insta and Sri Gold were also followed from which, it was observed that the vegetative growth of the crop was enhanced.

3.5.3. Weed Control Measures

Weed growth was observed too much during the crop growth period. Manual weeding process was initiated by using hand tools, spade and rake. Weeding was effectively done thrice at the gap of two weeks during the crop growth period (Figure 3.8).

Figure 3.8 Field with weeds and without weeds

3. 6. Irrigation Scheduling of the crops

For conducting experiment, it is necessary to apply water as per the water requirement of crop in micro irrigation system. The water requirement of crop is based on the Evapo-transpiration of the crop. The Potential Evapo-Transpiration was estimated by using Penman-Monteith method using CROPWAT 8.0 software. This method is based on the daily data of maximum and minimum temperature, relative humidity, sun shine hours and wind velocity. For calculating Potential Evapo-transpiration, the previous three years average climatic data of December, January, February, March and April were collected from Meteorological Department located in Agricultural College Farm, Bapatla.

1. **The following equation of Penman-Monteith method is used.**

$$ET_o = \frac{0.408\Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad \text{……….} \ \mathbf{(3.1)}$$

where ET_o = reference evapotranspiration [mm day^{-1}],

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = soil heat flux density [MJ m^{-2} day^{-1}],

T = mean daily air temperature at 2 m height [°C],

u_2 = wind speed at 2 m height [m s^{-1}],

e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa],

e_s-e_a = saturation vapour pressure deficit [kPa],

Δ = slope vapour pressure curve [kPa °C^{-1}],

γ = psychrometric constant [kPa °C^{-1}].

1. **Water requirement of plant in lit/plant/day**

$$= \text{ETp} \times \text{crop factor} \times \text{Gross area per plant} \qquad \textbf{.................... (3.2)}$$

2. **By taking water application efficiency in micro irrigation as 90 % amount of water to be applied to a plant in lit./day**

$$= \frac{Water\ requirement\ of\ a\ plant}{Application\ efficiency}$$

.... (3.3)

3. **Period of irrigation:**

$$\text{Drip system operating period} = \frac{\text{Amount of water to be applied to a plant}}{Discharge\ of\ dripper}$$

.....................(3.4)

Based on the Penman-Monteith equation, equation 3.2,3.3,3.4 volume of water for brinjal and tomato crops were calculated.

3. 7. Details of observations

Data on different parameters of the experiment related to the root growth, plant height, yield response and wetting pattern of drip irrigation under different row to row spacing's and fertilizer application techniques are discussed and reported in the subsections of this section.

3. 7. 1. Height of crop

For studying the effect of plant spacing and method of irrigation applied on plant growth characteristics, 15 days interval of systematic observations from selected plants in each row were made on the height of crop as shown in the Figure 3.9 with scale. The height was measured from the ground surface to the tip of the plant.

Figure 3.9 Measurement of height of the crop

3. 7. 2. Root length and its distribution

For studying the effect of plant spacing and method of irrigation applied on root distribution, trench was made around the selected plants in each plot after the final harvest. After removing the root system from the soil, it was carefully arranged on a graph paper and root distribution was measured.

3. 7. 3. Yield of the crop

The harvest of brinjal and tomato was carried out from Febraury 2nd to March 30th, 2014. The crop yields were harvested at an interval of 4-5 days. The weight of the produce was recorded in each picking for each plot and the total yield for each plot was calculated.

3. 7. 4. Wetting Pattern

Wetting pattern in different treatments under automated drip irrigation was recorded on time basis for 4 hours with an interval of 30 min. The x_1, x_2 and y as directions *i.e*, right side of the plant, left side of the plant and root zone of the plant respectively. The depth of penetration was measured by cutting the soil beneath the dripper and the readings were measured by using scale.

Fig 3.10. Measurement of wetting pattern

3.7.5. Uniformity coefficient

Uniformity coefficient of the drip irrigation system was tested by placing the collecting cans randomly under the drippers and operated for 10 min and collected water was measured with the measuring jar. To characterise the uniformity of distribution, commonly used. Christiansen's coefficient of uniformity is calculated with the following equation.

$$Cu = 100(1 - \Sigma X/mn) \qquad \text{…………. (3.5)}$$

Where, Cu = coefficient of uniformity,

ΣX= absolute value of the deviation of the individual observation of discharge from the mean value m, and

m = mean of observations,

n = total number of observations.

3.8. Linear programming

It is the method of determining an optimum program of interdependent activities in view of available resources. The word linear implies that all relationships involved in a particular problem are linear. The term programming refers to the process of determining a particular program or plan of action.

Linear programming (LP) or linear optimization is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. Linear programming is a specific case of mathematical programming (mathematical optimization).

3.8.1. Formulation of a LP Model

1. Identify the decision variables and express them in algebraic symbols.
2. Identify all the constraints or limitations and express as equations.
3. Identify the Objective Function and express it as a linear function.

3.8.2. General Mathematical Formulation of LPP

Optimize (Maximize or Minimize)

$Z = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n$

Subject to:

$a_{11} x_1 + a_{12} x_2 + \ldots + a_{1n} x_n$ (<=, =, >=) b_1

$a_{21} x_1 + a_{22} x_2 + \ldots + a_{2n} x_n$ (<=, =, >=) b_2

.

.

$a_{m1} x_1 + a_{m2} x_2 + \ldots + a_{mn} x_n$ (<=, =, >=) b_m

and x1, x2, …xn >=0

The above formulation may also be expressed with the following notations:

Optimize (Maximize or Minimize) $z = \Sigma c_j x_j$ for j = 1,2,............n

Subject to:

$\Sigma a_{ij} x_j$ (<=, =, >=) b_i ; for j = 1,2,…… ..n, i = 1,2, ………m

(Constraints)

and x_j>=0 ; j= 1, 2, ……..n

(Non negativity restrictions).

3.8.3. Steps for Graphical Solution

1. Define the problem mathematically.
2. Graph by constraints by treating each inequality as equality.
3. Locate the feasible region and the corner points.
4. Find out the value of objective function at these points.
5. Find out the optimal solution and the optimal value of objective function.

LP model for brinjal and tomato crops were formulated for optimizing the water supplies and maximizing the profit. The objective function is formulated by knowing the contribution of brinjal and tomato crop towards the profit. The constraints are formulated by considering the water supplied to crops and power consumption to supply the required amount of water.

3.9. Statistical Analysis

It is a science which deals with collection, tabulation, analysis and interpretation of data. In the present study completely randomized block design (CRBD) was used for the analysis of collected data.

When the treatments are arranged randomly over the whole experimental area when it is homogeneous, the design is called completely randomized design. It is used in lab experiments, pot culture experiments, green house experiments, polyhouse etc. where the entire experimental area is homogeneous. It is the simplest of all designs.

3.10. Economics of Automated Drip System and Low Cost Soil Moisture Sensor

The cost economics of automated drip system and low cost soil moisture sensor were analysed from the data collected which includes the initial cost of the system components and costs of electrical cables and accessories.

3.10.1. Depreciation

Depreciation is defined as the value of an asset over its useful life. How depreciation is calculated determines how much of a depreciation deduction you can take in any one year, so it is important to understand the methods of calculating depreciation. Depreciation is calculated by using formula as indicated below.

$$D = \frac{C-S}{10} \times I \qquad \textbf{(3.6)}$$

Chapter - IV

RESULTS AND DISCUSSION

This chapter deals with the results of experimental observations that have been carried out, analyzed and discussed in relation to the brinjal and tomato crop under different irrigation systems with different row to row spacings and methods of irrigation applied. The yield response, vegetative growth characteristics, wetting pattern in the soil, economics of system and optimization of water supplies are mainly discussed.

4.1. Soil Moisture Sensor

The soil moisture sensor for the automated drip irrigation system was designed and developed in field irrigation laboratory of College of Agricultural Engineering, Bapatla.

4.1.1. Development of low cost soil moisture sensor

Low cost soil moisture sensor was working using the following circuit design (Figure 4.1). The sensor works mainly on the principle of electrical conductivity.

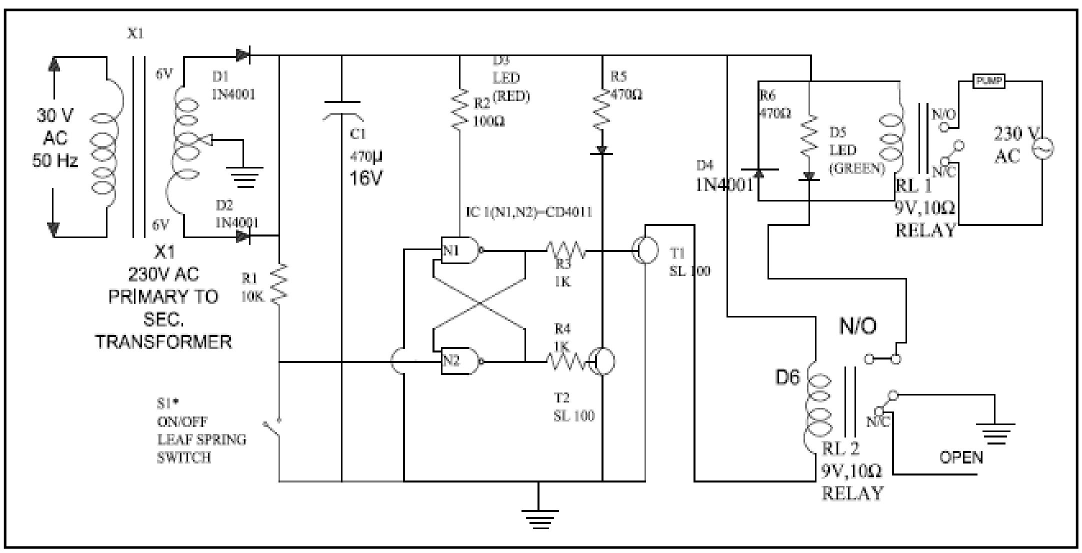

Figure 4.1 Circuit diagram of soil moisture sensor

The circuit is prepared by using a transformer, diode, capacitor, integrated circuit, resistor, transistor, electromagnetic relay etc as discussed in chapter III. The transformer acts as step down transformer reducing AC 230 V to AC 6V. Diode is a valve for current allowing it to go in only one direction. Capacitors are used to store energy by producing a charge imbalance. Integrated circuit CD4011 is the most commonly used complementary metal oxide Semiconductor (CMOS) chip. The working voltage range of the IC is 5V to 16V.Each output can deliver output current of about 10mA at 12V but this range can reduce as the power supply voltage reduces. An electromagnetic relay is used which allows a relatively small electrical voltage or current to control a larger voltage or current. The circuit diagram is drawn on a board and the circuit components are fixed on the board by soldering using solder iron and soldering lead. A plastic box is used for covering the circuit board as shown in Figure 4.2. Two aluminium strings are used as probes and the probes are placed at effective root zone depth of crops at a distance of wetted diameter of dripper.

Farmers who use electrically-operated water pumps for irrigation find it very inconvenient to switch on and switch off the pump when the water is applied, specially when they are busy. So there is plenty of water wastage as well as wastage of power (consumed by the pump). However, there is a solution to get rid of this headache by using soil moisture sensor. The circuit given above will switch off the pump when the soil moisture reaches field capacity level and switch on the pump when the soil moisture reaches 20% deficit moisture. All you have to do is switch off the power supply to the circuit as shown in the Figure.4.2 when you are relatively free. The heart of the circuit is the CMOS latch CD4001.

4.1.2. Principle of working involved in the soil moisture sensor

The basic working principle involved in the development of soil moisture sensor circuit (Figure 4.2) is electrical conductivity. As the moisture content of the soil increases, the electrical conductivity of the soil increases. The electrical conductivity of the probes can be related to the soil moisture of the soil. Usually the electrical conductivity is read manually from a multimeter (Figure 4.3).

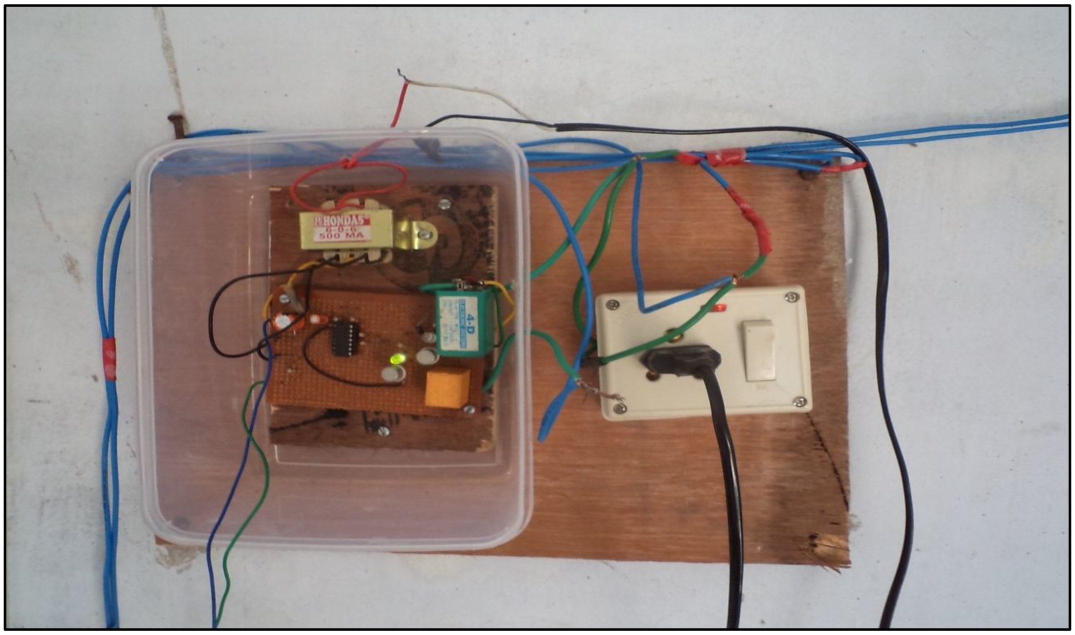

Figure 4.2 Circuit board of soil moisture sensor

4.1.3. Calibration of soil moisture sensor

In order to determine the relationship between the sensor output voltage and soil moisture, an experiment was carried out for finding the soil moisture content using oven drying method by collecting the soil samples at different moisture levels. A digital multimeter as shown in Figure 4.3 was used for measuring sensor output voltage. When testing the voltage using multimeter connect the red test lead to “V Ω Ma” jack and black test lead to “COM” jack. Figure 4.4 shows a plot of sensor voltages against different soil moisture samples that yielded a linear relationship between voltage and soil moisture sensor.

The gradient and intercept value from Figure 4.4 are -4.278 and 28.91 respectively. The moisture of the soil increased with a decrease in voltage value. The soil moisture sensor is calibrated to switch on the motor when soil moisture reaches field capacity and switch of the motor when soil moisture reaches 80% of field capacity.

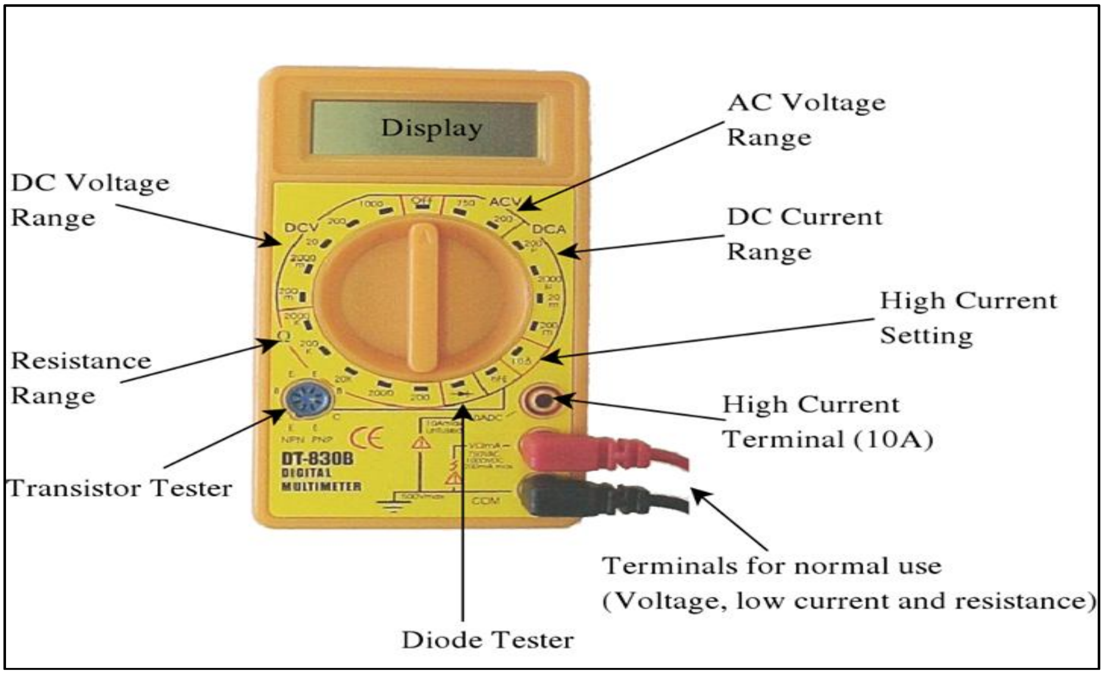

Figure 4.3 Digital multimeter

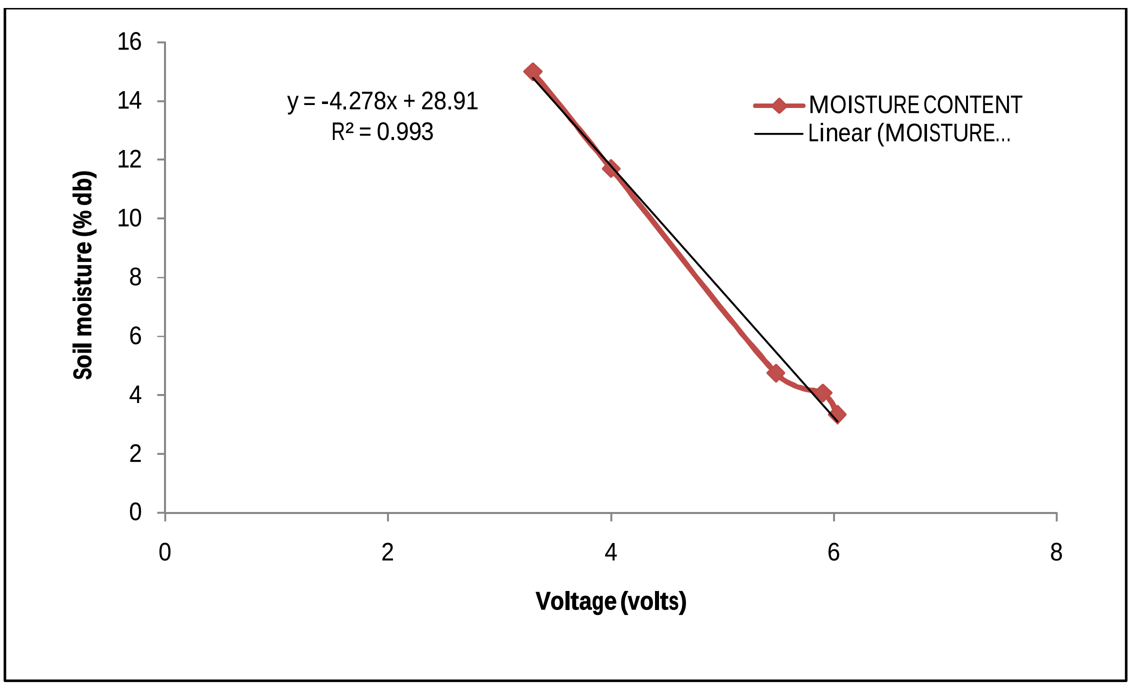

Figure 4.4 Relationship between soil moisture and sensor output voltage

4.2. Hydraulic Performance of Automated drip irrigation system

4.2.1. Wetting pattern

The surface wetted diameter and depth of percolation of water were recorded in all the four treatments during the process of application of water. The water was applied according to crop water requirement for a period of 90 min in each application, on every day during the entire crop period. The moisture front advances horizontally and vertically were recorded at an interval of every 30 min to know the spreading pattern.

The observations were shown in Figure 4.5. The wetted circle diameter increased gradually from 17 cm after application of water in the first 30 min to 34.5 cm at the end of irrigation i.e. after 90 min hours.

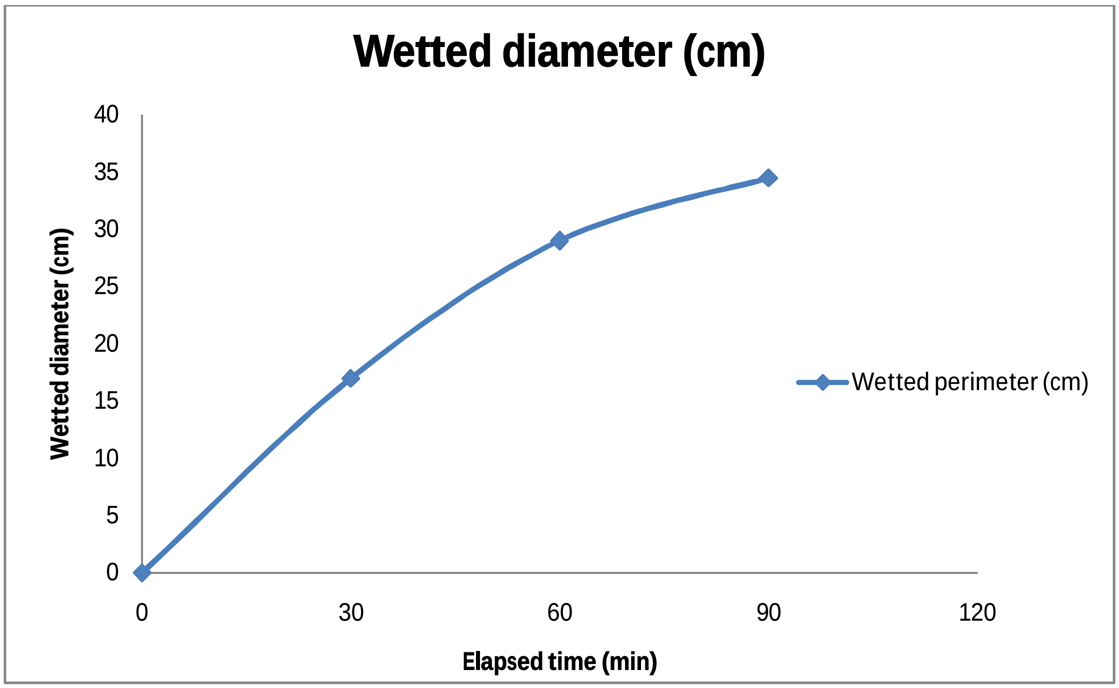

Figure 4.5 Moisture front advance in horizontal direction under point source of Application

The depth of percolation was also recorded at specified timings of 30 min, 60 min, 90 min and its wetting spread is drawn as shown in Figure 4.6 below.

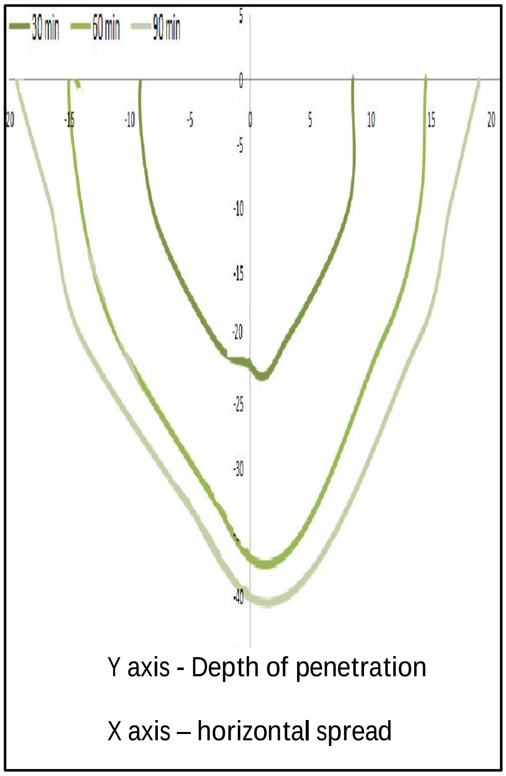

Figure 4.6 Moisture front advance in vertical direction under point source of Application

From the above Figure 4.6 it is evident that the depth of percolation increased gradually from 23 cm after 60min to 40 cm after 90 min.

4.2.2. Uniformity coefficient

The uniformity coefficient was measured by collecting discharge at each dripper by using catch cans.

Table 4.1. Amount of water collected in catch cans at each dripper of three laterals

Dripper	**Amount of water (ml)**	**Amount of water (ml)**	**Amount of water (ml)**
1.	360	355	350
2.	360	355	340
3.	355	350	350
4.	350	340	340
5.	355	350	345
6.	355	355	350
7.	350	345	340
8.	345	340	340
9.	345	340	330
Average	352.7	347.7	342.7

Table 4.2. Computation of uniformity coefficient

Frequency (1)	Observation (2)	Application * Frequency (3)	Numerical deviation (4)	Frequency * Numerical deviation (1)* (4) X
2	360	720	12.3	24.6
6	355	2130	7.3	43.8
7	350	2450	2.3	16.1
4	345	1380	2.7	10.8
7	340	2380	7.7	53.9
1	330	330	17.7	17.7
	Total	9390		166.9

m = sum of all observations/ no of observations

= 9390/27

= 347.7

Coefficient of uniformity $Cu = 100(1 - \Sigma X/mn)$

= 100(1 – 166.9/9390)

= 98.2%

4.2.3. Plant height of brinjal and tomato crop

The height of brinjal and tomato plant was measured at 15 days interval in all subplots. While recording the height of the plants, two laterals at randomly from each sub plot were chosen and also the plants were selected from the rows on either side of the lateral. The trend of the growth of the plant in relation to days of growth is indicated in Figure 4.7 & Figure 4.8 respectively.

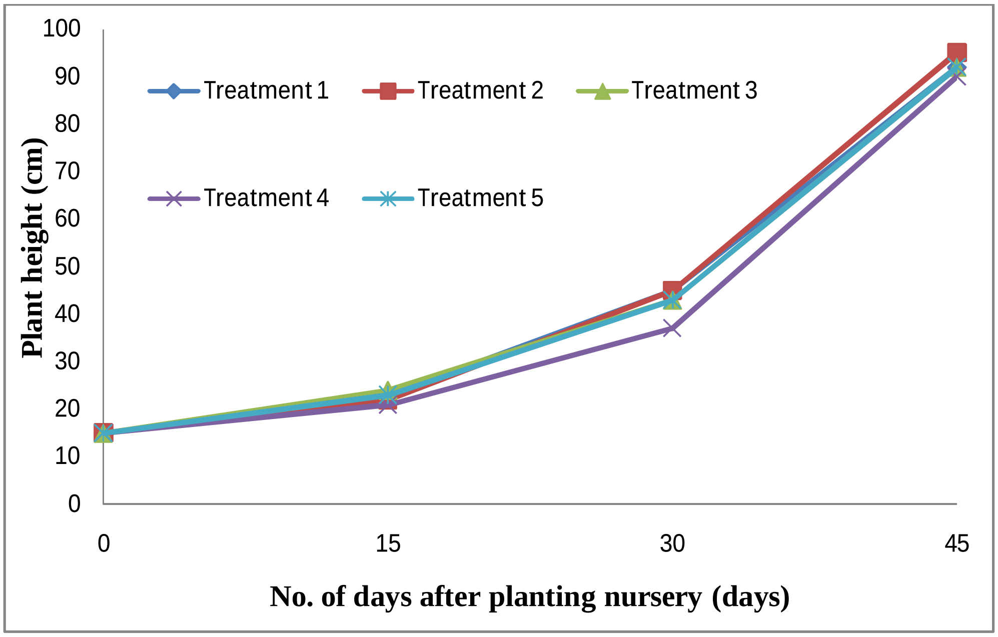

Figure 4.7. Trends to the height of the brinjal plant in different irrigation treatment plots

From the above Figure 4.7, it can be concluded that the brinjal plant height of 95 cm pertaining to sub plot II with drip irrigation was observed to be higher than the other treatments.

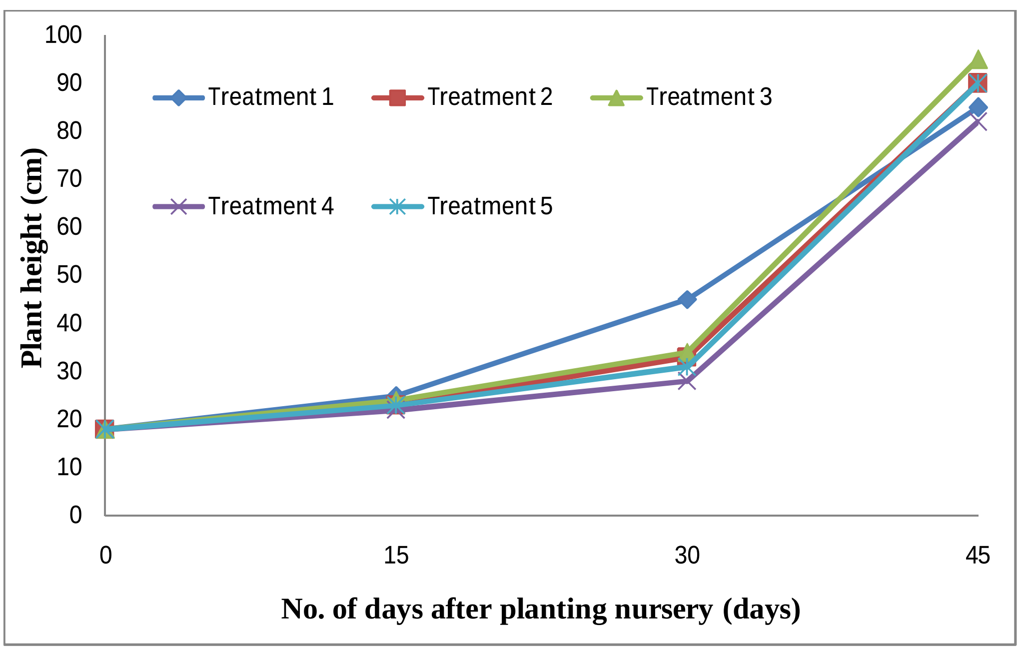

Figure 4.8. Trends to the height of the tomato plant in different irrigation treatment plots

From the above Figure 4.8, it can be concluded that the tomato plant height of 95 cm pertaining to sub plot III with drip irrigation was observed to be higher than the other treatments.

4.2.4. Yield response of brinjal and tomato in combination with three different methods of irrigation application

The total yield of brinjal in 6 pickings from February 12th to 6th March with 3-4 days interval is presented in Table 4.3. The yield in the plot by Soil moisture sensor based automatic drip irrigation with paired row spacing was observed to be higher as 8.06 t/ha compared to the yield obtained in other methods of irrigation application.

The total yield of tomato in 6 pickings from February 22nd to 16th March with 3-4 days interval is presented in Table 4.4. The yield in the plot by Soil moisture sensor based automatic drip irrigation with paired row spacing was observed to be higher as 6.52 t/ha compared to the yield obtained in other methods of irrigation application.

This higher yield can be attributed due to maintenance of field capacity level moisture in root zone depth. The root development was observed to be higher in sensor based irrigation. The water used for irrigation is saline and may have caused low yields in all the treatments of brinjal and tomato crops when compared with their average yields of 16.3 t/ha and 15.9 t/ha respectively.

Table 4.3. Total yield of brinjal under different irrigation application methods

Method of irrigation application	Yield/Plot of 60 sq. m area (kg)	Yield (kg/ha)	Yield (t/ha)
Flood irrigation	44.22	7373.30	7.37
Time based automatic Drip irrigation	44.00	7333.33	7.33
Time based automatic Drip irrigation with paired row spacing	47.76	7690.00	7.69
Soil moisture sensor based automatic drip irrigation	42.45	7075.00	7.07
Soil moisture sensor based automatic drip irrigation with paired row spacing	48.37	8061.66	8.06

Table 4.4. Total yield of tomato under different irrigation application methods

Method of irrigation application	Yield/Plot of 60 sq. m area (kg)	Yield (kg/ha)	Yield (t/ha)
Flood irrigation	36.61	6102.16	6.10
Time based automatic Drip irrigation	36.20	6034.83	6.03
Time based automatic Drip irrigation with paired row spacing	38.10	6351.16	6.35
Soil moisture sensor based automatic drip irrigation	36.42	6070.16	6.07
Soil moisture sensor based automatic drip irrigation with paired row spacing	39.13	6522.33	6.52

4.2.5. Statistical Analysis of Yield Response

The data was analysed using the standard procedure of completely randomized block design. An analysis of variance was carried out at 5% probability level. The yield response was observed for each treatment plots of brinjal and tomato. The observations were statistically analyzed for its variance and presented in Table 4.5. and Table 4.6. respectively for brinjal and tomato crops. The analysis depicted that there is a significant difference among the observations. Thus confirming that the yield response was significant throughout the experiment.

Table 4.5. ANOVA test for yield response of brinjal crop

Source	df	SS	MSS	F calculated	F tabulated
Treatments	4	6.60072	1.65018	3.56621	3.06
Error	15	6.94089	0.46273		
Total	19	13.5416			

Since F calculated ≥ F tabulated the null hypothesis is rejected that means there is a significant difference in brinjal yield response in all treatments with coefficient of variance (CV %) of 6%.

Table 4.6. ANOVA test for yield response of Tomato crop

Source	df	SS	MSS	F calculated	F tabulated
Treatments	4	1.61241	0.4031	33.9625	3.06
Error	15	0.17804	0.01187		
Total	19	1.79045			

Since F calculated ≥ F tabulated the null hypothesis is rejected that means there is a significant difference in tomato yield response in all treatments with coefficient of variance (CV %) of 1.16%.

The analysis of variance inferred that there is a significant difference in yield response at all treatment plots of brinjal and tomoto.

4.2.6. Root depth

To observe the root development, initially the soil was kept wet for about an hour and dug until the tip of the root exposed. The results are tabulated in Table 4.7. and Table 4.8. The average values were recorded in the table after considering 10 plants at randomly selected.

Table 4.7. Maximum root depth and root distribution of brinjal plant in different irrigation treatments

Treatment No	Mean of maximum root depth (cm)	Mean of maximum lateral length (cm)
1	98	12.62
2	101	13.57
3	109	15.43
4	102	14.18
5	111	15.96

From the above table values, it can be concluded that the maximum root depth of 111 cm pertains to treatment 5 was observed to be higher than the other treatments. it also confirms to higher yield as indicated previous.

Table 4.8. Maximum root depth and root distribution of tomato plant in different irrigation treatments

Treatment No	Mean of maximum root depth (cm)	Mean of maximum lateral length (cm)
1	85	10.84
2	92	11.25
3	96	12.68
4	94	12.14
5	98	13.25

From the above table values, it can be concluded that the maximum root depth of 98 cm pertains to treatment 5 was observed to be higher than the other treatments. It also confirms to higher yield as indicated earlier.

4.2.7. Water use efficiency

Water use efficiency for different treatments of brinjal crop was calculated and furnished in Figure 4.9. The results of water use efficiency stated that the treatment T5 is the best among all other treatments.

Table 4.9. Water applied, yield and water use efficiency of brinjal crop in different irrigation treatment plots

Treatments	Water applied (cm)	Yield per plot (t)	Water use efficiency (t/ha-cm)
T1	10.0	0.044	0.737
T2	7.0	0.044	1.047
T3	6.5	0.048	1.224
T4	4.8	0.042	1.474
T5	4.2	0.049	1.919

From the above table values, it can be concluded that maximum yield of 0.049 t pertains to treatment T5 with water use efficiency of 1.919 t/ha cm was observed to be higher than the other treatments.

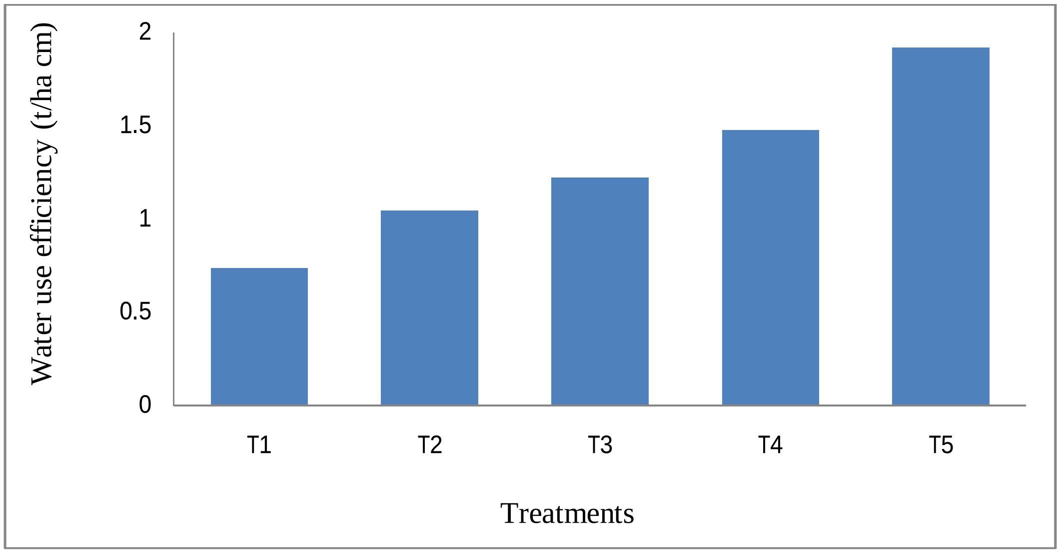

Figure 4.9. Water Use Efficiency (WUE) of the brinjal crop under the different treatments

The treatment T5 of soil moisture sensor based automated drip irrigation with paired row spacing recorded high water use efficiency followed by treatments T4, T3, T2 and T1.

Water use efficiency for different treatments of tomato crop was calculated and furnished in Fig 4.10. The results of water use efficiency stated that the treatment T5 is the best among all other treatments.

Table 4.10. Water applied, yield and water use efficiency of tomato crop in different treatment plots

Treatments	Water applied (cm)	Yield per plot (t)	Water use efficiency (t/ha-cm)
T1	10.50	0.037	0.581
T2	7.50	0.036	0.805
T3	6.25	0.038	1.016
T4	5.00	0.036	1.214
T5	4.20	0.039	1.552

From the above table values, it can be concluded that maximum yield of 0.039 t pertains to treatment T5 with water use efficiency of 1.552 t/ha-cm was observed to be higher than the other treatments.

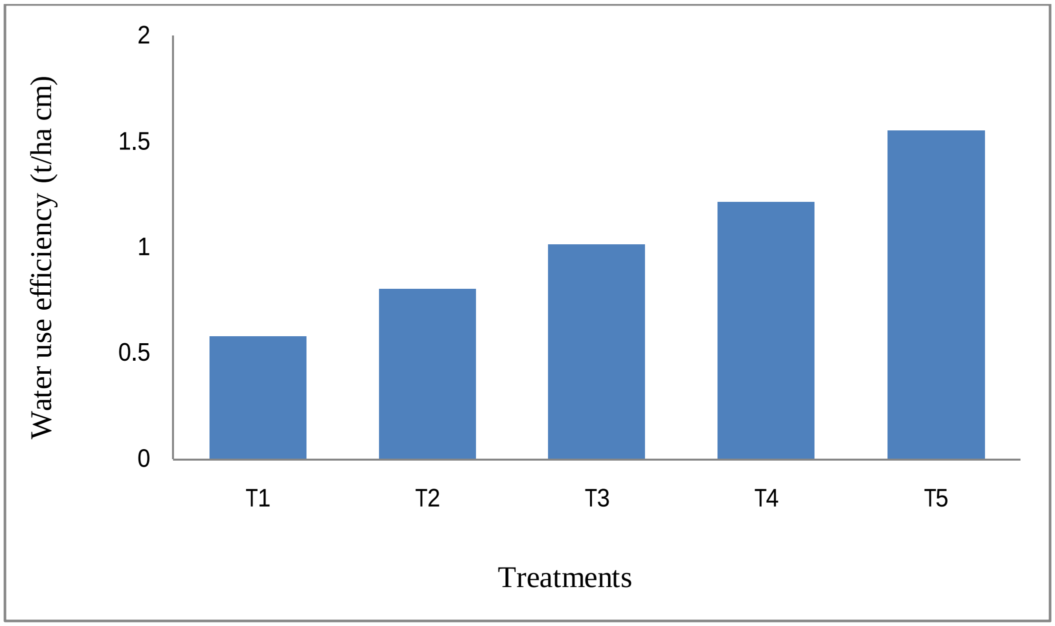

Figure 4.10. Water Use Efficiency (WUE) of the tomato crop under the different treatments

The treatment T5 with soil moisture sensor based irrigation of paired row spacing recorded high water use efficiency followed by treatments T4, T3, T2 and T1.

4.3. Economics of Automated Drip Irrigation System

Initial cost of the sensor based automatic drip irrigation system and time based automated drip irrigation system were considered.

Table 4.11. List and cost of circuit components in soil moisture sensor circuit.

Item Number	Quantity	Description	Unit cost (Rs)	Total cost (Rs)
1.	1	Transformer 6-0-6 v	50	50
2.	4	Diode 4007	2	8
3.	1	Capacitor 470/16 v	15	15
4.	1	Integrated circuit CD 4011	50	50
5.	4	Resistors	1	4
6.	1	Transistor 7806	10	10
7.	2	Electromagnetic relay 9v	70	140
8.	2	Led indicator	2	4
9.	1	Pin base	10	10
10.	1	Flexible wire packet	100	100
11.	1	Connectors or sockets plastic	50	50
12.	1	Soldering lead bundle	5	5
13.	1	Paste bottle	5	5
14.	1	Solder iron	35	35
15.	1	Covering box plastic	50	50
16.	1	Multimeter	250	250
Total cost (Rs)				786

Table 4.12. List and cost of components in NMC NANO Automation Controller

Item Number	Quantity	Description	Unit cost (Rs)	Total cost (Rs)
1.	1	NMC-NANO Controller 8 valve	38400	38400
2.	1	Single phase controller	3840	3840
3.	1	2” pressure release valve	5733.60	5733.60
4.	1	2” bermad valve	12360	12360
5.	1	Power line protector	5520	5520
6.	1	Servo stabilizer 1 KVA single phase	12500	12500
7.	1	Spike guard set	2000	2000
8.	1	Electrical cables set of 1 sq mm for field valves	1800	1800
9.	1	Electrical cables & accessories for stabilizer	5000	5000
Total cost (Rs)				87153.6

From the above Table 4.11 and Table 4.12 it is evident that soil moisture sensor based drip irrigation system is low cost when compared with NMC NANO automatic controller.

4.3.1. Cost economics of brinjal and tomato crop

The cost economics of brinjal and tomato crop analyzed by calculating the annual cost, cost of cultivation, seasonal total cost, yield produced, selling price, income from produce, benefit codst ratio, internal rate of return as shown in Table 4.13 and Table 4.14.

Table 4.13. Cost economics of brinjal crop in all five treatments

S.No	Particulars	T1	T2	T3	T4	T5
1	Annual Cost (Rs) (Depreciation, Interest, Repair & Maintenance)	0	36938.9	23288	27283	13642
2	Cost of Cultivation (Rs) (FYM, Seed, Fertilizers& Pesticides, including labor charges)	50,000	23000	23000	23000	23000
3	Seasonal total cost (1+2) Rs/ha	50000	59938.9	46288	50283	36642
4	Yield produced(t/ha)	7.37	7.33	7.69	7.07	8.06
5	Selling price(Rs/t) @Rs 15/kg	15000	15000	15000	15000	15000
6	Income from produce (4x5) Rs	110550	109950	115350	106050	120900
7	Benefit cost ratio (6/3)	2.21	1.83	2.49	2.11	3.30

From the above table values, it can be concluded that the maximum benefit cost ratio of 3.30 pertains to treatment T5 was observed to be higher than the other treatments. It also confirms to higher yield as indicated previous.

Table.4.14. Cost economics of tomato crop in all five treatments

S.No	Particulars	T1	T2	T3	T4	T5
1	Annual Cost (Rs) (Depreciation, Interest, Repair & Maintenance)	0	36938.9	23288	27283	13642
2	Cost of Cultivation (Rs) (FYM, Seed, Fertilizers& Pesticides, including labor charges)	50,000	23000	23000	23000	23000
3	Seasonal total cost (1+2) Rs/ha	50000	59938.9	46288	50283	36642
4	Yield produced(t/ha)	6.102	6.034	6.351	6.07	6.522
5	Selling price(Rs/t) @Rs 10/kg	10000	10000	10000	10000	10000
6	Income from produce (4x5) Rs	61020	60340	63510	60700	65220
7	Benefit cost ratio (6/3)	1.22	1.01	1.37	1.21	1.78

From the above table values, it can be concluded that the maximum benefit cost ratio of 1.78 pertains to treatment T5 was observed to be higher than the other treatments. It also confirms to higher yield as indicated previous.

4.4 Linear Programming Approach for Maximization of Profit and Optimal Allocation Water Supplies

A program was written on spread sheet to represent the linear programming formulation. During cropping period, the total crop water requirement was estimated to be 325.3 mm and 514 mm for brinjal and tomato crops.

The linear programming model consisting of three major components: an objective function for maximization of net return, a set of linear constraints and a set of non-negativity constraints was developed. The model was formulated to allocate water supplies among the different crops, in order to maximize the net profit.

The objective function $P = 0.084x + 0.068y$

Where P is the profit

x is litres for brinjal

y is litres for tomato

The above objective function is formed by knowing the contribution of brinjal and tomato crop towards the profit. It is the ratio of total income generated from produce to the total water applied.

$$Contribution\ of\ crop = \frac{Total\ income\ generated\ (Rs)}{Total\ water\ applied\ (lt)}$$

Contribution of brinjal crop = 1365/16200

= 0.084 Rs/lt.

Contribution of tomato crop = 1110/16500

= 0.068 Rs/lt.

4.4.1 Water availability constraint

This constraint state that the total water required for irrigating brinjal and tomato crops should not exceed the total water applied and is represented by equation.

$$x + y \leq 32700$$

4.4.2 Power availability constraint

The above power availability constraint function is formed by knowing the contribution of brinjal and tomato crop towards the total power. It is the ratio of total power utilised to the total water applied.

$$Contribution\ of\ crop = \frac{Total\ power\ utilised\ (watts)}{Total\ water\ applied\ (lt)}$$

Contribution of brinjal crop = 3251/16200

= 0.2 watt/lt.

Contribution of tomato crop = 3251/16500

= 0.197 watt/lt.

This constraint state that the total power required for irrigation of brinjal and tomato crops should not exceed the maximum total power available and is represented by equation.

$$0.2x + 0.197y \leq 3251$$

The objective function is subjected to constraints $x + y \leq 32700$ and $0.2x + 0.19y \leq 3251$

The above objective function is solved in an excel spread sheet and the decision variables are obtained for maximising the profit (i.e objective function) is shown in Table 4.15.

Table 4.15. Developed linear programming model

Crops	Brinjal	Tomato	Total
Decission variables	16255	0	
Contribution	0.084	0.068	1365.42

The LP formulation considered the water applied and the power consumed by motor as the state variables and the applied water requirement in litres as decision variables.

Thus the maximum value of P is 1365.42, and this occurs when y = 0 and x = 16255. The maximum profit of Rs.1365.42/- is obtained when only brinjal crop is irrigated alone with 16255 litres of water. The maximum profit of Rs.46060/- per acre is obtained when brinjal is irrigated with 546480 litres of water.

Chapter - V

SUMMARY AND CONCLUSIONS

The experimental field with an area of 600 sq m was selected at field irrigation laboratory, Department of Soil and Water Engineering, College of Agricultural Engineering, Bapatla. The field was divided into five sub plots for each crop with 3 × 20 m size to conduct experiments under drip irrigation with brinjal and tomato crops. The yield response of brinjal and tomato crops for different row to row spacings (50 cm row to row spacing and 30×70 cm paired row spacing) and irrigation application methods (flood irrigation, time based irrigation, soil moisture sensor based irrigation) under drip irrigation was evaluated.

Research in water management in the developed countries is progressing towards real time irrigation, decision support systems and expert systems. As the farm holdings are not large enough in India and also high cost of automation cannot be realized in India, low cost automatic irrigation is suitable to farmers, if developed and can be made as a technology, farmers can feel comfortable in view of the frequent power cuts and less power available in his farm. To apply simple electronic circuit principles in irrigation an attempt has been made to develop low cost automatic irrigation based on soil moisture.

The crop duration was for 130 and 135 days for brinjal and tomato crops respectively and the water was applied as per the crop water requirement. The fertilizers and pesticides were applied to enhance the fertility status of soil and protect the crop from diseases and insects. At every 15 days interval during the crop growth, initial observations on plant height were made from each plot. Finally, yield response for the treatments, root depth & distribution and wetting pattern were recorded in all 5 treatments and analyzed the collected data. The following are the conclusions drawn from the experimental results.

1. Development of a simple device functioning underneath the soil which can assist electronic circuit board to either switch off or switch on the motor as per the required moisture.
2. Soil moisture sensor was calibrated to switch off the motor when soil moisture reaches field capacity and switch on the motor when soil moisture reaches 80% of field capacity.
3. The wetting pattern observed as 34.5 cm diameter on surface and 40 cm depth of penetration after 90 min of irrigation. The same trend of wetting pattern was observed in all treatments.
4. The uniformity coefficient for drip irrigation was observed to be 98.2%.
5. Overall, the yield response was observed to be best in soil moisture sensor based irrigation with paired row spacing.
6. The analysis of variance inferred that there is a significant difference in yield response at all treatment plots of brinjal and tomato.
7. Maximum penetration of root depth and well developed distribution was observed in soil moisture sensor based irrigation with paired row spacing compared to other treatments in both brinjal and tomato crops.
8. The cost economics of automated time based irrigation and soil moisture sensor based irrigation was carried out and results revealed that soil moisture sensor based irrigation system is low cost with initial system cost of Rs.786/- when compared with automated time based irrigation with initial system cost of Rs.87153.6 /-
9. Maximum benefit cost ratio of 3.30 and 1.78 of brinjal and tomato crops respectively were observed in soil moisture sensor based irrigation with paired row spacing.
10. Water allocation to tomato and brinjal crops was optimized by using linear programming model for maximization of profit. The maximum profit of Rs. 1365.42/- is obtained when only brinjal crop is irrigated alone with 16255 liters of water. The maximum profit of Rs. 46060/- per acre is obtained when brinjal is irrigated with 546480 liters of water.

SUGGESTIONS FOR FUTURE WORK

1. Development of low cost soil moisture sensor by using micro controller.
2. New circuit diagrams may be developed for 3 phase motor pump set with the help of electronics experts with low cost.
3. The timer based and soil moisture based sensors can be combined for better efficiency.
4. An experiment with complete control over the environmental factors either by isolation of the replication or by using controlled environment agriculture (CEA).

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Appendix - I

Average of Five Years Meteorological data used for Research Work

Month	Minimum Temperature (°C)	Maximum Temperature (°C)	Humidity (%)	Wind speed (km/day)	Sun shine(h)	Radiation (MJ/m²/day)	Eto (mm/day)
January	17.8	29.8	79	95	11.3	22.3	3.97
February	18.6	31.3	75	104	11.6	24.6	4.63
March	21.8	33.1	79	147	12	27.1	5.5
April	25.9	34.3	78	199	12.5	28.8	6.31
May	28	38.3	68	216	12.8	29	7.49
June	27	38.3	57	233	13	29	8.07
July	25.3	34.3	71	190	12.9	28.9	6.68
August	25.4	34.3	72	190	12.6	28.6	6.55
September	25.1	34.1	78	147	12.2	27.5	6.01
October	24	32.4	81	104	11.8	25.3	5.19
November	20.9	30.8	81	130	11.4	22.7	4.4
December	18.6	30.3	79	95	11.2	21.5	3.92
Average	23.2	33.4	75	154	12.1	26.3	5.73

Appendix – II

Crop Water Requirements of Brinjal Crop

Month	Decade	Stage	Crop factor Kc	ET_c (mm/day)	ET_c (Mm/dec)	Effective rain (mm/dec)	Irrigation Requirement (mm/dec)
Oct	2	Initial	0.7	3.63	14.5	21.2	0
Oct	3	Initial	0.7	3.45	37.9	45.3	0
Nov	1	Initial	0.7	3.26	32.6	37.6	0
Nov	2	Development	0.71	3.13	31.3	31.5	0
Nov	3	Development	0.79	3.33	33.3	21	12.3
Dec	1	Development	0.87	3.53	35.3	0.1	35.2
Dec	2	Development	0.95	3.71	37.1	0	37.1
Dec	3	Mid	1.02	4	44	0	44
Jan	1	Mid	1.02	4.05	40.5	9.9	30.6
Jan	2	Mid	1.02	4.07	40.7	14.9	25.8
Jan	3	Mid	1.02	4.29	47.2	9.9	37.3
Feb	1	Late	1.01	4.46	44.6	0.1	44.5
Feb	2	Late	0.97	4.47	44.7	0	44.7
Feb	3	Late	0.93	4.6	13.8	0	13.8
				TOTAL	497.8	191.6	325.3

Appendix – III

Crop Water Requirements of Tomato Crop

Month	Decade	Stage	Crop factor Kc	ET_c (mm/day)	ET_c (Mm/dec)	Effective rain (mm/dec)	Irrigation Requirement (mm/dec)
Nov	1	Initial	0.6	2.8	2.8	3.8	2.8
Nov	2	Initial	0.6	2.64	26.4	31.5	0
Nov	3	Initial	0.6	2.54	25.4	21	4.4
Dec	1	Development	0.6	2.45	24.5	0.1	24.4
Dec	2	Development	0.69	2.68	26.8	0	26.8
Dec	3	Development	0.82	3.24	35.6	0	35.6
Jan	1	Development	0.96	3.8	38	9.9	28
Jan	2	Mid	1.09	4.32	43.2	14.9	28.3
Jan	3	Mid	1.12	4.71	51.8	9.9	41.9
Feb	1	Mid	1.12	4.95	49.5	0.1	49.4
Feb	2	Mid	1.12	5.2	52	0	52
Feb	3	Late	1.12	5.53	44.2	0	44.2
Mar	1	Late	1.1	5.73	57.3	0	57.3
Mar	2	Late	0.99	5.44	54.4	0	54.4
Mar	3	Initial	0.87	5.01	55.1	0.1	55
Apr	1	Initial	0.79	4.75	14.3	2.9	9.5
				TOTAL	601.3	94.3	514

Chapter - I

Introduction

Chapter -II

Review of Literature

Chapter -III

Material & Methods

Chapter -IV

Results & Discussion

Chapter-V

Summary & Conclusions

Literature Cited

Appendices