

**DESIGN, DEVELOPMENT AND EVALUATION OF AN
AUTOMATED DRIP IRRIGATION SYSTEM**

By

NAVNEET SHARMA

(2012-18-106)

Thesis

Submitted in partial fulfilment of the
requirement for the award of degree of

Master of Technology

in

Agricultural Engineering

(Soil and Water Engineering)



Faculty of Agricultural Engineering and Technology

Kerala Agricultural University, Vellanikkara, Thrissur

**DEPARTMENT OF LAND & WATER RESOURCES AND
CONSERVATION ENGINEERING**

**KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND
TECHNOLOGY**

TAVANUR - 679 573, MALAPPURAM

Kerala

2014

DECLARATION

I hereby declare that this thesis entitled “**Design, Development and Evaluation of an Automated Drip Irrigation System**” is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me for any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Place: Tavanur

Date: 06.06.2014

Navneet Sharma

(2012-18-106)

Dr. Abdul Hakkim, V. M.

Date: 06.06.2014

Associate Professor and Head

Department of Land & Water Resources and Conservation Engineering

Kelappaji College of Agricultural Engineering & Technology,

Tavanur, Malappuram, Kerala

CERTIFICATE

Certified that this thesis entitled “**Design, Development and Evaluation of an Automated Drip Irrigation System**” is a bonafide record of research work done independently by **Mr. Navneet Sharma (2012-18-106)**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Place: Tavanur

Dr. Abdul Hakkim, V. M.

Date: 06.06.2014

Chairman

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr. Navneet Sharma** a candidate for the degree of Master of Technology in Agricultural Engineering majoring soil and water engineering agree that the thesis entitled “**Design, Development and Evaluation of an Automated Drip Irrigation System**” may be submitted by **Mr. Navneet Sharma.**, in partial fulfilment of the requirement for the degree.

Dr. Abdul Hakkim, V. M.
(Chairman, Advisory Committee)
Associate Professor and Head
Département of LWRCE
Kelappaji College of Agricultural
Engineering & Technology, Tavanur,
Malappuram- 679573

Dr. E.K. Kurien
Associate Professor
Dept. of LWRCE,
KCAET, Tavanur
(Member)

Dr. Levan, K.V.
Associate Professor
Dept. of IDE,
KCAET, Tavanur.
(Member)

Dr. Jayan, P.R.
Associate Professor and Head
Dept. of FPME
KCAET, Tavanur.
(Member)

(EXTERNAL EXAMINER)

Acknowledgement

With profound and reverence I express my sincere gratitude to **Dr. Abdul Hakkim V. M.** Associate Professor and Head Department of LWRCE, KCAET, my guide for his valuable suggestion, abiding encouragement and acumen which served as a blessing all throughout my work. With deep sense of gratitude and due respect, I express my heartfelt thanks to **Dr.M. Sivaswami**, Dean, KCAET, Tavanur for his professional guidance and constructive suggestions offered during this study.

I engrave my deep sense of gratitude to **Dr. E.K. Kurien**, Associate Professor , Dept. of LWRCE, **Dr. Jayan, P.R.**, Associate Professor, Head Dept. of FPME and **Dr. Levan, K.V.**, Associate Professor, Department of IDE, KCAET, Tavanur, members of the Advisory Committee for their constant backing of constructive suggestions and kind support.

It gives me immense pleasure to express my deep sense of gratitude and indebtedness to **Mr. Aneesh Kumar**, Manager, Invade Technologies, Kannur for his valuable guidance, profound suggestions and constant encouragement and advice throughout the project work.

I am immensely thankful to **Dr. Sathian, K.K.** Associate Professor, **Er. Vishnu B.** and **Er. Priya G. Nair**, Assistant professors, Dept. of LWRCE, KCAET, Tavanur for giving valuable suggestions and constant backing at all stages of this research work

I express my heartfelt thanks to **Dr. Rema K.P.** Associate Professor and **Er. Anu Varughese**, Assistant Professor, Department of IDE, KCAET, Tavanur for their help and support.

It is my privilege to acknowledge the sincere help and suggestions from **Dr. Habeeburrahman, P. V**, Professor and Head, KVK, Malappuram. I am highly thankful to **Dr. Berin Pathrose**, Assistant professor, Entomology and **Dr. Krishnakumary, K.** Professor, Agronomy, KVK, Malappuram for their valuable advices throughout my research work.

I consider it is a pleasure to express my profound gratitude to **Mr. Bijo Lawrence T.**, Teaching Assistant, Department FPME, KCAET for their sincere help and co-operation for the completion of my thesis work

It gives me immense pleasure to express my deep sense of gratitude and indebtedness to **Smt. Jishachand, A.R.**, Research Associate, **Miss. Vineetha, V.** and **Smt. Sabitha, P.P.**, Senior Research Fellows and **Smt. Divya K.**, Computer Operator, Precision Farming Development Centre (PFDC), KCAET Tavanur for their valuable suggestions and support throughout the project work.

My sincere thanks to **Sri. Unnikrishnan V.M.** Laboratory Assistant, KCAET, Tavanur and to all my M.Tech and B.Tech friends for their suggestions and invaluable help during my study. I sincerely acknowledge the help and co-ordination rendered by all the labourers especially **Karthayyani K.V.**, **Sujatha P.** and **Sasi Kumar, C.**, PFDC, KCAET, Tavanur.

I express my thanks to all the **staff members of Library**, KCAET, Tavanur for their ever willing help and cooperation. I express my sincere thanks and gratitude to **Kelappaji College of Agricultural Engineering & Technology** for giving me an opportunity to undergo my P.G studies and **Kerala Agricultural University** for

approving my thesis work during my study. Above all, I bow my head to Him who had been constantly present with me during my work and for invigorating, enlightening and making me confident and optimistic throughout my life.

Navneet Sharma

CONTENTS

Chapter No.	Title	Page No.
	LIST OF TABLES	VIII
	LIST OF FIGURES	IX
	LIST OF PLATES	XI
	SYMBOLS AND ABBREVIATIONS	XII
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	6
III	MATERIALS AND METHODS	40
IV	RESULTS AND DISCUSSION	84
V	SUMMARY AND CONCLUSION	102
	REFERENCES	105
	APPENDICES	116
	ABSTRACT	119

LIST OF TABLES

Table No.	Title	Page No.
3.1	Electrical conductivity at different salt concentrations.	70
4.1	Calibration of electrical resistivity types sensors using different EC solutions.	86
4.2	Calibration of capacitor types sensor using different EC solutions.	88
4.3	Calibration data of capacitor sensor and electrical resistivity sensors for varying moisture content in sandy loam soil. (first trail).	90
4.4	Calibration data of capacitor sensor and electrical resistivity sensors for varying moisture content in Sandy loam soil. (second trail).	91
4.5	Calibration data of capacitor sensor and electrical resistivity sensors for varying moisture content in laterite soil.(first trail).	94
4.6	Calibration data of capacitor sensor and electrical resistivity sensors for varying moisture content in laterite soil.(second trail)	95

LIST OF FIGURES

Figure No.	Title	Page No.
3.1	Block diagram of irrigation control system .	41
3.2	Circuit capacitive type soil moisture sensor.	44
3.3	Controller board circuit diagram.	46
3.4	Conductivity based soil moisture sensors.	47
3.5	CA3130 operational amplifier.	48
3.6	Pinout CA3130 operational amplifier.	49
3.7	Circuit User keypad.	49
3.8	Circuit Microcontroller with LCD.	50
3.9	Microcontroller unit.	51
3.10	Pin diagram Microcontroller unit.	53
3.11	Liquid crystal display.	53
3.12	Pin diagram Liquid crystal display.	54
3.13	Motor control circuit.	54
3.14	Darlington pair.	55
3.15	Relay driver.	55
3.16	Electrical relays.	56
3.17	Pin diagram serial interface to PC.	58
3.18	MAX 232 IC.	58

3.19	Block diagram (Power supply).	59
3.20	Transformer.	59
3.21	Rectifier circuit.	60
3.22	Flow chart of the simulation program.	63
3.23	Experimental layout.	83
4.1	Particle size distribution of the soil sample 1.	85
4.2	Particle size distribution of the soil sample 2.	85
4.3	Calibration curve for electrical conductivity sensors.	87
4.4	Calibration curve for capacitor sensors.	88
4.5	Calibration curve for sensors in sandy loam soil (first trail).	91
4.6	Calibration curve for sensors in sandy loam soil (second trial).	92
4.7	Calibration curve for sensors in laterite soil (first trail).	94
4.8	Calibration curve for sensors in laterite soil (second trail).	95
4.9	Soil moisture distribution pattern 2 hr after irrigation	100
4.10	Soil moisture distribution pattern 6 hr after irrigation.	101

LIST OF PLATES

Plate No.	Title	Page No.
3.1	LCD system display and keys for user input.	65
3.2	Terminal for data loggers.	65
3.3	Calibration of moisture sensors in salt solution.	71
3.4	Pressure plate and membrane apparatus.	72
3.5	Calibration of soil moisture sensors in different soils.	74
3.6	Determination of soil moisture content by weighing machine.	75
3.7	230 volts AC input and output connecting terminals.	77
3.8	Terminal for connecting soil moisture sensors.	77
3.9	Field layout with drip irrigation system.	80
4.1	Field evaluation conductivity sensors in amaranthus crop.	99
4.2	Field evaluation capacitor sensor in amaranthus crop.	99

LIST OF ANNEXURES

No.	Title	Page No.
1.1	Particle size distribution of soil sample 1.	116
1.2	Particle size distribution of soil sample 2.	117
2	Hydrometer Analysis of soil sample 1.	118

SYMBOLS AND ABBREVIATIONS

USA	United states of America.
USAD	United states Department of agriculture.
Viz	Namely.
M ha	Million hectare.
CWC	Central water commission.
MI	Micro irrigation.
%	Percent.
DMI	Drip micro irrigation.
SMI	Sprinkler micro irrigation.
Kg/ha	Kilogram per hectare.
(mS/m).	milliSiemens per meter
COM	Communication.
PC	Personal computer.
DC	Direct current.
AC	Alternate current.
ppm	Part per million.
PFDC	Precision farming development center.
SWE	Soil water engineering.
Lph	Liter per hour.
NS	Non-significance.
Log	Logarithm.
WUE	Water use efficiency.
CD	Critical difference.

RF	Radio frequency.
GSM	Global system for mobile communication.
ADC	Analog to digital converter.
R	Resistivity types.
C	Capacitor types.
LCD	Liquid crystal display.
IC	Integrated circuit.
MS	Microsoft.
EC	Electrical conductivity.
MOWR	Ministry of water resources.
INCID	Indian national committee on irrigation and drainage.
pH	Potential of hydrogen

CHAPTER-1

INTRODUCTION

Water is a scarce resource and its rational use is compulsory. Problems derived from lack of water is likely to increase, if long term predictions on global climate changes. Meteorological records forecast significant increase in temperature and decrease in annual precipitation, which will entail reduction of the available water resources of the 21st century (Turrall et al., 2011). Industry and tourism, among other productive activities, compete for water resource for increasing profitability and productivity. Nowadays, the economic sector that most fresh water is consumes agriculture is 70% of the total resources, against the 20% used by industry and the 10% for domestic use (Anon., 2009). In addition, considering the expected increase in world population (Anon., 2008), it is essential to find urgent solutions to ensure food security. This can only be achieved by increasing the world agricultural yield and water productivity; mainly from the irrigated areas as suggested by the aforementioned data.

Water resources are found to be deteriorated in terms of quality as well as quantity. Mark *et al.* (2002) reported that by the year 2025, about 33 per cent of India's population will live under absolute water scarcity condition. The per capita water availability in terms of average utilizable water resources in the country was 6008 m³ in 1947 and is expected to dwindle to 760 m³ by 2025 (Kumar, 2003).

The irrigation sector, which currently consumes over 80 percent of the available water in India, continues to be the major water consuming sector due to the intensification of agriculture (Anon., 1990). Though India has the largest irrigated area in the world, the coverage of the irrigation is only 40 percent of the gross cropped area as of today. One of the main reasons for the low coverage of irrigation is the predominant use of flood (conventional) method of irrigation, where water use efficiency is very low. Available estimates indicate that water use efficiency under

flood method of irrigation is only about 35 to 40 percent because of huge conveyance and distribution losses (Rosegrant, 2002; Anon., 2004)

India has to increase use of land, conserve water and other natural resources to meet the demands in tune with the increasing population. Indian agriculture today faces the challenge of meeting demand for safe and quality food. Care has to be taken in protecting the natural resources and the environment in the race for food security. Agriculture intensification is commonly attained through irrigation and fertilizer application. Over irrigation may prove detrimental in terms of its demerits and fertilizer application at doses higher than recommended lead to pollution of the environment. Suitable methods which are both eco and farmer friendly have to be developed.

Micro irrigation is one of the viable options for expanding area under cultivation. The area under drip micro irrigation has increased from 15,000 ha in 1985 to 70,859 ha in 1991-92 and further to 5, 00,000 ha as on March Anon.,2003 .Similarly, the area under Sprinkler micro irrigation has increased from 0.23 M ha in 1985-86 to 1997-98 and further 1.63 M ha in 2004-05.

As the fast deterioration of irrigation potential and increasing demand for water from different sectors, all possible efforts are needed to increase the adoption of water saving technologies to avoid water scarcity in future.

Indian agriculture is dependent on the monsoons which is not a reliable source of water. Hence an automatic irrigation system is needed to predict and supplement water to the crops according to the moisture demand and soil types. Modern drip irrigation is the need of the hour because water resources are very limited and diminishing day by day. The only possible solution to this problem is providing an automated drip irrigation system. In the field of agriculture, use of proper method of irrigation is important and well known that irrigation by drip system is very economical and efficient. In the conventional drip irrigation system, the farmer has to

follow a schedule for watering, which is different for different crops. In the automatic microcontroller based drip irrigation system, irrigation will take place only when there is intense requirement of water. A variety of automated drip irrigation methods have been proposed, but most of them have been found very expensive and complicated to use. In future, each and every farmer, whether poor or uneducated, might wake up in need of such a system and therefore the proposed applications targeting an automatic irrigation system with minimum cost, time and through human computer interaction.

A more rational approach for optimizing irrigation is the use of automatic irrigation controllers. The major factor behind automatic control is the use of feedback. Feedback is a mechanism, process or signal that is looped back to control a system within itself. In the field of automatic irrigation, measurements of soil, plant and atmosphere variables related to the plant water status can provide the information of the consequences of previous actions to calculate the next irrigation dose.

Automation in irrigation management refers to those innovations which partially or fully replace manual intervention from watering operations. Larger numbers of experiments have been carried out on automation in irrigation at various level during last two decades. However, the concept of automation in irrigation water management is relatively newer in India. Automation in micro-irrigation system is gaining momentum slowly in India. This is mainly due to less labour dependency, smooth operation during day and night hours and energy savings.

Recently, technological advances have been made in soil water sensors for efficient and automation operation of irrigation system by which exact quantity of required water can be supplied to the crop. Automation soil water sensor-based irrigation seeks to maintain a desired soil water range in the root zone that is optimal

for plant growth. This types of system adapts the amount of water applied according to plant needs and soil conditions throughout the season.

Once the general strategy is defined, depending on the feedback of the sensors the irrigation decision are made and necessary action is carried out. These types of sensors rely on the conductive property of moisture and consists of at least two electrode inserted into the soil and a means to measure the resistance, conductivity and capacitance between these electrodes. The resistance and conductivity property of soils changes with its chemical composition. Soil is properties such as salinity and acidity greatly affect resistive and conductive properties.

In the last two decades, with the proliferation of powerful low cost microprocessors 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 input, increased production, reduced losses and man power and finally increase farmer's net income.

Presently different types of soil moisture deficit sensors are available for application in the lab as well as in the field. However these sensors need to be appraised not for their performance, but also for their economic viability, with particular reference to micro irrigation system. In field condition, in addition to soil moisture, the nutrients and other salts present in the rhizosphere may also influence the performance of sensors. Hence the sensors are to be evaluated for their compatibility to the corresponding environment of irrigation.

Automated irrigation is getting popular in India due to acute labour shortage condition. Measuring the soil moisture, collection and interpretation of the data are essential in order to convert the soil moisture information into practical irrigation decisions. One way of collecting the soil moisture data in the field is by fixing sensors at various location in the field and observe their electrical resistance and capacitance

for recording the relative soil moisture. There is a need for low cost logging for information systems and automatic controls in developing countries like India, China and Brazil. Appropriate low cost technology has to be developed to facilitate high water use efficiency and to enhance the crop productivity.

The present study aims to automate the irrigation by measuring moisture levels in the field and irrigating the field based on the moisture content. 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. Hence it is suggested to replace the imported components with the following objective locally designed gadgets.

With these are in view, a study was conducted to design and develop an automated irrigation control system with following specific objectives:

- To assess the compatibility of different types of soil moisture sensors for automated drip irrigation system.
- To design and develop a simple, portable automated system for drip irrigation.
- To evaluate the performance of the developed automated drip irrigation system under sensor based on irrigation scheduling for red amaranthus.

CHAPTER- 2

RIVIEW OF LITERATURE

Sensors for soil moisture monitoring have been used for various natural resource management practices, such as research on crop yield, watershed management, environment monitoring, precision agriculture and irrigation scheduling. One such application, which forms the focus of this research, is the role of electrical sensor in irrigation scheduling. By knowing the soil moisture content agricultural producers can make timely decision of when to start and when to stop water application, so as to optimize water use and produce a good quality crop (Hanson *et al.*, 2000). Furthermore, scheduling irrigation is important for environment quality management by reducing chemical percolation and nutrient loss in the soil, and in achieving crop-specific water requirement, which would help the irrigators (Leib *et al.*, 2002)

In innovative agriculture, many instruments and methods have been used to monitor and measure soil moisture. Tensiometer, resistance blocks, gravimetric methods and granular matrix sensors have been commonly used for many decades and will continue to be widely applied in irrigation scheduling (Leib *et al.*, 2002). These irrigation management techniques and instruments vary with respect to their accuracy, labour intensity, cost and simplicity of use. Previously many studies have been conducted to evaluate soil water device both qualitatively and quantitatively in respect to setup requirement, maintenance, initial cost, accuracy and data interpretation. At the same time, sensors industry coupled with rapidly advancing computer technology has resulted in variety of new sensors for irrigation scheduling. The newly-designed sensors monitor soil moisture content continuously and on a real-time basis.

In particular the timing and amount of irrigation and important factors for efficient on-farm water management. Scientific irrigation scheduling (SIS) is distinct in using crop evaporation and transpiration data, as well as soil moisture based sensor

technologies to precisely calculate when and how much to irrigate. This technology, if incorporated into commercial farm practices would result in timely and efficient water management (Leib *et al.*, 2002). For both field and high tunnel grown crops, daily growing season irrigation decision must consider several factors simultaneously: available soil moisture, weather, plant developmental stage and air or soil temperature. Given that these factors change with time, irrigation scheduling decisions require a regular assessment of soil moisture at different soil depths to complement a grower's subsequent water application to the field.

Today in commercial agriculture, technology plays an important role in different sectors of farm management; in particular soil moisture sensor technologies have proven to be efficient in helping corporate growers manage irrigation. Here, Time Domain Reflectometer (TDR) based soil sensors have been valuable in irrigation management, especially in the cultivation of crops with requirements for larger and timely water application (Jeffrey, 2004). Irrigation managers traditionally used simple thumb rules for decision making, typically based on depletion of available soil water. Recently research has proven that in high value crops such as intensively managed strawberries, thumb-rule is not sufficiently accurate method for making irrigation decisions (Bierman, 2005). Management allowable depletion (MAD), the percentage of available soil water content that can be withdrawn from the soil before the crop is subject to yield affecting stress, has been used to develop recommendations based on irrigation methods, crop stage, and climatic variability (Brace Center for Water Resources Management, 2008).

2.1 Approaches of measuring soil moisture

Soil moisture is the fundamental measurable parameter for making irrigation management decision. Different methods have been used to estimate soil moisture at particular soil depth in relation to the crop rooting depth (Charlesworth, 2005). These measurement methods can be classified into direct (gravimetric) and indirect (i.e. soil moisture sensor technologies). The installation of a sensor at particular location is the key factor in obtaining reliable soil moisture reading. In addition to selection of an appropriate site in the field, placement of the sensor with respect to irrigation lines and crop is an important criterion to consider when using this technology.

2.1.1 Gravimetric methods

The most extensively adopted and frequently used direct method of soil moisture measurement involves removing soil moisture by heating the soil sample at 105°C. The accuracy of this method depends on the accuracy of weighing. However, these errors are negligible in relation to soil variability in the field. (Campbell and Mulla, 1990). The moisture content can be expressed in terms of percent water by volume or centimeters of water per meter depth of soil. This technique is cost effective, easy and accurate, but it is labor and time intensive, destructive and difficult to use with rocky soils. The use of the gravimetric method is intricate with heterogeneous soil profiles.

While this method is fairly accurate there are practical issues which may prevent its use for scheduling irrigation. Besides being very time and labor intensive, it requires repeated disturbance of the soil, equipment and at least 24 hours after sampling to obtain results. While gravimetric soil moisture content measurement only requires auger sampling, volumetric soil content requires the use of sampling cylinders of known volume to calculate soil bulk density.

2.1.2 Indirect methods

Indirect water content measurement requires the installation of instrumentation and soil moisture sensing in the soil profile. These methods can be broadly categorized according to the principle involved: soil dielectric properties or soil suction pressure (i.e., soil matric potential) both of which vary with the wetness or dryness of the soil. The earliest soil moisture sensors were analog soil tensiometers, which displayed soil matric potential, or soil tension according to the moisture content of soil. Their ease of use and low cost led to their wide adoption by growers and they remain among the most widely used soil moisture sensors (Campbell and Mulla, 1990).

2.1.2.1 Soil dielectric properties

One method for indirect measurement of soil moisture employs the dielectric constant of soil (K_a). For dry soil, $K_a < 10$; for air, $K_a = 1.0$, while for water $K_a = 80$ (Fares and Polyakov, 2006). This content can be estimated by either time domain reflectometry (TDR) or frequency domain reflectometry (FDR). As soil moisture and hence the K_a increases, the time for an electromagnetic wave pulse to travel from one electrode to another and reflect back through the soil increases. Thus, for a given electrode spacing, depth and orientation (usually parallel and roughly 0.05 m apart), for measuring a pulse's travel time in a soil at different gravimetrically measured moisture content allows one to develop a linear or quadratic relationship between the travel time and soil moisture content (Prichard *et al.*, 2004). In the TDR methods, the sensor consists of two or more parallel rods installed on the soil at a particular depth and in a particular orientation. A pulse is emitted and travel time is measured, which is then converted into soil moisture readings. In the FDR method, the capacitance or dielectric permittivity is measured using two electrodes that are separated by a dielectric material (i.e., a material which is a poor conductor). This principle is used in capacitance probes, where an oscillator applies set frequency in range of 50 to 150 MHz to the

electrodes. These electrodes then produce a resonating frequency, which is smaller as the soil is wetter (Prichard *et al.*, 2004). Hence, the output of the FDR based sensor can be defined as “the frequency response of the soil’s capacitance due to the soil moisture level” (Fares and Polyakov, 2006).

2.1.2.2 Capacitance and frequency domain reflectometry

Frequency Domain Reflectometry (FDR) is similar to TDR, but FDR provides an estimate of the soil moisture content on the basis of a variation in the frequency of a signal due to the dielectric properties of the soil (Robock *et al.*, 2000). The electrical capacitance of a capacitor that uses the soil as a dielectric depends on the soil moisture content. When the capacitor is coupled to an oscillator, forming an electrical circuit, changes in the frequency of the circuit indicate changes in the soil moisture content. The oscillator frequency is restricted within a certain range to determine the resonant frequency. This gives a measure of the water content of the soil (Munoz-Carpena *et al.*, 2004). This technique gives accurate results but requires soil specific calibration. The ambiguity in measurement of the automatic travel time of the instrument, restricted sphere of influence (about 4 cm), sensitivity to air gaps, soil salinity, temperature, bulk density and clay content limit the use of this method (Evelt, 2003; Erlingsson *et al.*, 2009).

2.1.2.3 Electrical conductivity

Morgan *et al.* (1998) determined the relationship between EC and soil volumetric water content and used this relationship to map field capacity over a field. In addition they explored the relationship between EC, pH, CEC and other soil test parameters.

Kuligod *et al.* (1999) reported that proper calibration and development of EM-38 equation could be a useful tool for quick diagnostic soil salinity surveys in country. The application of EM-38 has not picked up in India because of the cost of the instrument, its limited application in mapping of saline lands.

Hartstock *et al.* (2000) studied nature and cause of soil conductivity variability using a Veris 3100 soil electrical conductivity sensor. Soil fertility (pH, P, K, Ca, Mg and organic carbon), surface soil moisture, surface temperature, top soil thickness, depth to clay and depth to bedrock were measured on a number of points in each field. Conductivity varied with respect both space and time, but the spatial patterns in conductivity were temporally stable. EC is controlled by ionic concentration; clay, soil moisture, relationships may vary depending on the soil series, timing of data collection, and soil moisture status.

Gartly (2003) quantified the soluble salts concentration in soil and measured the electrical conductivity (EC) of either the soil solution or soil water extract. As soluble salts increase in the soil, the soil solution becomes a better conductor of electricity and EC increases.

Brevik *et al.* (2004) stated that soil temperature influence EC reading and temperature can fluctuate considerably in the upper 10 cm of the soil during a day. EC readings were taken in the horizontal and vertical dipole orientations once between 8 A.M. to 8 P.M. for four sites. Soil temperature readings were taken at four depths the same times. EM-38 reading remained steady at all four sites all 3 days. When temperature in the upper 10 cm was plotted against EC yielded low r^2 values and slopes, indicating no correlation between soil temperature in the upper 10 cm and EC values.

Ristolainen *et al.* (2005) measured soil electrical conductivity (EC) and permittivity dependent on soil water, of four fields with different soil. Temporal variations in soil electrical conductivity reflect change in soil water content and the amount of fertilizer nutrients in the soil. Field scale spatial patterns of both soil EC and permittivity remained stable over three years despite annual agricultural practices. Based on this the relationship was temporally variable and soil type and water holding

capacity especially soil water content at the time of measurement clearly were major factors contributing to soil electrical conductivity surveys.

Sudduth *et al.* (2005) studied the EC data to measure soil properties across a wide range of soil types, management practices and climatic condition. Data were collected with a non-contact, electromagnetic based EC sensor.

2.1.2.4 Soil suction

A popular method for measuring soil moisture is by monitoring soil moisture potential. The conventional tensiometer, consisting of a transparent tube with a ceramic cup has been used for many decades. The tube is filled with water and is airtight so as the water reaches equilibrium with the soil surrounding it, the suction pressure varies and this indicates the wetness or dry of the soil. The tensiometer can be replaced or can be reset by refilling the tube and placing it in the soil (Prichard *et al.*, 2004). Another indirect way of measuring tension is by measuring the electrical resistance of soil. In this measurement procedure, inexpensive, easy install and low-maintenance electrically resistant blocks are used which have a wider working range (0 to 200 kPa) than conventional tensiometers (Thompson *et al.*, 2006).

2.1.3 Soil moisture monitoring

Management strategies allow the irrigator to monitor soil and water conditions to ensure that water is delivered in the most efficient manner possible. By collecting information, farmers can make decisions about scheduling, applying the appropriate amount of water for particular crop and any system action that may be needed. Farmers have to rely on a number of factors to monitor soil moisture including temperature and humidity, crop growth stage, soil moisture, such as time domain Reflectometry (TDR) probes or tensiometers were also available to famers.

Brandelik and Hiibner (1996) developed electromagnetic measurement techniques of soil moisture. Three new sensors were used, which improved the accuracy of exiting measurement device and extend the range applications. The first one is an in-situ sensor, which evaluates soil moisture profile down to 2.5 m with a vertical resolution of 3 cm and an accuracy of 1.5 absolute volumetric water content. The second sensor measures the water content in the surface layer of the soil. Third one is a moisture sensitive cable. It is use the technique of the time domain reflectometry and frequency domain reflectometry.

Morris (2006) surveyed some low-cost soil moisture monitoring tools and methods, including new generation of sophisticated and user-friendly electronic device and explained the process of water detention by soil. The soil moisture monitors didn't tell when the irrigation is needed. We have to develop guidelines for your own crops and soil and the there is no substitute for experience, suitable observations and judgment that make someone a good farmer.

Thompson *et al.* (2007) determined lower limit values for irrigation management using continuously monitored data from volumetric soil water content (SWC) sensors. Four indices were derived from SWC data. Indices were calculated for 0-20 and 20-40 cm soil depth in four drying cycles applied to melon and to autumn and spring tomato crops. In each cycle, there were well watered and unwatered irrigation treatments.

2.2 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.

2.2.1 Campbell scientific water content reflectometer

To measure gravimetric soil moisture content or volumetric soil content, the water content reflectometer (WCR) employs the principles of time domain reflectometer to calculate the moisture within the soil. One difference between TDR

and WCR is that the measurement frequency of the WCR is generally between 15 to 45 MHz (Seyfried and Murdock, 2001), whereas for the TDR it can be as high as 1 GHz. Water content reflectometers (WCR) function along with the principles of the TDR to calculate the soil's permittivity. (Czarnomski *et al.*, 2005; Kelleners *et al.*, 2005). Two rods (sensor probes) attached to the WCR along which the electrical signal is propagated based on the capacitance of the soil in which they installed, the determination of soil permittivity and conductivity. The probes used in this study (WCR CS625, Campbell scientific inc, Logan UT) were the latest model of soil moisture sensor currently in widespread use. The WCR were permanently installed for the growing season at a depth of 0-0.3m. Soil temperature has significant effect on WCR and this effect increases with increase in the magnitude of volumetric soil moisture content.

A scatter-plot of WCR 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). 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, which was stated to be accurate for soils having an EC < 0.5 dS m^{-1} , a bulk density < 1.55 Mg m^{-3} and a clay content < 30% (Campbell Scientific, 2006). Variations in these parameters affect the soil electrical conductivity and at low frequencies, also affect soils electrical properties.

2.2.2 Gro-Point

The Gro-Point (GP) moisture sensor also operates on TDR principles, but the voltage pulse is transient in nature and not reflected by wire guides. Placement of the sensor requires a trench at a required depth and proper hand packing to avoid any air pockets. A data logger is attached to the sensors and proprietary software is used to interpret the data. The sensors are usually factory calibrated for particular soil types. The GP sensor is designed and manufactured by Environmental sensors Inc.

2.2.3 Portable field scout TDR

In Time Domain Reflectometry (TDR) the propagation velocity (v) of an electromagnetic energy pulse in the soil is determined. To determine velocity in soil, very short electrical pulses are sent through a metallic 2 or 3-rod probe. From the travel time (T) and the length of the probe (L), which has been travelled along twice, the propagation velocity $v = 2L/t$ is calculated (Worsching et al., 2006). The velocity of the pulse changes with the change in soil moisture content due to the relatively large dielectric value of water (Muñoz-Carpena, 2012). The pulse velocity in the probe is measured and correlated to the soil moisture. A lower velocity indicates a wetted soil. TDR has been used for measuring volumetric soil water content by several workers (Yuan and Drnevich, 2004). TDR is a non-destructive and relatively less labor intensive technique; the instrument used is portable, easy to install and safe to operate. This technique allows reliable measurements of volumetric water content to be made within a short time. No soil specific calibrations are required (Ferrara and Flore, 2003). This technique gives accurate results within an error limit of $\pm 1\%$ and allows continuous measurements to be obtained over the full soil moisture range (Chandler et al., 2004), along with measurements of the electrical conductivity of the soil (Robinson et al., 2003; Thomsen et al., 2007). However, the probe length influences the accuracy of moisture measurement. TDR probes are environment sensitive, thus the

measurements could be erroneous due to gaps between the soil and probe. It has limited applicability in highly saline soils.

Time domain reflectometer based sensors have different designs, of which the Field Scout (TDR 300, Spectrum Technologies Inc; 2007) is portable. The TDR 300 calculates permittivity based on the propagation time of electromagnetic wave, typically within 0.1 nano second. While for water permittivity (ϵ) is 80 (depending on temperature) for other soil constituents, such as minerals $2 < \epsilon < 5$. 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).

2.2.4 C-probe

EnviroScan system may have several FDR sensors mounted on a probe, which is then inserted into a access tube. Before installation all the sensors are normalized by taking reading in air and submerged in water. The installation requires a certified person to ensure good probe-soil contact and operation of all the mounted FDR sensors. A separate data logger is attached to download and store the data. Data transfer to a computer for interpretation requires proprietary software developed by EnviroScan. The device was designed and is produced in Australia by Sentek Environmental Technologies (<http://www.sentek.com.au>).

2.2.5 Echo probe

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 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.

2.2.6 Theta probe

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).

2.2.7 Tensiometers

This device 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 (<http://www.irrometer.com>). The same principle is used with Water Mark equipment data reading, expressed in centibars.

This technique is non-destructive and cost effective. It is capable of determining the moisture distribution under both saturated and unsaturated conditions. Long term use is possible if the equipment's maintained properly. It can provide continuous measurements of soil moisture without causing disturbance to the soil. No

complex electronics is involved and the use of ethylene glycol water solution allows tensiometers to be used in cold regions. But tensiometers have been found to be unsuitable for measurements in dry soils.

Whalley *et al.* (2001) reported unpredictable behavior of the sensors in wetter soils. They used of porous material sensors for matric potential, which were originally intended for soil drier than + 100 kPa. They have studied the design of porous material sensors of matric potential in soil and propose a hypothesis to explain this unpredictability, and suggested recommendations for a design of sensor which behave more reliably. It operate between 0 and + 60 kPa, and both the drying and wetting moisture characteristics were measured. In this sensor the porous material was a ceramic and its water content was measured with a dielectric water content sensor. The high maintenance requirements limit the use of this method in research (Dukes *et al.*, 2010).

2.2.8 Neutron probe

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. However, due to perceptions of radiation safety threat, its use has declined.

The equipment used in obtaining soil moisture content using neutron probe technology consists of a probe and an electron counting scalar 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. 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. Neutron probes yield accurate results (Muñoz-Carpena, 2012) 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. 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. The depth resolution is inadequate, making soil moisture measurements difficult.

2.2.9 Electrical resistance sensors

Soil moisture 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.

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 used to ensure firm contact with surrounding soil. The moisture data is transmitted to and stored in a data logger. These sensors read in centibars of soil tension, ranging from 0-200 kPa, and then converted to volumetric soil moisture content (McCann *et al.*, 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. The field data presents soil moisture and resistance measurements at three different sites.

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's 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 to 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 the 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 performs well and it could save nearly 20% of water compared to conventional furrow irrigation

Kolev (2005) evaluated the soil moisture content by using electrical resistance methods and soil moisture meter with gypsum blocks housing in the soil profile.

Lee *et al.* (2006) explained corrosion monitoring of steel in soil environments by thin film electrical resistance sensor having high sensitivity for corrosion rate measurement. Thin film electrical sensor could be used to measure the corrosion rate of steel embedded in soil. Using ER sensor it was possible to eliminate the effect of soil resistance on corrosion rate measurements.

Thompson *et al.* (2007) determined thresholds of soil matric potential (SMP) and available soil water content (AMC) required to prevent water limitations between irrigations for bell pepper, melon and spring and winter tomato grown in Mediterranean types greenhouses on the south-eastern coast of Spain. For the four crop 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 efficiently 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 condition had different results. Reasons for the different response were not clear, but might be involved factor such as clay type and soil salinity.

2.3 Comparison and calibration of sensors

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 without evoking bound water. This equation was tested using graphite sand mixture in which electrical conductivity varied systematically.

Evans *et al.* (1996) stated that manufacturers of most soil water measuring devices provide a calibration curve for their equipment. However, manufacturer's calibration curves were developed for general conditions and were not adequate for site-specific soil conditions. For best results, soil water measuring device should be calibrated for the major soil types in each field being irrigated. They provided step by step description of how use the gravimetric method to calibrate soil water measuring equipment. The purpose of calibration is to establish the specific relationship between

the plant available water (PAW) on a soil site with the readings of the soil water measuring device. It is important to calibrate each different type of equipment for each major soil where it will be used.

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. While only electric and electromagnetic sensors were widely used at this time. 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 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 reaffirmed their conclusion that all the devices required soil specific calibration except for the conventional TDR system 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 with 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 performance of the CS616 (Campbell scientific, Ltd., Shepsed, UK) sensor and the Aquaflex sensor were compared 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 soil the standard calibration performed better and smaller corrections were found for a sandy loam 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 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 Aquaflex 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 CropSense soil moisture probes in a drip irrigated carrot seed field to determine whether one type of sensor was more useful than other another. Watermark sensors reflect soil water potential. CropSense probe measure the volumetric water content of the soil. CropSense 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 Soil available water

The development of a proper rooting system and the uptake of the required amount of water from the soil are critical at very stage in plant growth. Too much or too little soil moisture can have direct effect on fruit production. When the soil moisture exceeds the field capacity, it causes water logging in soil and depresses oxidative has been drained by gravity (Hanson *et al.*, 2004). On the other hand, if the soil moisture drops to a level below the permanent wilting point, then the rooting system cannot extract the moisture from the soil, because the soil is too dry. The

available soil water (AW) is defined as the difference between field capacity and permanent wilting point.

2.5 Automated drip irrigation studies

Luthra *et al.* (1997) developed an auto irrigation system which monitors soil water stress at the root zone continuously and controls irrigation as per preset values of soil water tension and duration of irrigation. The magnetic contacts and PVC material used in the construction of the gate valve prevent corrosion and sparking. The low power requirement of the system can be easily met through a 12 V storage battery in float with a solar panel. The auto pumping unit ensures the storage of water in an overhead tank for the supply of irrigation water to the drip system. This indigenously developed low cost auto irrigation system ensures better returns to Indian farmers through considerable savings in labour and other farm inputs.

Dukes *et al.* (2003) conducted study on bell pepper (*Capsicum annuum* L.) 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 deep within the crop root zone to maintain soil moisture at a set level. The two sensor based irrigation treatment with the largest seasonal irrigation volume resulted in similar yields the two as 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/m³ for the sensor based treatments while those of daily treatments ranged from 703 to 1612 kg/ha/m³. Sensor based irrigation treatments resulted in significantly higher soil volumetric moisture levels at 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. The highest bell pepper yields were produced with typical manual irrigation of once or twice daily (M2). The next highest yields were produced by M3,

M4, A2, and A3. A2 and A3 are automatic irrigation treatments used approximately 50% less water than the M3 and M4 treatments with similar yield results. Water use efficiency was highest on the A2 and A3 (automatically irrigated).

Carpena and Dukes (2005) conducted studies on recent advances in soil water sensors which can make the commercial use of this technology possible to automate irrigation management for vegetable production. However, research indicates that different sensor types may not perform alike under all conditions. Reductions in water use range as high as 70% compared to farmer practices with no negative impact on crop yields. Due to the soil's natural variability, location and number of soil water sensors may be crucial and future work should include optimization of sensor placement. Additional research should also include techniques to overcome the limitation of need for a soil specific calibration.

Carpena *et al.* (2005) developed and tested low-volume/high frequency (LVHF) soil moisture based drip irrigation system on shallow sandy soil in a commercial tomato (*Lycopersicon esculentum*) farm in southern Florida. Four treatments were made by interfacing two types of soil moisture sensors (switching tensiometers and granular matrix sensors with control modules) set at two moisture points (wet = 10 kPa, optimal = 15 kPa) in a closed control loop with the irrigation timer programmed at the ET-100% schedule. Results showed that the six LVHF treatments reduced water use while not significantly affecting tomato yields. Switching tensiometers at the 15 kPa set point performed the best (up to 73% reduction in water use when compared to the control, 50% with respect to ET-100%). The results show that water use below historical ET levels can be obtained without sacrificing yield by keeping the root zone moisture at controlled levels with the soil-moisture based system. Routine maintenance was critical for reliable operation of the switching tensiometers. Granular matrix sensor based irrigation behaved erratically and did not improve water savings compared to 100% ET, indicating that this system was not effective under the conditions of the area due to the sensor's slow response to frequent

wetting-rewetting cycles and characteristics of the interface. One year of yields for tomatoes irrigated with an automated irrigation system based on feedback from tensiometers and SMS were similar to that obtained with standard commercial irrigation scheduling practices and reduced total applied water by up to 73%. Switching tensiometers at 15 kPa performed the best.

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 or MAD) for 100% of the time during the study.

Nemali and Iersel (2006) suggested an automated irrigation system which results in leaching and runoff; our system had 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 insignificant 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 and thus the level of stress that the plant is exposed to.

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 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. Accordingly, when the amount of irrigation water applied was reduced

both percolation of water and $\text{NO}_3\text{-N}$ leaching decreased significantly. These results show that soil water based irrigation can be used as a water conservation tool and as a means to reduce $\text{NO}_3\text{-N}$ leaching below the root zone of commercial vegetable cropping systems.

Fernandez *et al.* (2008) developed one of the most innovative and promising approaches for the automation of irrigation is based on the measurement of sap flow in conductive organs of a plant. They have developed an automatic irrigation controller based on sap flow measurements. The system was used to daily irrigate mature olive trees using an irrigation dose estimated from sap flow measurements in the trunk of representative trees.

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 resulting from encountered problems resulted in a more robust system that can be installed at the beginning of the season and left alone until harvest. 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.

Javadi *et al.* (2009) developed a Fuzzy Logic Controller (FLC) prototype based on a Mamdani 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 another 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 system can save a lot of water and is very cheap to implement.

Romero *et al.* (2009) and Fernandez *et al.*, (2010) 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 be useful in reducing water losses by drainage, evaporation and runoff.

Cardenas-Lailhacar and Dukes (2010) evaluated sensors from brands Acclima, Rain Bird, Irrrometer, and Water Watcher were buried at 7–10 cm depth, on plots with common Bermuda grass [*Cynodon dactylon* (L.) Pers.]. A calibrated CH2O probe was also installed in every plot, at the same depth, to monitor soil water content continuously. When comparing the ECH2O readings with θ sensed by the SMSs, significant correlations were found for the three AcclimaRS500 (AC) systems tested, and for two of the three systems of Irrrometer Watermark 200SS/WEM (IM) and Rain Bird MS-100 (RB). Most of the SMS-based treatments bypassed the majority of the SICs during rainy periods, and allowed irrigation during the dry periods. On an average, 71% of the SICs were by passed by the SMS treatments, without detriment to the turfgrass quality. However, most of the SMSs were not found to be precision instruments, because sometimes they bypassed SICs and sometimes they did not, even when reading the same or a lower soil water content. Considering the average soil water content range of over which the different SMS treatments always allowed or always bypassed irrigation, brand AC resulted in the significantly narrowest range (1.4%) followed by RB (3.2%), suggesting that they were more consistent and precise in measuring soil water content than Water Watcher DPS-100 (WW) and IM (7.4 and 7.8%, respectively). These results are consistent with the reported water savings achieved by these SMSs in related studies.

Migliaccio *et al.* (2010) Conducted evaluation of papaya irrigation research by including key physiological and production measurements by irrigation treatment. Papaya irrigation may be managed successfully either by monitoring soil water or using historic ET values without influencing the measured physiological and production characteristics. 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.

O'Shaughnessy and Evett (2010) investigated the effect of irrigation scheduling/control method on cotton (*Gossypium hirsutum* L.) yield and water use efficiency. Methods used were automatic irrigation scheduling and control of a center pivot system, and manually scheduled irrigation to replenish soil water to field capacity. Cotton was irrigated with low energy, precision application (LEPA) drag socks in furrow dikes; three blocks were irrigated manually and three were irrigated automatically. Six replications of the manual and automatic irrigation treatments were included in the randomized block design. Manual irrigations were based on the weekly replenishment of soil–water to field capacity in the top 1.5m of the soil profile and included a fully irrigated treatment (I_{100}) and treatments receiving 67% (I_{67}) and 33% (I_{33}) of the I_{100} amount, plus a non-irrigated treatment (I^0). Automatic irrigations were triggered using a time temperature threshold (TTT) algorithm, which was designated as the I_{100} treatment and treatments receiving 67%, 33%, and 0% of that amount (I_{67} , I_{33} and I_0 , respectively). In 2007, overall mean lint yields (102.3 and 101.6 gm^{-2} , manual and automatic, respectively) were not significantly different. Similarly, yields were not significantly different across automatic and manual treatments in the same treatment level, with the exception of the I_{67} treatment where the manual treatment yields were 11% greater. In 2008, the mean yields were 70% less than those in 2007 for both methods of irrigation (30.3 and 30.9 gm^{-2} , manual and automatic, respectively) due to harsh climatic conditions at emergence and heavy rainfall and

cooler temperatures in the month of August. Yields from the automatically irrigated plots in the I_{100} and I_{67} treatments, however, were significantly greater than yields from the corresponding manually irrigated plots; though there was no significant difference between yields in the drier treatments (I_{33} and I_0) plots.

Xinjian (2011) and Zhu and Li (2011) reported that irrigation controllers which uses a combination of soil water content (SWC) and weather data to control drip irrigation. Xinjian's fuzzy logic controller measured air temperature, light intensity and SWC and was tested in vineyard's drip irrigation. The Zhu and Li's controller used air temperature, humidity, evaporation, rain and SWC measurements. They applied state space analysis methods to implement the irrigation control based on a knowledge base and an expert system rule base.

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 pic16f84 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 required time to pump water according to the irrigation programs 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. These were compared with the control treatment. The automated system maintained the soil moisture level at the desired level for the full treatment and took over irrigation events, started and stopped the irrigations throughout the entire growing season. Even though yield value was high in treatment $I_{1.0}$, the best quality parameters were obtained from $I_{0.75}$. In the deficit treatments $I_{0.50}$ and $I_{0.25}$, 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. It provided a common basis that could be configured to support different irrigation strategies and user preferences.

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, water to improve production and ultimately profit.

Romero *et al.* (2012) developed and evaluated two new methods for measuring sap flow, capable of a measurement range wider than those of most current methods, and suitable for the measurement of reverse flows. This is of great interest for the study of phenomena related to hydraulic lift in the root system of fruit trees.

Singh and Sharma (2012) reported that, through 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.

Yi-Jie Li *et al.*, (2012) conducted research under controlled conditions for irrigation scheduling of drip irrigated muskmelon based on the TDR instrument inside the plastic greenhouse. Results indicated that the vegetative development, fruit yield and quality of muskmelon can be influenced by soil water content. The experiment was carried out with irrigation levels ranging from 120.1 to 178.6 mm throughout the

season. Adequate water supply enhances vegetative growth, plant height and stem diameter with increasing the amount of applied irrigation water from I_{45} to I_{75} . In particular, the amount of irrigation water increased yield not only by increasing the mean fruit weight, but also by increasing fruit size which was performance in fruit length and diameter. Of the four irrigation thresholds set-up, the highest fruit yield (27.45 t/ha) and IWUE (153.7 kg/ha mm) were obtained from the treatment I_{75} . The most deficient irrigation water levels often prove to be the most efficient. This did not happen in the study, in which relative lower efficiency was found in the treatment which was subjected to water restrictions, which may be accounted for by the smaller production obtained. Different thresholds of soil water content were set up during the whole growth period, I_{65} (65% field capacity) was the best treatment in quality through comprehensive evaluation, but there was no significant difference between I_{65} and I_{75} . The experiment did not enable to know what the response of the actual production and quality performance would have been above the 75% of field capacity established in the treatment which received the highest amount of irrigation water. Therefore, based on growth, yield and quality of muskmelon, treatment of I_{75} would be the most appropriate thresholds for muskmelon starting irrigation by drip-irrigated during one crop season at one location.

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 at 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 *et al.* (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.

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.

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.

Zheng *et al.* (2013) studied of the two-year field experiments on responses of tomato fruit yield and quality to various SMP thresholds allowed to identify related yield and quality responses. Results of the soil water balance shown to be coherent and crop coefficients adjusted to actual conditions were successfully derived from plant density and height. The resulting Kcare appropriate to be further used to support the irrigation scheduling practice. A linear relationship was found between yields and

the seasonal ET a and the irrigation depth applied. Tomato fruit yields (total, high-quality, marketable-quality) increased with the seasonal ET a and the seasonal irrigation depth. It was found that high tomato yields could be obtained with -30 or -40 kPa, i.e., without or with just mild water stress. Higher percentages of large size fruits were obtained for no stress but differences to mild stress were not significant. Yields were significantly reduced only when $SMP < -40$ kPa. Differently, the quality of fruits was better for treatments showing moderate or mild water deficits. Thus, adopting mild water stress with SMP of -30 or -40 kPa is advisable. Water productivity was computed for high-quality and marketable-quality of fruits and their relations with related yields showed that the best results for either yields or water productivity may be achieved when irrigation depths are only 10% below the maximum irrigation depth required for maximum yields. This result corresponds to a SMP threshold close to -40 kPa; however, the threshold of -30 kPa may be used as alternative to avoid the SMP falling much below that threshold. Further research is required to assess the water deficit strategy that leads to the best economic returns.

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.

2.6 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 wetted coconut basin of 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 (Anil *et al.*, 2001) 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.

Jain *et al.* (2001) conducted studies on the response of potato under drip irrigation and plastic mulching. The results revealed that maximum water was required 1.0 V volume in irrigated treatments (11.23 cm), followed by 0.8 V level (9.39 cm)

and 0.6 V level (7.56 cm). It also showed that maximum saving of water was obtained in drip irrigated at 0.6 V level (36.66 per cent), followed by 0.8 V level (16.32 per cent).

Reddy *et al.* (2001) conducted experiment on water, nutrient and root distribution of sweet orange under drip irrigation and micro nutrient management. Soil moisture three days after basin irrigation, was 13.28 per cent in surface layer while it was 9.79 per cent with drip irrigation. Similar trend was observed at lower depths of soil. At a distance of 1 m away from drip line to a depth of 1 m, soil moisture was 10.5 per cent.

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 just below the drip emitter (0-10cm) and decreased as the distance from the water source increased.

Based on the review of the work done in the past, a soil moisture sensor was developed. The soil moisture sensor is based on the electrical conductivity offered by the soil for conducting the electricity in between the electrodes. Comparison and calibration of electrical conductivity sensors and capacitive type sensor was done and field evaluation was carried out.

CHAPTER 3

MATERIALS AND METHODS

In the present study an attempt was made to develop an automated drip irrigation system and to evaluate the performance of soil moisture sensors by using the relationship between moisture content and electrical conductivity. Material used and methodology adopted for the study are briefly discussed in this chapter.

3.1 Drip automation unit

3.1.1 Considerations

A drip automation unit for field use was developed in such way that to supply the required quantity of water for the crop at time. Sites of irrigation measurement are often remote and overall weight and configuration of automation unit are also on important parameter. Since the calibration function is dependent on soil types, response time should be short so that the whole measurement sequence shall be rapid as possible. The unit developed is to be moisture proof.

3.1.2 Components of drip automation system

The aim of optimal probe design was to obtain a representative sampling value with a robust and practical design while minimizing the EC across the probe. The soil moisture measurement is measured in terms of EC. The soil moisture sensors used for experiment were tested and calibrated for automatic scheduling the irrigation. The automation system is designed a simple, light weight and easy to handle. The components of the system are shown in Fig. 3.1.

The automation system consists of

1. Soil moisture sensor (conductivity/resistivity types)
2. Soil moisture sensor (Capacitor type)
3. User keypad
4. Electronic control board (microcontroller unit)

5. LCD display
6. Motor interface
7. RS 232 serial communication
8. PC

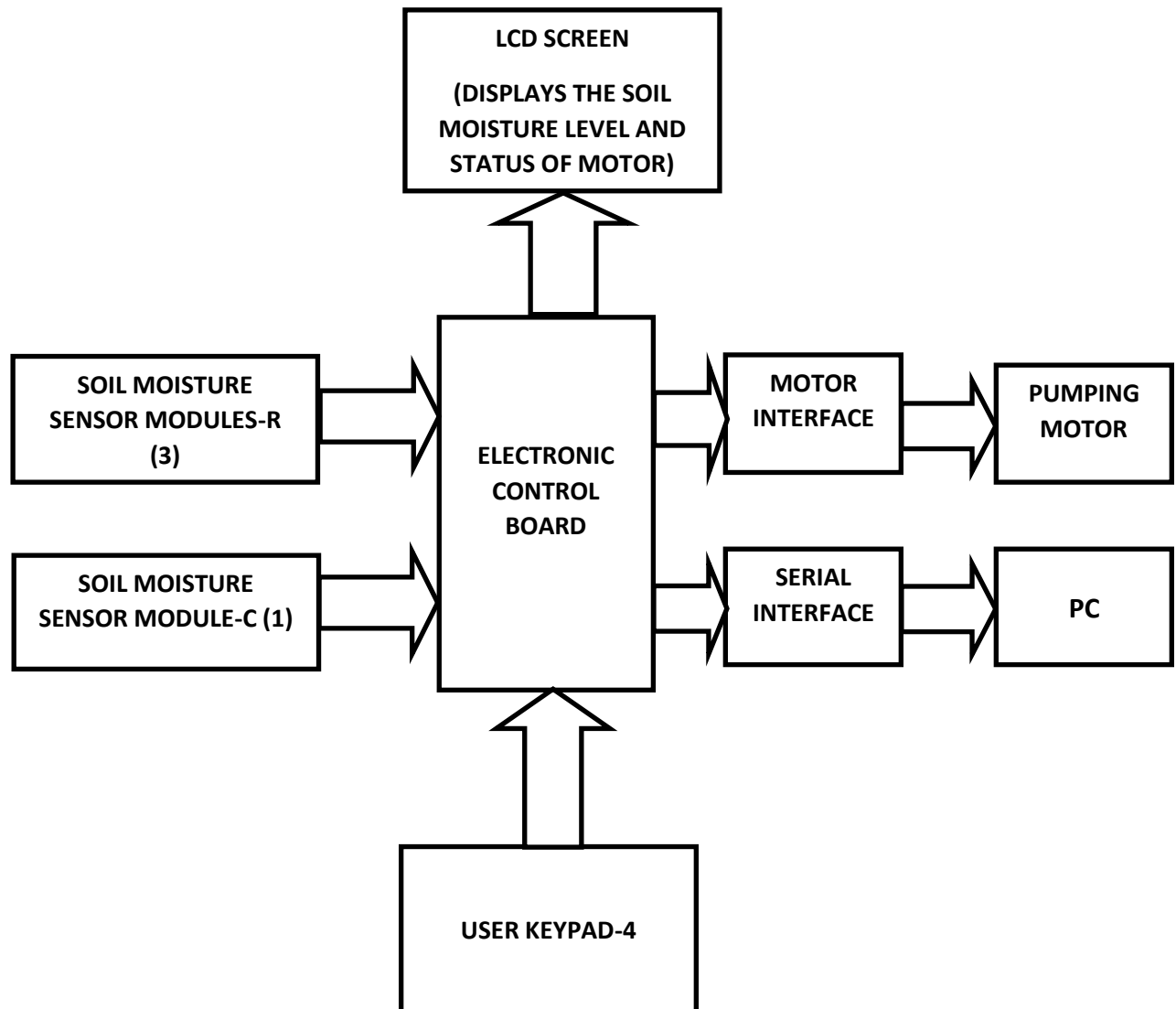


Fig. 3.1 Block diagram of irrigation control system.

3.1.2.1 Soil moisture sensor (R)

Water or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, fruit, or wood. Water content is used in a wide range of scientific and technical areas and is expressed as a ratio. Metallic probes are used for the detection of soil moisture. The conductance of soil is measured and soil moisture content is calculated.

These 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 a pull up resistors. Three 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 to the moisture content of the soil. This signal from the voltage divider arrangement is further amplified and then transfer to the microcontroller.

3.1.2.2 Soil moisture sensor (C)

A capacitor type soil moisture sensor is also included in the system. Capacitance sensors (or Dielectric sensors) use [capacitance](#) to measure the [dielectric permittivity](#) of a surrounding medium. The average value of the capacitive sensor and the three conductivity type moisture sensors were used to control the water pump.

3.1.2.3 User keypad

A keypad is interfaced to the system which helps the user to set the high and low limit of the moisture level. There are four keys connected to the system. A download key which helps the user to download the stored data to the computer.

3.1.2.4 Electronic control board (microcontroller unit)

The microcontroller unit (MCU) controls all the functions of other blocks of the circuit. MCU read data from the keypad and the soil moisture sensors and controls all the functions of the whole system by manipulating these data. The microcontroller

detects the moisture level of the soil with the help of four sensors. It then determines the average moisture level. If this average moisture level is below the lower limit set via the keypad, 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 as per the average moisture level. It cannot operate a motor directly. It operates the motor through the interfacing circuits. The microcontroller also stores the recording during every 1 minute. This data can be later downloaded to the pc.

3.1.2.5 LCD display

LCD display is used for displaying the state of the unit. It displays the four sensor outputs, its average value and the state of the motor. LCD module is a dot matrix liquid crystal display that displays alphanumeric, kana (Japanese character) and symbols. The built in controller and driver LSI, provide convectional connecting between LCD and most 4 or 8 bit microcontroller. The CMOS technology makes the device ideal for applications in handheld portable and other powered instruments with low power consumptions.

3.1.2.6 Motor interface

This is required because the current output from the microcontroller is very small that it is not sufficient to magnetize the relay which is used to control the motor. Hence it is necessary to have an amplifying circuit.

The output of the microcontroller is fed to the TIP122 IC for current boosting. TIP 122 is used as switch to control the energizing condition of the relay. A relay is an electrical switch that opens and closes under the control of another electrical circuit. Relays are used here for the control pump, as per the outputs from the four sensors, MCU operates the relay. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. Because a relay is able to

control an output circuit of higher power than the input circuit, it can be considered to be, in a broad sense, a form of an electrical amplifier.

3.1.2.7 RS 232 serial communication

The RS- 232 is used to interface the microcontroller with PC display. RS-232 (Recommended Standard 232) is a standard for serial binary single-ended data and control signals connecting between a DTE (Data Terminal Equipment) and a DCE (Data Circuit-terminating Equipment). It is commonly used in computer serial ports, that defines the electrical characteristics and timing of signals, the meaning of signals, and the physical size and pin out of connectors. The serial interface connected to PC is RS232 and MAX232 is the IC used.

3.1.2.8 PC communication

The microcontroller is interfaced to the PC via serial interface. The stored data can be downloaded and viewed in the PC. The sensor outputs and the average value recorded for every minute will be shown.

3.1.3 Circuit details

3.1.3 .1 Soil moisture sensor (capacitive type)

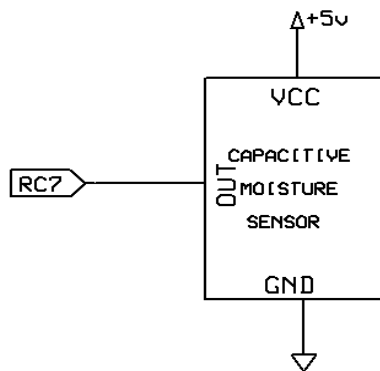


Fig. 3.2 Circuit of capacitive type soil moisture sensor

These sensors measure the volumetric water content (VWC) of the soil by measuring the dielectric constant of the media through the utilization of frequency domain technology. Since the dielectric constant of water is much higher than that of air or soil minerals, the dielectric constant of the soil is a sensitive measure of volumetric water content.

The sensor has a low power requirement and very high resolution. The weight of the single soil moisture sensor is approximately 10 gram. This gives the ability to make many measurements (i.e. hourly) over a long period of time with minimal battery usage. In addition, the sensors incorporate a high frequency oscillation, which allows the sensor to accurately measure soil moisture in any soil with minimal salinity and textural effects. The output of the sensor is interfaced to RC7 of the microcontroller.

Specification

- Working Voltage: +5V
- Reading outputs every 100ms, very fast response time
- Output Format: Serial Data at 9600 baud rate (8 bits data, No parity, and 1 stop bits). Outputs four ASCII bytes per reading.
- Dimensions: 18mm width x 160mm length of total sensor, sending probe is 110mm long, wire length is 2 meters.

Sensor Pinouts

- Green / TX-OUT = Transmit output. Output serial data of 5V logic level, usually connected to RXD pin of microcontrollers/RS232/USB-UART.
- Red / +5V = Regulated 5V supply input.
- Black / GND = Board Common Ground

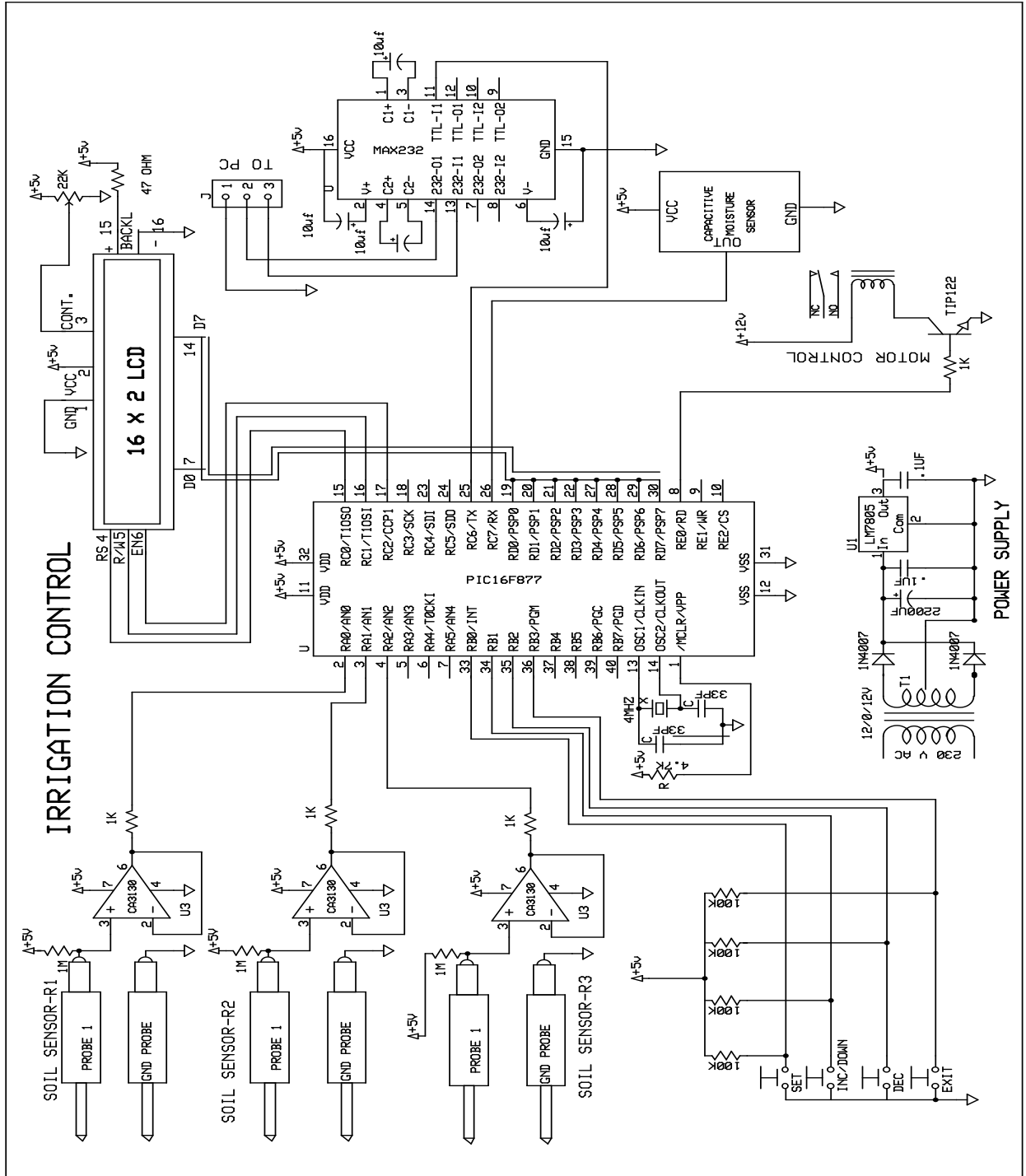


Fig. 3.3 Controller board circuit diagram

3.1.3.2 Soil moisture sensor (conductivity types)

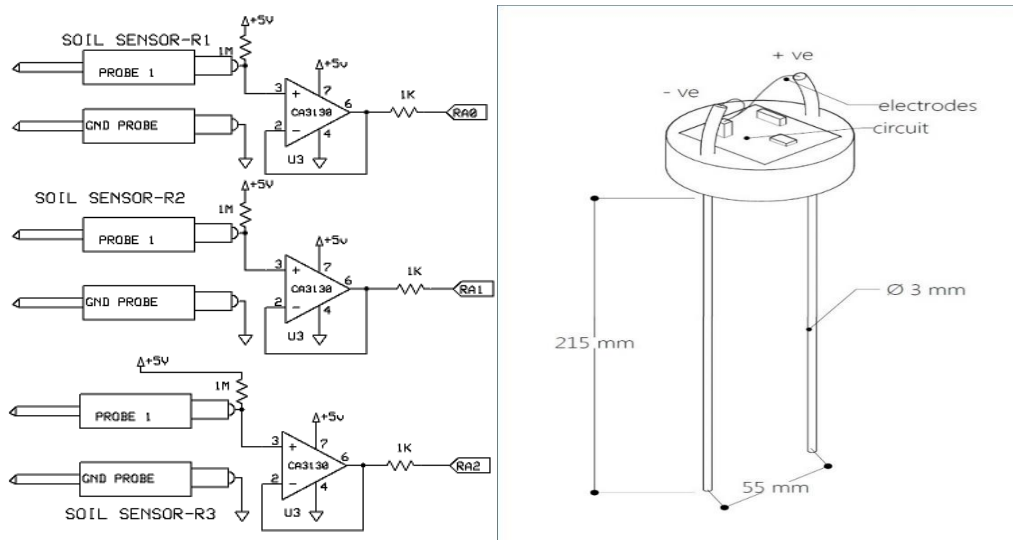


Fig. 3.4 Conductivity based soil moisture sensors

These sensors are made of high quality stainless steel probes for durability are used as the conduction sensors. The soil moisture sensor consisted of two electrodes i.e. positive and negative separated by a nonconductor medium (Fig. 3.4). Nonconductor is a nylon circular plate. The electrodes of the sensor were built of round cylindrical shape. The complete sensor length is 215 mm and spacing between the electrodes is 55 mm. It is made up of stainless steel, 3 mm thickness. The weight of the single soil moisture sensor is approximately 100 gram. The stainless steel material is used to avoid the oxidation with the soil. It occurs depending on the water conductivity in the soil. One probe is connected to V_{cc} via a 1.0 M ohm resistor, thus acting as a voltage divider. The other one is grounded. When there is sufficient moisture content in the soil, the conductivity is high, hence the voltage divider output is high. When the soil becomes dry, its conductivity decreases thus increasing the voltage divider output. This is then given to an op-amp based voltage follower. CA3140 is used here as the operational amplifier. The output of the sensor is connected to MCU through the voltage follower made by the CA3140. Voltage

follower is used here for impedance matching purpose. The sensor outputs are interfaced to MCU via RA0,RA1 & RA2.

CA3130A and CA3130 are operational amplifier that combine the advantage of both CMOS and bipolar transistors. Gate-protected P-Channel MOSFET (PMOS) transistors are used in the input circuit to provide very high input impedance, very low input current and exceptional speed performance. The use of PMOS transistors in the input stage results in common mode input voltage capability down to 0.5V below the negative supply terminal, an important attribute in single supply applications.

3.1.3.3 CA3130



Fig. 3.5 CA3130 operational amplifier

A CMOS transistor pair, capable of swinging the output voltage to within 10mV of either supply voltage terminal (at very high values of load impedance) is employed as the output circuit.

The CA3130 series circuits operate at supply voltages ranging from 5V to 16V, 2.5V to 8V. They can be phase compensated with a single external capacitor and have terminals for adjustment of offset voltage for applications requiring offset null capability. Terminal provisions are also made to permit strobing of the output stage. The CA3130A offers superior input characteristics over those of the CA3130.

3.1.3.4 Pinout

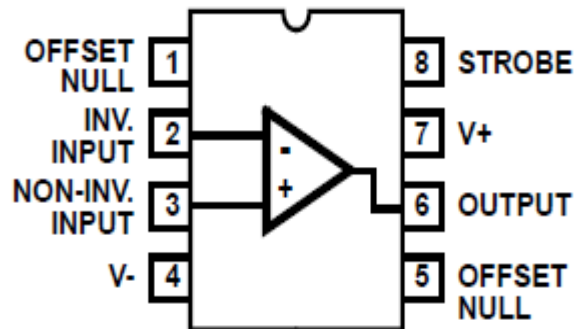


Fig. 3.6 PinoutCA3130 operational amplifier

3.1.3.5 User keypad

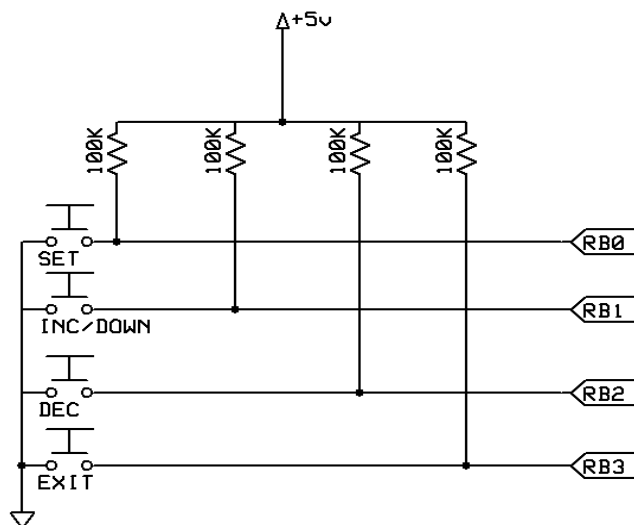


Fig. 3.7 Circuit user keypad

Keypads used to set the high and low limit of the moisture value. Miniature type micro switches momentarily operated are used here. 100K resistor array is used to interface the switches with the MCU. Voltage divider network is used here. The logic state transition from high to low is detected from the MCU by the action of each switch. When the switches are not pressed logic HIGH is interfaced to microcontroller, whereas if any of the key is pressed, the corresponding pin of the microcontroller goes to logic zero. The setup switch is used to enter into the mode, increment or decrement to set the limit and exit to retrieve from it. By pressing the download key data can be downloaded to PC.

3.1.3.6 Microcontroller with LCD

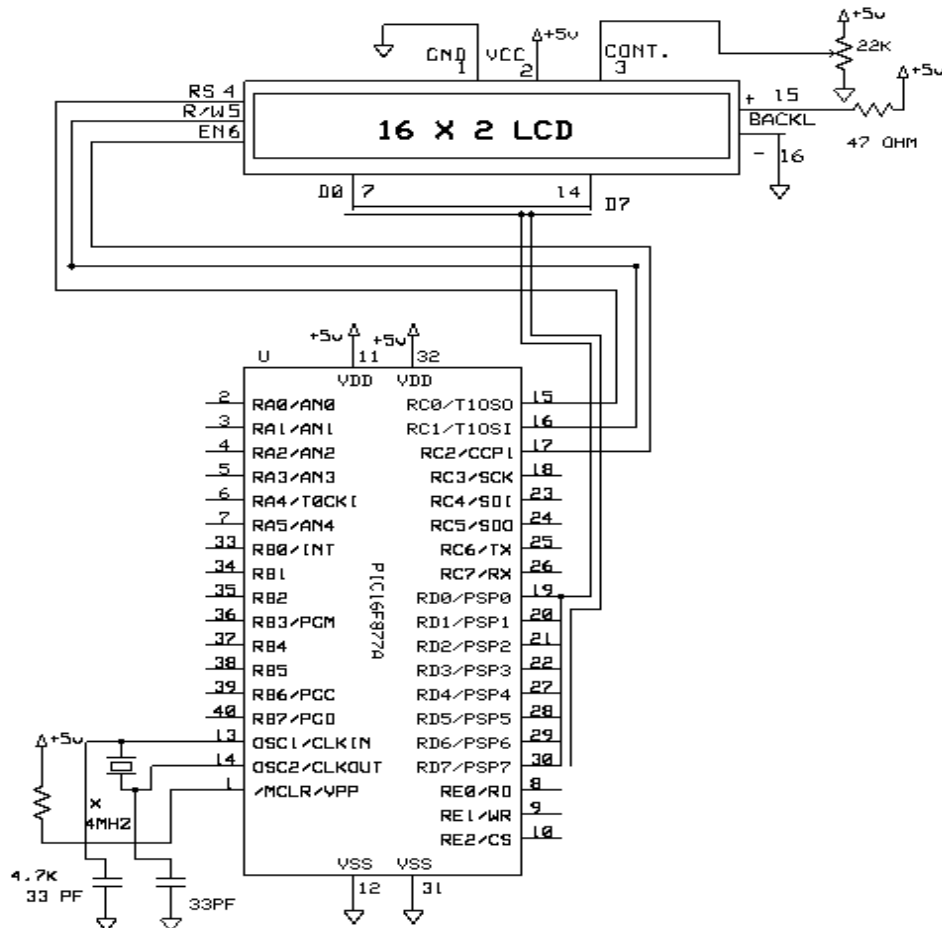


Fig. 3.8 Circuit microcontroller with LCD

PIC16F877 is used as the microcontroller unit. The MCU reads the sensor output and does the further processes. By determining the moisture level, it controls the motor.

The LCD is used to display the status of the system. Software communication takes place between the controller of the LCD and the microcontroller . Control lines of the LCD modules (RS,R/W,EN) are connected to RC0,RC1,RC2 of the microcontroller respectively.The data transfer from LCD to MCU takes place through port D. Data lines of the LCD are connected to port D as shown in the Fig.3.8

3.2 Component details

3.2.1 Microcontroller unit (MCU)



F**Fig. 3.9 Microcontroller unit**

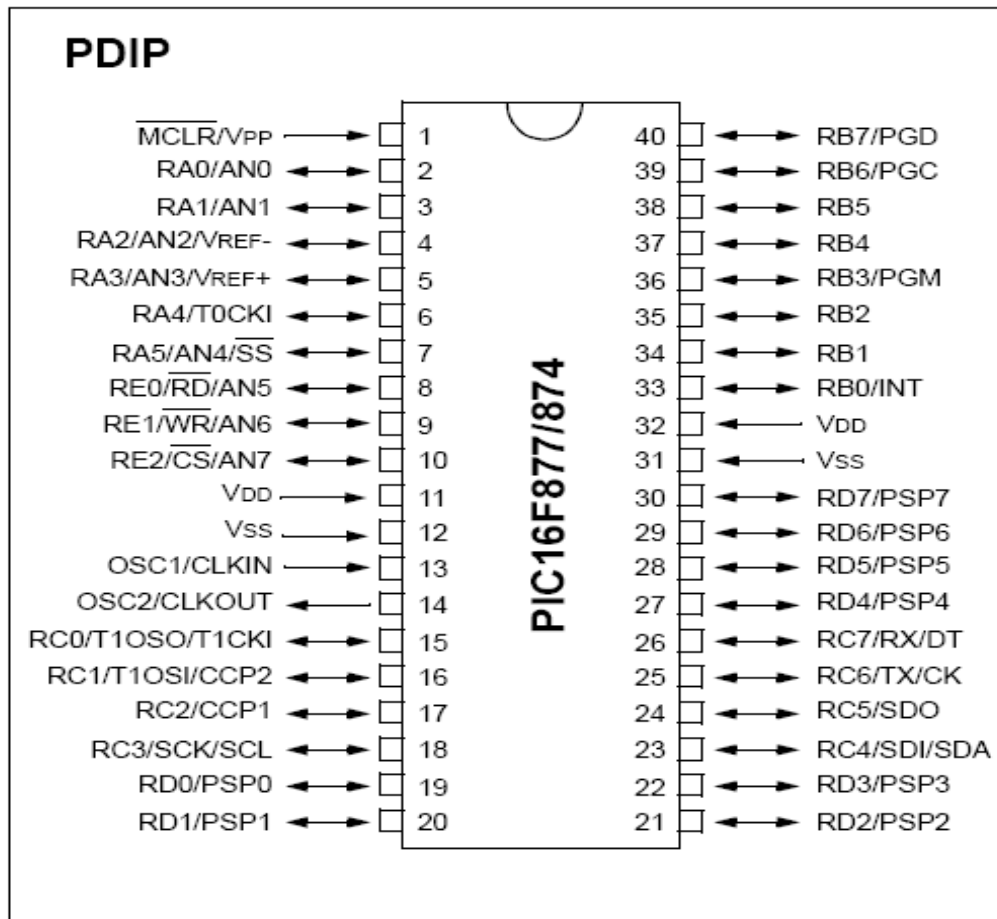
The popular microcontroller PIC 16F877 from MICROCHIP Corporation is used as the CPU of the system. PIC microcontrollers are the most popular 8 bit microcontroller in the world. They are available in wide variety in pin outs, memory capacity and have lots of integrated peripherals like ADC, SERIAL modules and EEPROM.

The PIC 16F877 is available in 40 pin DIP package and have program memory capacity of 8 Kb , ram of 368 bytes and 256 bytes of EEPROM. They are working in clock speed range of 0 Hz to 20 MHz and the operation is fully static also. They have 5 I/O ports named as PORTA, PORTB, PORTC, PORTD and PORT E. Among these PORT A is 6 bit wide and PORT E is 3 bit wide and all other ports are 8 bit wide. Most of the peripheral I/O functions are multiplexed with PORTC pins. The ADC inputs are available in PORT A and PORT E.

The PIC controllers have 14 bit wide program memory space by which an instruction occupies only one memory space. This allows more program density. These are addressed with a 13 bit wide program counter during execution .The program memory is addressed from 0000h to 0004h and the reset vector is at 0000h

and interrupt vector is at 0004h. The program counter points the address of the memory location to be executed next and increments in every machine cycles. One machine cycle consists of 4 clock cycles.

Generally they are low power devices and works in voltage range of 2V to 5.5V. They have 13 interrupt sources like external pulse interrupt and serial receive



interrupt etc. These chips are supplied with in circuit serial programming facility and are flash technology also. The flash memory can be re written 1000 times.

Fig.3.10 Pin diagram Microcontroller unit

3.2.2 Liquid crystal display (HD 44780)



Fig. 3.11

Liquid crystal display

The HD 44780 is a liquid crystal dot matrix display module that consists of LCD panel LCD control driver, and driver and is capable of providing 16 characters x 2 lines display. It contains a controller, a data RAM and a character generator ROM required for providing display. Data interfacing is in 8-bit parallel or 4-bit parallel and data can be written in or read from a microprocessor.

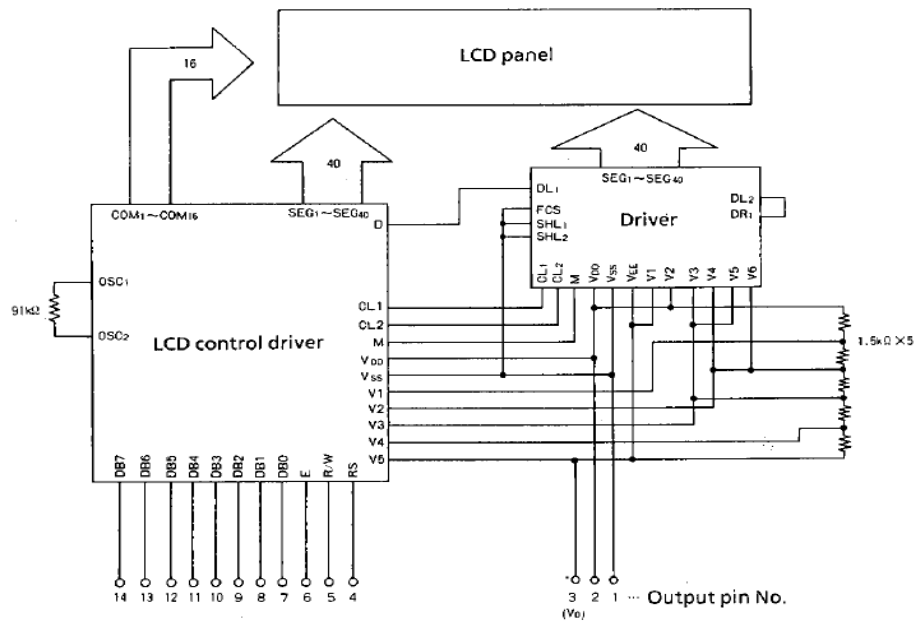


Fig. 3.12 Pin diagram of liquid crystal display

3.2.3 Motor control circuit

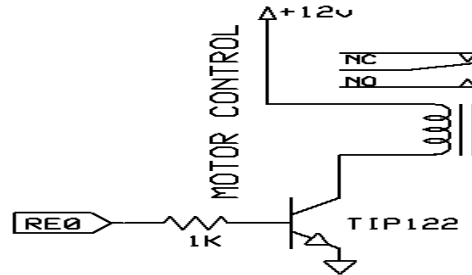


Fig. 3.13 Motor control circuit

Electrical relays are interfaced to the MCU via the driving circuits. These relays are used to control the motor pump. Commonly relays are inductive loads and are operated in 12V range. Because of these reasons there is a need of interfacing circuits between these relays and MCU. Darlington pair array TIP 122 is used here for interfacing. The three TIP 122 transistors are interfaced to MCU via RE0.

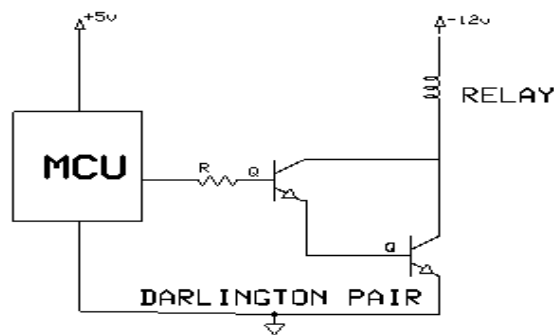


Fig. 3.14 Darlington pair

Darlington pair is a compound structure consisting of two [bipolar transistors](#) connected in such a way that the current amplified by the first transistor is amplified further by the second one. This configuration gives a much higher [current gain](#) than each transistor taken separately. MCU output has inefficient current to energize the

relay. So it is fed to the Darlington pair for current amplification. Output from this circuit is capable for driving the relay.

3.2.4 Relay driver

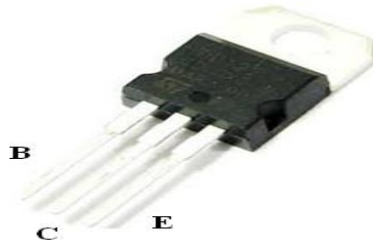


Fig. 3.15 Relay driver

Driving relays are slightly complicated due to their inductive nature because; the relay is activated by an electromagnetic coil. The inductive loads always produce back Electro motive force (EMF) which has amplitudes of several 100 volts. This will damage drive electronics. To prevent this back emf rising usually a protection diode is inserted across the relay coil or drive electronic switch in reverse bias. The popular Darlington transistor TIP122 comes with this protection diod built in. So no separate diodes are used externally.

The TIP120, TIP121 and TIP122 are silicon Epitaxial-Base NPN power transistors in monolithic Darlington configuration mounted in edec TO-220 plastic package. They are intended for use in power linear and switching applications.

3.2.5 Electrical relays



Fig. 3.16 Electrical relays

A relay is an electrical switch that opens and closes under the control of another electrical circuit. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. It was invented by Joseph Henry in 1835. Because a relay is able to control an output circuit of higher power than the input circuit, it can be considered in a broad sense a form of an electrical amplifier.

A simple electromagnetic relay is an adaptation of an electromagnet. It consists of a coil of wire surrounding a soft iron core, an iron yoke, which provides a low reluctance path for magnetic flux, a movable iron armature and a set or sets of contacts. The armature is hinged to the yoke and mechanically linked to a moving contact or contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed and the other set is open. Other relays may have more or fewer sets of contacts depending on their function.

When an electric current is passed through the coil, the resulting magnetic field attracts the armature and the consequent movement of the movable contact or contacts either makes or breaks a connection with a fixed contact. If the set of contacts is closed when the relay is de-energized, then the movement opens the contacts and breaks the connection and vice versa if the contacts are open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force to its relaxed position. Usually this force is provided by a spring, but gravity is used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low voltage application, this is to reduce noise.

3.2.6 Serial interface to PC

MAX232 IC is used to interface the microcontroller with PC. The 11th pin of the MAX232 IC is connected to the serial port TX of the microcontroller i.e. to pin RC6. RS232 connectors were used to connect the MAX232 output to the PC serial port.

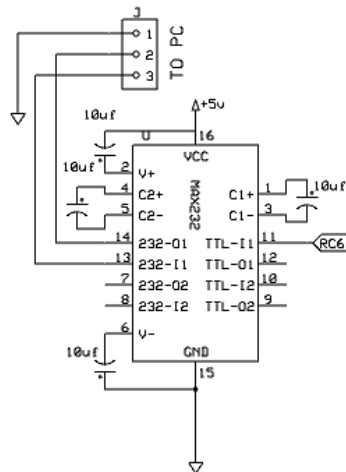


Fig. 3.17 Pin diagram serial interface to PC

3.2.7 MAX 232 IC

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply TIA/EIA-232-F voltage levels from a single 5-V supply. Each receiver converts TIA/EIA-232-F inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V a typical hysteresis of 0.5 V and can accept ± 30 -V inputs. Each driver converts TTL/CMOS input levels into TIA/EIA-232-F levels. The driver, receiver and voltage-generator functions are available as cells in the Texas Instruments Lin ASIC library.



Fig. 3.18 MAX 232 IC

3.3 Power supply

The AC voltage, typically 220V root mean square (rms) is connected to a transformer which steps that AC voltage down to the level of the desired DC output. A diode rectifier provides a full wave rectified voltage that is initially filtered by a simple capacitor filter to produce a DC voltage. This resulting DC voltage usually has some ripple or AC voltage variation. A regulator circuit removes the ripples and maintains the same DC value even if the input DC voltage varies or the load connected to the output DC voltage changes. This voltage regulation is usually obtained using one of the popular voltage regulator IC units.

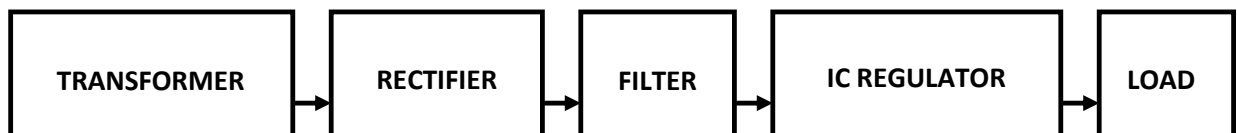


Fig. 3.19 Block diagram (Power supply)

3.3.1 Centre tap transformer

In electronics, a center tap is a connection made to a point half way along a winding of a [transformer](#) or [inductor](#) or along the element of a [resistor](#) or a [potentiometer](#). Taps are sometimes used on inductors for the coupling of signals and may not necessarily be at the half-way point, but rather, closer to one end. 230V /12-0-12 transformer is used here.



Fig. 3.20 Transformer

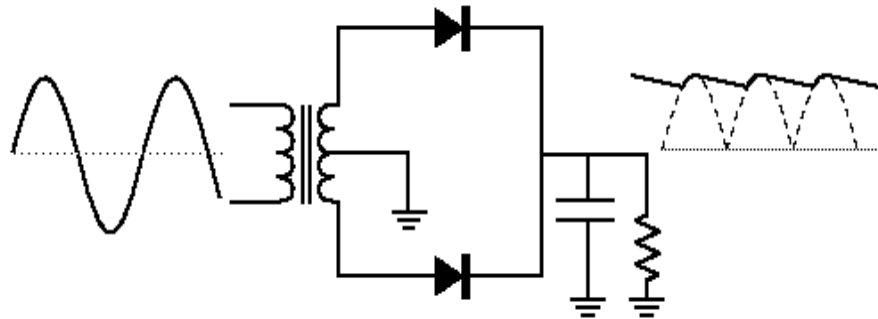


Fig. 3.21 Rectifier circuit

3.3.2 Rectifier

A rectifier is an electrical device that converts [alternating current](#) (AC), which periodically reverses direction, to [direct current](#) (DC), which is in only one direction, a process known as rectification. Here bridge rectifiers are used. The bridge rectifier circuit produces a higher output voltage than the conventional full-wave rectifier circuit.

3.3.3 Filter

The capacitor is used after rectification for filtering the rectified output and then regulated by using regulator IC LM7805. The capacitor C2 is connected to the input of the regulator to eliminate inductive effect due to long distribution leads. The output capacitor C6 improves the transient response.

3.3.4 IC voltage regulators

The power supply is the most indispensable part of any circuit. IC regulators are versatile and relatively inexpensive. The regulated circuit is used to maintain constant output level. The integrated circuit regulator, sometime called the three terminal regulators contains the circuitry of reference source error amplitude control device and overloaded protection all in a single IC chip. They are connected between output of the filter and input of the load.

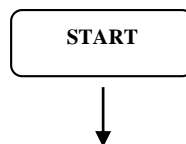
3.4 Simulation software

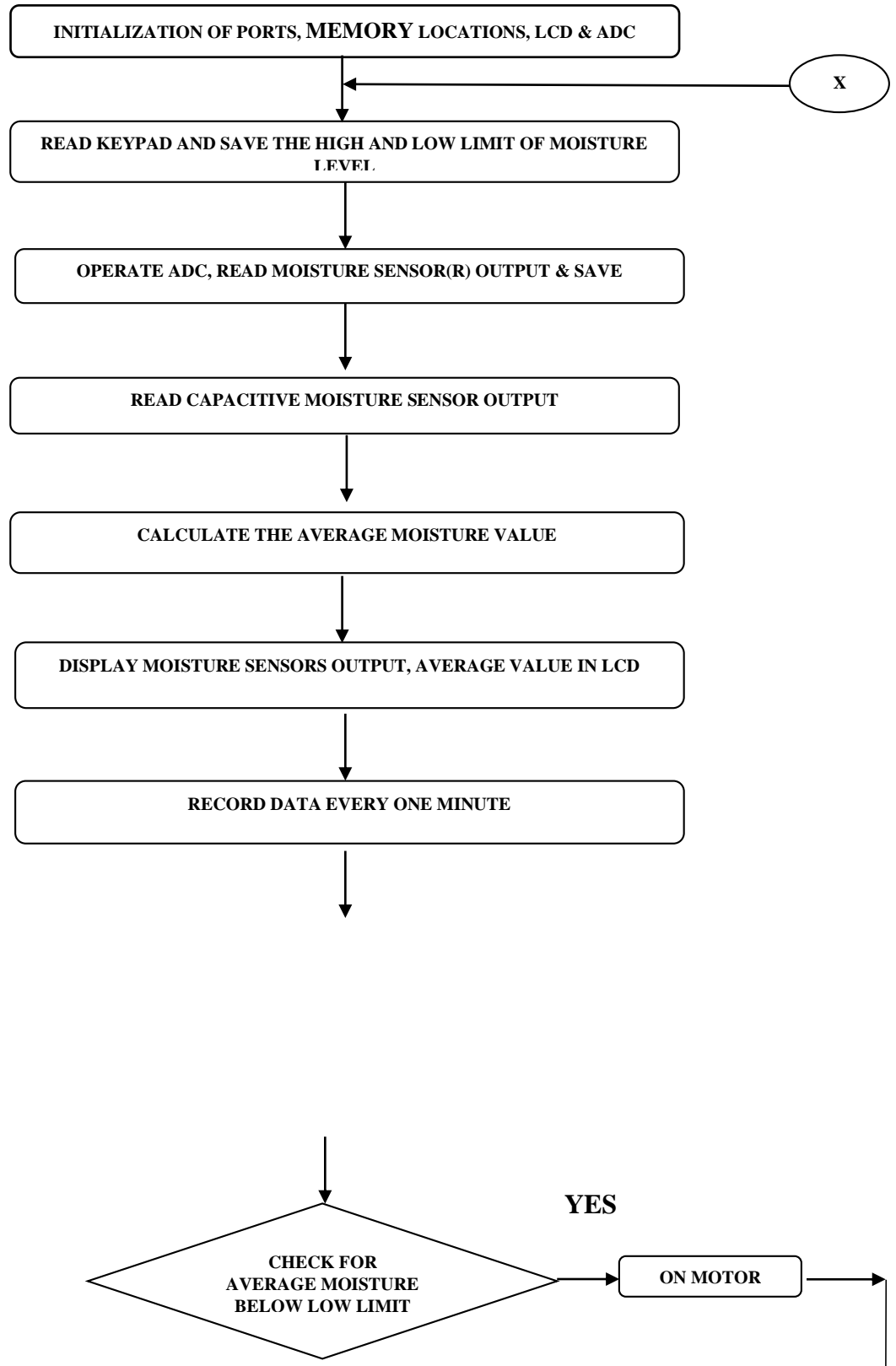
The whole circuit was simulated by using the simulation software MPLAB. MPLAB is a windows program package that makes writing and developing a program easier. It includes a host of software components for application development and debugging. It could best be described as developing environment for a standard program language that is intended for programming a PC. Some operations which were done from the instruction line with a large number of parameters until the discovery of “Integrated Development Environment” (IDE) are now made easier by using the MPLAB. IDE also serves as a single, unified graphical user interface for additional Microchip and third party software and hardware development tools. It supports the free software simulator, hardware debug, and programming tools using a single standardized graphical user interface.

3.4.1 MPLAB components

- Grouping the projects files into one project. It deals with the place where the software is developed.
- Generating and processing a program.
- Simulator of the written program used for simulating program function on the microcontroller.

3.4.2 Flow chart simulation programme





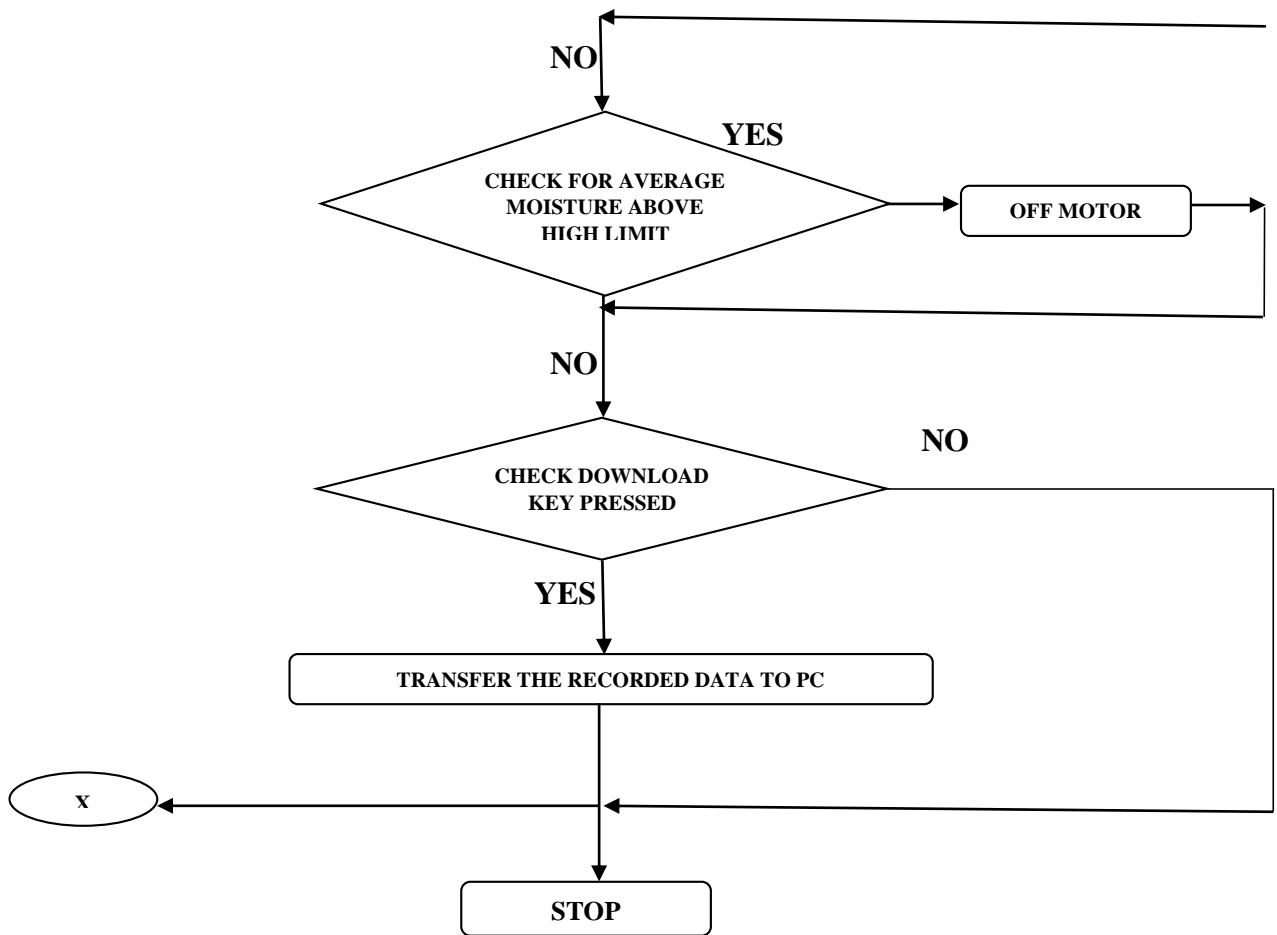


Fig. 3.22 Flow chart of the simulation program

3.5 Design of drip automation unit

The system was developed taking into the considerations of portability, corrosiveness, toughness to weather parameters, quick response, easy for installation

and fixation of the sensors. Whole circuit was simulated by using the simulation software.

The sensors developed can provide quick information to make decision in application of irrigation. The microprocessor circuits combined with a computer programming can help to estimate the irrigation duration on the basis of field data. The working principle of electrical resistance soil moisture sensor is the basis principle of using electrical conductivity of soil. Two electrodes were supplied with a constant electrical current of AC types. As soil moisture changes, the conductivity of soil sensor also changes. The electric conductivity between the two electrodes increases the moisture content of soil increases. The conductivity values are related to the water content of soil.

Another sensor is capacitive sensor which measures the dielectric constant of the soil in order to find its volumetric water content (VWC). It obtains volumetric water content by measuring the dielectric constant of the media through the utilization of frequency domain technology. Since the dielectric constant of water is much higher than that of air or soil minerals, the dielectric constant of the soil is a sensitive measure of volumetric water content.

The drip automation system monitors the soil conductivity based on the moisture content conductivity sensors are used in the process. The data acquired from multiple sensors is processed using Micro Controllers and displayed in the LCD panel. The average data obtained from multiple sensors is logged in the device based on the average data motor condition ON/OFF and it can be transferred to PC for further data analysis. From main menu, select the transfer to PC so that the data logged in the system is sent to the PC and initialize the data logger for further use after transferring the data to PC as shown in Plate.3.1

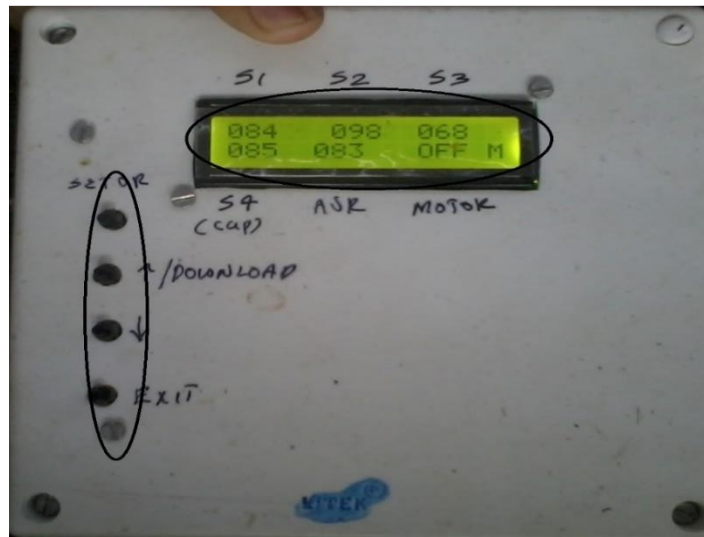


Plate 3.1 LCD system display and keys for user input

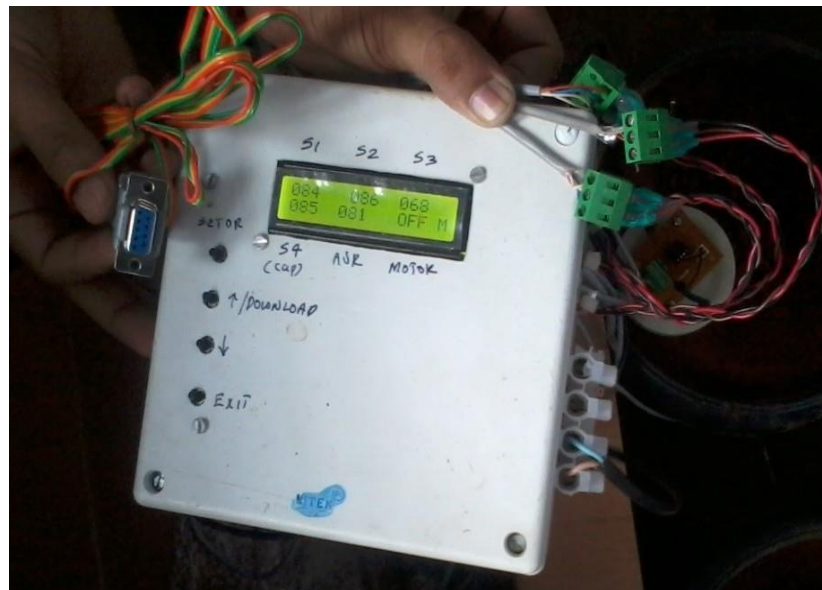
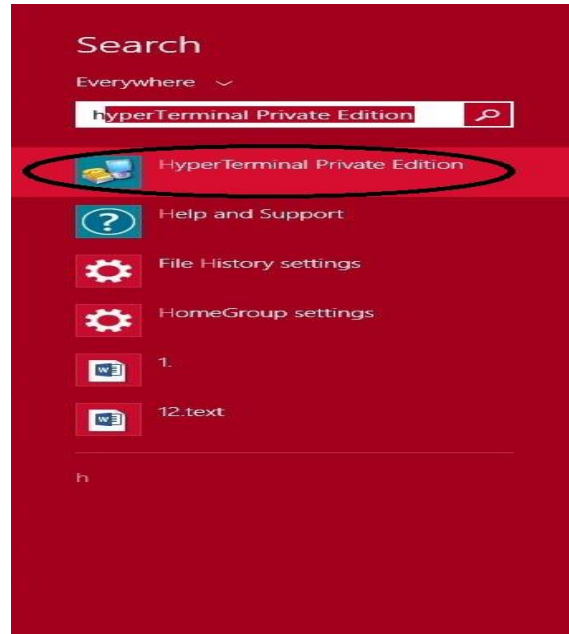


Plate 3.2 Terminal for data loggers

The data logging can be done by connecting drip automation system with hyper terminal from the start menu of MS windows 8.1 laptop and configuring can be done by port available in the system. Soil moisture data can be transferred to PC as follows.

1. Choose search menu a, type the hyper terminal and click on hyper terminal



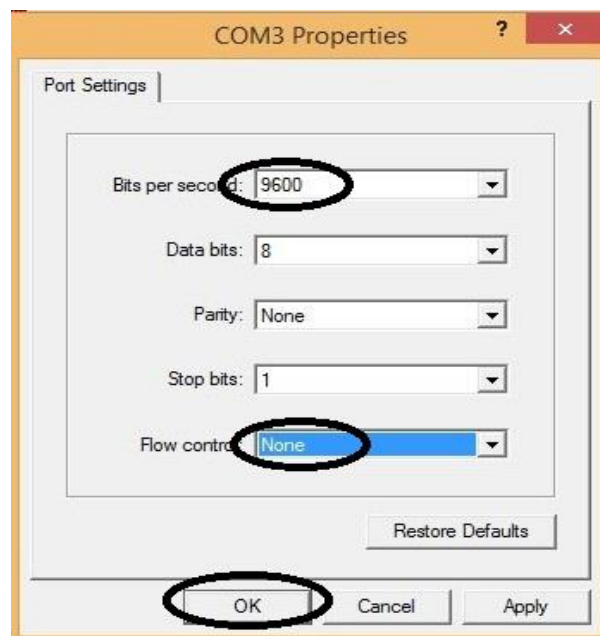
2. Do you want to do this ?



3. Given the location information and click ok



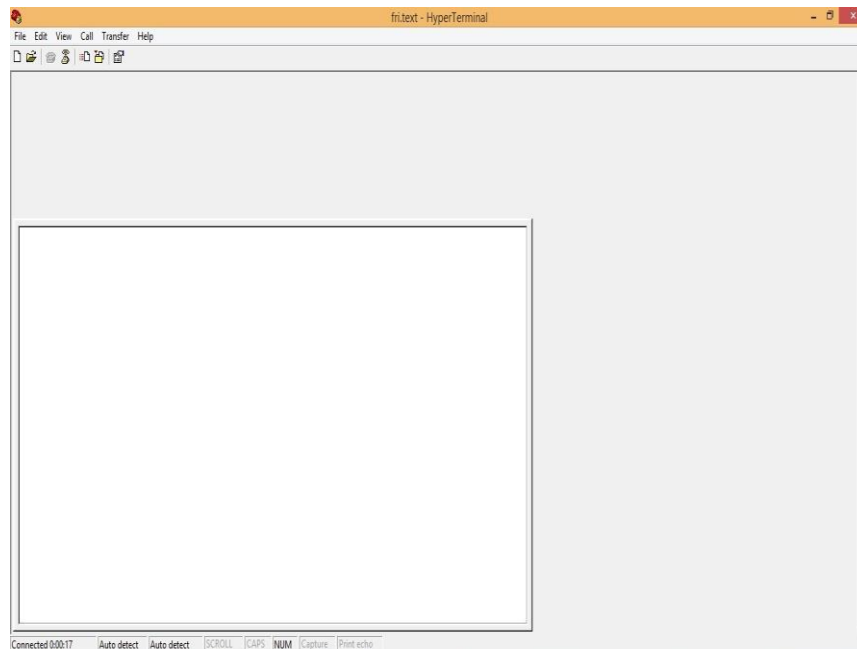
4. Complete COM 3 properties like bite per second and details of flow control



5. Give any name to the hyper terminal connection



6. Get data from menu of automation on the hyper terminal



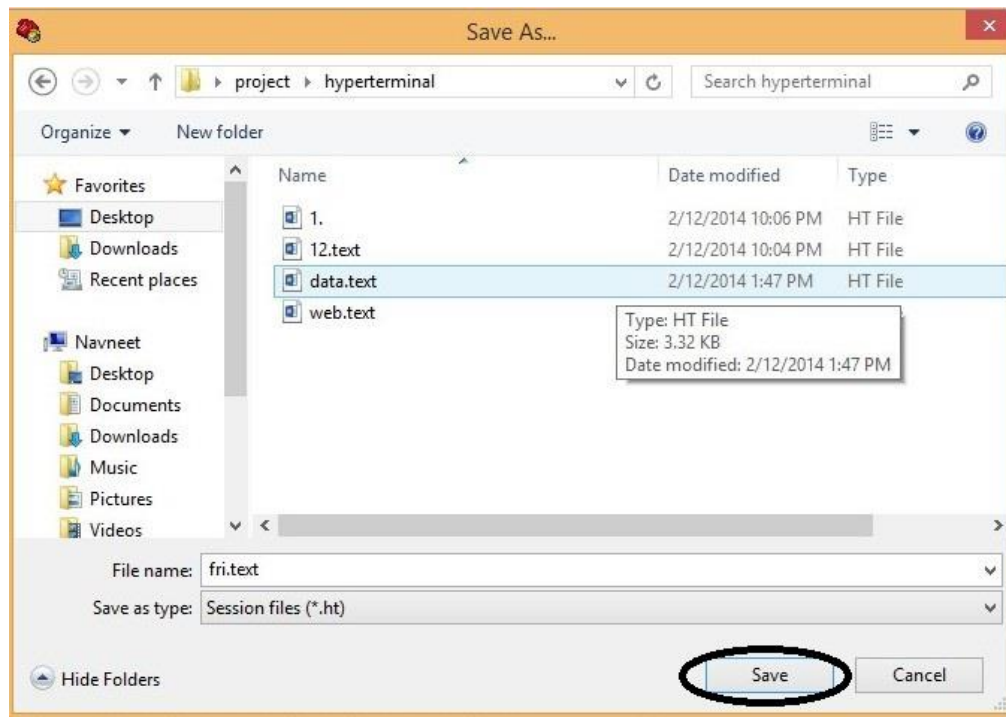
7. Click on download button at datalogger, start downloading data

```

web.text - HyperTerminal
File Edit View Call Transfer Help
S1:000 S2:235 S3:000 S4:000 Average:058
021
S1:239 S2:226 S3:243 S4:122 Average:207
022
S1:217 S2:216 S3:221 S4:118 Average:193
023
S1:200 S2:206 S3:205 S4:000 Average:152
024
S1:186 S2:196 S3:192 S4:000 Average:143
025
S1:176 S2:187 S3:182 S4:000 Average:136
026
S1:000 S2:000 S3:000 S4:123 Average:029
027
S1:000 S2:000 S3:000 S4:000 Average:000
028
S1:000 S2:000 S3:000 S4:119 Average:030
029
S1:000 S2:000 S3:000 S4:049 Average:012
030
S1:000 S2:000 S3:000 S4:043 Average:010
031
S1:000 S2:000 S3:000 S4:120 Average:030
032
S1:222 S2:000 S3:000 S4:000 Average:055
033
S1:000 S2:000 S3:000 S4:000 Average:000
034
S1:000 S2:000 S3:000 S4:000 Average:000
035
S1:000 S2:000 S3:000 S4:000 Average:000
036
S1:242 S2:000 S3:_
Connected 001:33 Auto detect 9600 8-N-1 SCROLL CAPS NUM Capture Print echo

```

8. Save data in the hyper terminal



3.6 Calibration of soil moisture sensor with different concentrations of salt solution

Distilled water and sodium chloride are used to prepare different EC solutions. For preparing solutions with different EC, the known quantities of sodium chloride were added in 200 ml of distilled water and presented in Table 3.1.

Table 3.1 Electrical conductivity at different salt concentrations

Sl. No.	Quantity of NaCl added (gram)	Concentration in (ppm)	Electrical conductivity (dSm ⁻¹)
1	0.1	500	1.1
2	0.2	1000	1.9
3	0.3	1500	3.02
4	0.4	2000	3.7
5	0.5	2500	4.6
6	0.6	3000	5.5
7	0.7	3500	6.3
8	0.8	4000	7.5
9	0.9	4500	9.3
10	1.0	5000	9.9

Different EC solutions were used to develop the calibration chart by dipping the moisture sensors in the different concentrations of salt solution and are shown in Plate 3.3.



Plate 3.3 Calibration of moisture sensor in salt solution

3.7 Soil physical properties

The field tests were conducted for identification and characterization of soil properties. Both disturbed and undisturbed soil samples were collected from three different locations of the study area. The selected locations were the KVK plot, paddy field near to the farm pond and near to the workshop from which sample 1, sample 2, and sample 3, were collected respectively. The field was divided into different homogenous units based on visual observation. The surface litter was removed at the sampling spot. The auger was driven to a plough depth of 15 cm and the soil sample was drawn. 10 to 15 samples were collected from each sampling unit and placed in a bucket or tray. A 'V' shaped cut was made to a depth of 15 cm in the sampling spot using a spade. Thick slices of soil was removed from top to bottom of exposed face of the 'V' shaped cut and placed in a clean container.

3.7.1 Particle size analysis

The analysis of grain size distribution of soils from the selected three plots was done by sieving. Dry sieve analysis was carried out using 2mm, 1mm, 600 μ m, 425 μ m, 300 μ m, 212 μ m, 150 μ m, and 75 μ m size sieves. Sieving was done using sieve shaker. Weight of soil retained in each sieves were taken. The mass retained in the receiver was then subjected to sedimentation analysis by Hydrometer method.

3.7.2 Soil moisture constants

A laboratory analysis for determine of soil moisture constants was carried out with the pressure plate apparatus developed primarily by Richards (1949, 1954). The apparatus consists of ceramic pressure plate or membranes 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 the 2 important soil moisture constants viz. field capacity and permanent wilting point.



Plate 3.4 Pressure plate and membrane apparatus

The procedure for determining soil moisture constants was as follows saturated porous plates and the soil (undisturbed or disturbed) were placed on these plates. The soil samples were also saturated 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. 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. It was ensured that there was no leakage from the chamber. Water starts to flow out from saturated soil samples through 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, volume basis (undisturbed soil).

The field capacity and permanent wilting point were determined by using pressure plate apparatus. The soil samples were filled in the ring of the respective pressure plates and soaked with water. The sample were kept overnight for complete saturation. The pressure plate apparatus was filled with compressed air in the chamber and valves were adjusted to apply varied pressures from the compressor. Each pressure was applied for long duration of more than 24 hours until the drainage of water was complete and no water dripped from the sample through the outlet. The moisture retained in media after application of varied pressures viz, $1/3$, and 15 bars was determined by gravimetric methods.

3.8 Water quality parameters

Bore well water was used for the irrigation. The water was pumped from bore well of 6 m depth near the experimental field. The quality of irrigation water was assessed. The physical and chemical properties like electrical conductivity, pH etc., were determined using standard procedure.

3.9 Calibration of soil moisture sensor with different soils

Laboratory test were conducted to evaluate the performance of the soil moisture sensors in laterite soils and sandy loam soils to develop calibration curves. To analyses the effect of soil moisture content on the sensor, laterite and sandy loam soils were collected from different locations of the KCAET campus. The sample were passes through is sieve and sedimentation analysis was done for particle size distribution.

Laboratory experiments were conducted using circular containers (plastic pot) made up of polyvinylchloride (PVC) which is an insulator having diameter 22 cm and height 20 cm. The containers with drainage holes in the base were filled with soil. Soil moisture sensors were located along the centerline of each container to minimize any interaction between the sensor or container edge effects. Plate 3.4 shows the laboratory setup to evaluate the performance of sensor with different soils.



Plate 3.5 Calibration of soil moisture sensors in different soils

Soil moisture sensor measures the conductivity between the electrodes, which is a function of soil moisture content. The soil moisture content and corresponding soil electrical conductivity were then monitored till constant moisture content was reached. Variation of moisture in soil caused variation in electrical conductivity across the electrodes of the sensors.

Two trials for two types of soil textured soil were carried out leaving one day for each trial to evaluate the performance of the sensors. Soil moisture content was measured from each plot twice daily at 10.00 AM and other at 4.00 PM. The conductivity corresponding to the field capacity of soil was determined.

3.9.1 Determination of moisture content

While evaluating the performance of the sensor, comparison of soil moisture content and the conductivity value are to be determined. The procedure followed for measuring soil moisture is shown in plate 3.5



Plate 3.6 Determination of soil moisture content by weighing machine

Steps:

- Empty plastic pot + soil moisture sensor was weighed and weight was recorded as W_0
- Oven dry soil sample was placed in the plastic pot and this weight was recorded as $W_{\text{dry}} + W_0$
- Saturate the soil by adding water and the weight was recorded as $W_{\text{wet}} + W_0$

The soil moisture content in dry weight basis was calculated using the following formula (Jackson M.L., 1968)

$$mc = \frac{(W_{\text{wet}} + W_0) - (W_{\text{dry}} + W_0)}{(W_{\text{dry}} + W_0) - (W_0)}$$

3.10 Operation of drip automation unit

The power is connected at the rear side of the of the drip automation system as shown in plate 3.6 There is no polarity in the connection. All Sensors is connected on the side of the controller. The two wire from the sensors are connected from right to left. Total four sensors can be connected as shown in plate 3.7.

Different keys are provided on the data logger display board for proper functioning of unit viz. Enter, Up/Down arrow and Exit keys. Following are the steps for operating the instrument.

- Switched on the unit with the ON/OFF
- Put the meter into soil sensor selection mode by pressing Exit key.
- Set the upper conductivity value at which the irrigation will start with the help of the Up and down arrow keys.
- Adjust the time of motor running is with Up and Down arrow keys
- Press Exit key after feeding the values

- Display will show the run command
- Press enter key to run the programme
- After pressing the run command, the microprocessor processes the data and display the actual conductivity value of the soil, the conductivity set by operator for running the motor



Plate 3.7 AC (230 Volts) input and output connecting terminals



Plate 3.8 Terminal for connecting soil moisture sensors

3.10.1 Range selection of the soil moisture sensor

The soil moisture sensor showed the reading of typical conductivity value in the air. The probe read out conductivity value from 0 to 17 (mS/m). The values were used for soil moisture measurement and as a day-to-day monitoring of soil sensor stability.

3.10.2 System maintenance

To run the system efficiently, following major steps were followed.

- Positive and negative terminals of the sensor were connected properly to the respective connections provide on the instruments.
- It was ensured that all parts of the sensor were properly fitted so that there exists no gap between the parts of the sensor to avoid entry of water.
- Sensor was properly inserted into the soil to avoid gap between the soil and soil moisture sensor.

3.11 Field experiments using automation system

3.11.1 Location

The design and fabrication of drip automation system was done at SWE laboratory and lab experiments for soil moisture content determination were carried out in the SWE laboratory at Kelappaji College of Agricultural Engineering & Technology, Tavanur, Malappuram. The field trial was conducted at the experimental plots of KCAET Instructional Farm, Tavanur during January 2014 to April 2014. This study is situated between 10⁰ 52' 30" North Latitude and 76⁰ East longitude.

3.11.2 Weather and climate

Agro climatically, the area falls within the border line of Northern zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon. The selected plot for the study was located in the eastern side of the

farm which was nearer to the Bharathapuzha river basin. The total area selected for the study was 20x10 m². The land preparation was done before the installation of the system in the field.

3.11.3 Crop and variety

Amaranthus (AmaranthusCaudatus L.) arun variety with duration of 90 days was used for the study. It is high yielding variety and it is well suited for this soil types and the region.

3.11.4 Experimental details

Among the various approaches for irrigation scheduling, the one suggested by Jadhav et al., (2002) was used schedule the irrigation of experimental plots. The procedure used was;

$$WR/Day/Plant = E_{pan} \times K_p \times K_c \times W_p \times A$$

Where,

WR = water requirement of a plant in lit/day

E_{pan} = Pan evaporation in mm,

K_p = Pan factor

K_c = Crop factor

W_p = Wetted percentage

A = Crop area in Sq.mt.

3.11.5 Field layout

The field layout plan for experiment main plot is depicted in Plate3.9. From the source water was pumped through a 0.75 HP motor and conveyed to the field using the 40 mm diameter PVC pipes. From main line to 12 mm lateral lines LDPE pipes

for each treatment were taken to irrigate the beds. There are total 22 beds. Length of main line was 20 m, length of laterals was 10 m, capacity of emitter used was 4 lph and size of plot was 20 X 10.



Plate 3.9 Field layout with drip irrigation system

3.11.5.1 Preparation of the field plot

The experimental plot was thoroughly ploughed with disc plough and repeatedly tilled with cultivator to bring optimum soil tilth. The plots size of 20 x 10 m² was separated and ridges were made around the plot. Raised beds (22 numbers) of 10 m length were prepared and at a spacing of 30 cm. Each plot was leveled manually and ridges and furrows were made. The drip system was laid and installed with complete unit.

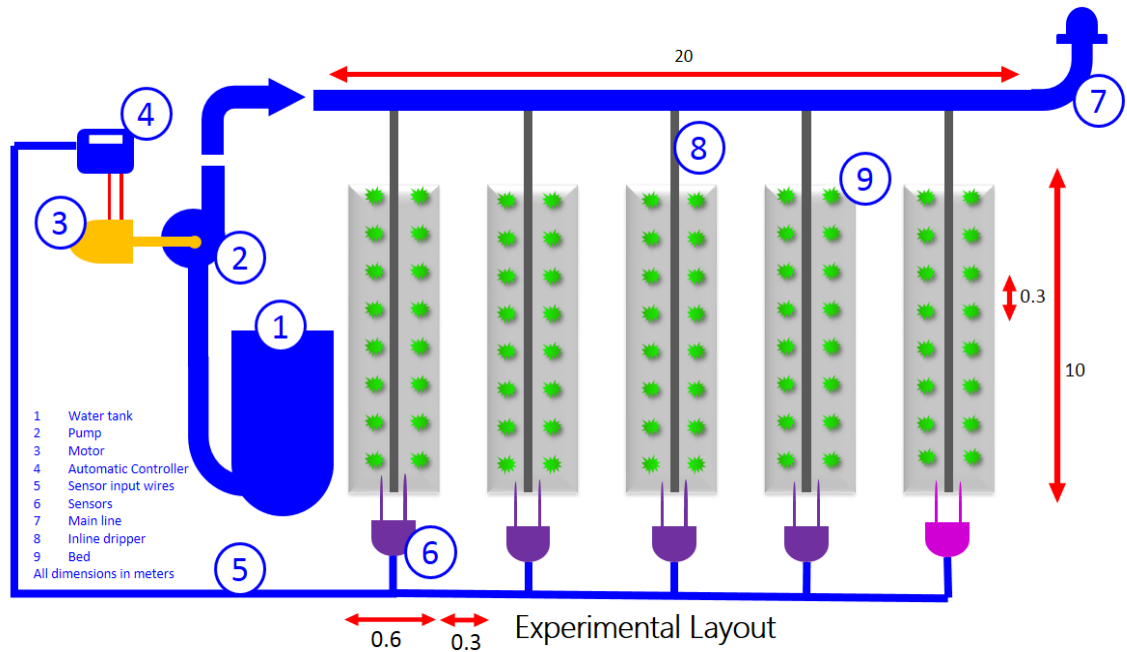


Fig.3.23 Experimental layout

3.11.5.2 Nursery preparation

Amaranth variety “Arun local” was chosen for cultivation. Amaranthus is a transplanted crop. Seeds were sown in the prepared soil bed of 5 X 1 m² at a seed rate of 4.2gm/m². The seedlings were transplanted after two week to the main field and maintained properly.

3.11.6 Irrigation

Immediately after transplanting of plants, irrigation was given to all beds. Drippers were fixed at 40 cm along the lateral line. The 4 lph capacity inline dripper were used for plot size of 20 x 10 m. There were 22 laterals with 25 emitters of 4 lph capacity each. Flow in each lateral was controlled by tap valve.

The irrigation time was set at a conductivity value of required soil moisture sensor before installation. The upper value was estimated by calibration of soil

moisture sensor. After pre-setting the upper value in the data logger, the soil moisture sensor was kept at a proper depth within the active root zone of the crop. As the soil moisture get depleted, conductivity decreased and when it reached the set upper limit, an LED in the control panel illuminated indicating to start irrigation. The system can also activate a single phase motor for pumping water. There is also a manual control for turning the motor ON/OFF.

3.11.7 Fertilizer application

The recommended levels of fertilizer for amranthus crop were used as per the Package of practices recommendations (POP) (KAU, 2005). The various dosages are as follows:

- 50 tonnes of FYM per ha as basal dose before planting.
- Nitrogen: 50 kg/ha in the form of urea
- Phosphorus: 50 ka/ha
- Potassium: 50 kg/ha

- Another 50 kg of N was applied at ten days regular intervals as top dressing. Spraying 1 per cent urea immediately after each harvest can enhance the yield.

3.11.8 Moisture distribution pattern in drip irrigation

Moisture distribution pattern in drip irrigation system was studied for different depth, before and after irrigation to get the variation in moisture distribution with variation in time. The soil moisture contour map was plotted using the computer software package “surfer” in windows version.

CHAPTER 4

RESULTS AND DISCUSSION

The present study was undertaken to develop a drip automation system and to evaluate the performance of the developed sensor based system with reference to the available sensors based on the soil moisture depletion. Experiments were conducted to evaluate the performance of the soil moisture sensors using different concentrations of salt solutions and to develop the calibration curve between the electrical conductivity of solution and sensor conductivity values. Performance of soil moisture sensors were evaluated in different types of soils and calibration curve between the soil moisture content and conductivity values were developed for sandy loam and laterite soil under laboratory condition. The performance of the automation system was evaluated by conducting a field study using the crop red amaranthus. Results obtained from different laboratory study and field experiments are discussed in this chapter.

To set the irrigation time the conductivity value of soil moisture sensor is required to be pre-set before installation. The upper values were estimated by calibrating the soil moisture sensor. After pre-setting the upper value in the data logger, the soil moisture sensor was kept at the desired depth (10 to 20 cm) within the active root zone of the crop. As the soil gets dried up, conductivity gets decreased and when it reaches the set upper limit, the LED in the control panel gets illuminated indicating to start irrigation. The system can be activated by using a single phase motor for pumping. There is also a manual option for turning the motor ON/OFF. The entire setup is shown in Fig.3.23

4.1 Particle size analysis

Soil samples from the selected location were analyzed for particle size distribution using sieve analysis and sedimentation analysis (hydrometer methods) and the results are given in Appendix 1.1 and Appendix2 respectively. Soil texture of

sample 1 is sandy loam and that of sample 2 is laterite particle size distribution curves are shown in Figure 4.1 and 4.2.

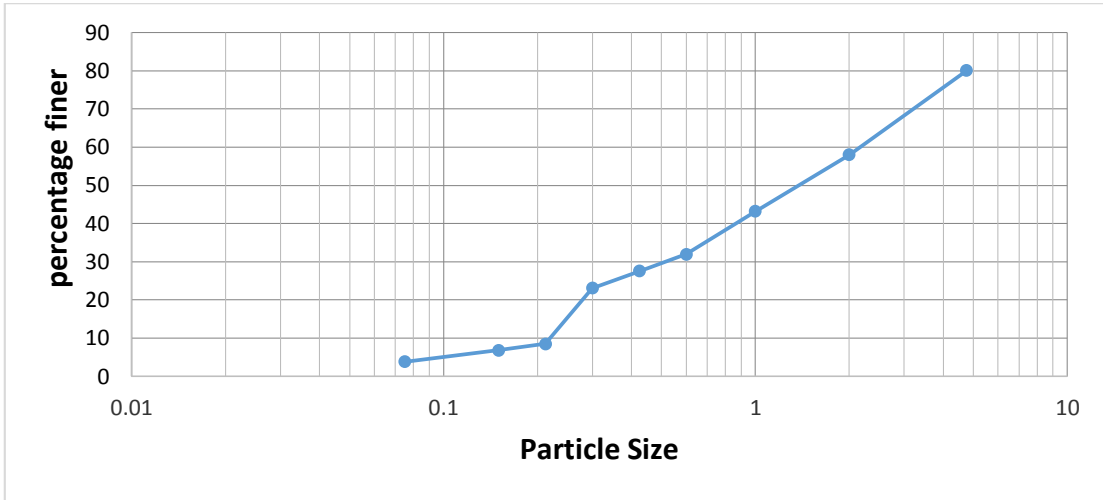


Fig. 4.1 Particle size distribution curve of soil sample 1

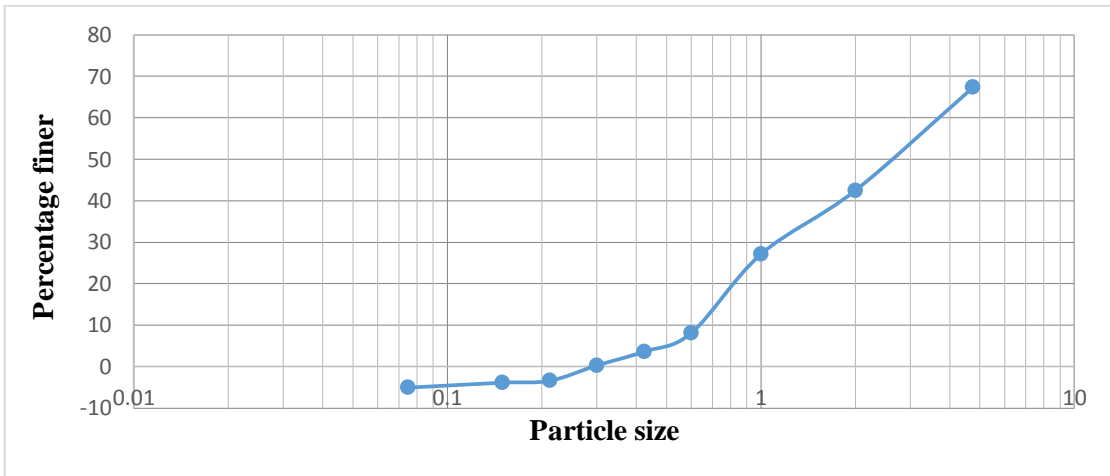


Fig. 4.2 Particle size distribution curve of soil sample 2

4.2 Soil moisture constants

Pressure plate apparatus was used to determine the 2 important soil moisture constants viz. field capacity (FC) and permanent wilting point (PWP). This was done

for scheduling irrigation for the test crop in the test plot (soil sample 1). Field capacity and permanent wilting point of sandy loam soil 18 % and 8% respectively.

4.3 Irrigation water quality

Quality of irrigation water was assessed by estimating the electrical conductivity and pH. The EC of irrigation water was 242 μS and the pH was 7.42.

4.4 Evaluation and calibration of sensor in different EC solutions

The calibration of sensor was done using different concentrations of salts solutions for different soils under laboratory conditions. The results obtained from the laboratory test are discussed below.

4.4.1 Performance soil moisture sensors using different EC solutions

The sensors were calibrated with different EC solutions prepared by adding NaCl salt in distilled water. A significant relation between EC and conductivity value of sensors was observed. The results obtained from calibration of soil moisture sensors with different salts solutions are given in Table 4.1 and the calibration curve is shown in Fig.4.3.

Table 4.1 Calibration of electrical conductivity sensor using different EC solutions

Sl. No.	Quantity of NaCl added in gram	Concentration in ppm	Electrical conductivity (dSm^{-1})	Sensor electrical conductivity (mS/m)
1	0	0	0.01	208
2	0.1	500	1.1	222
2	0.2	1000	1.9	233
3	0.3	1500	3.02	242
4	0.4	2000	3.7	243
5	0.5	2500	4.6	240
6	0.6	3000	5.5	239
7	0.7	3500	6.3	248
8	0.8	4000	7.5	246
9	0.9	4500	9.3	251
10	1.0	5000	9.9	249

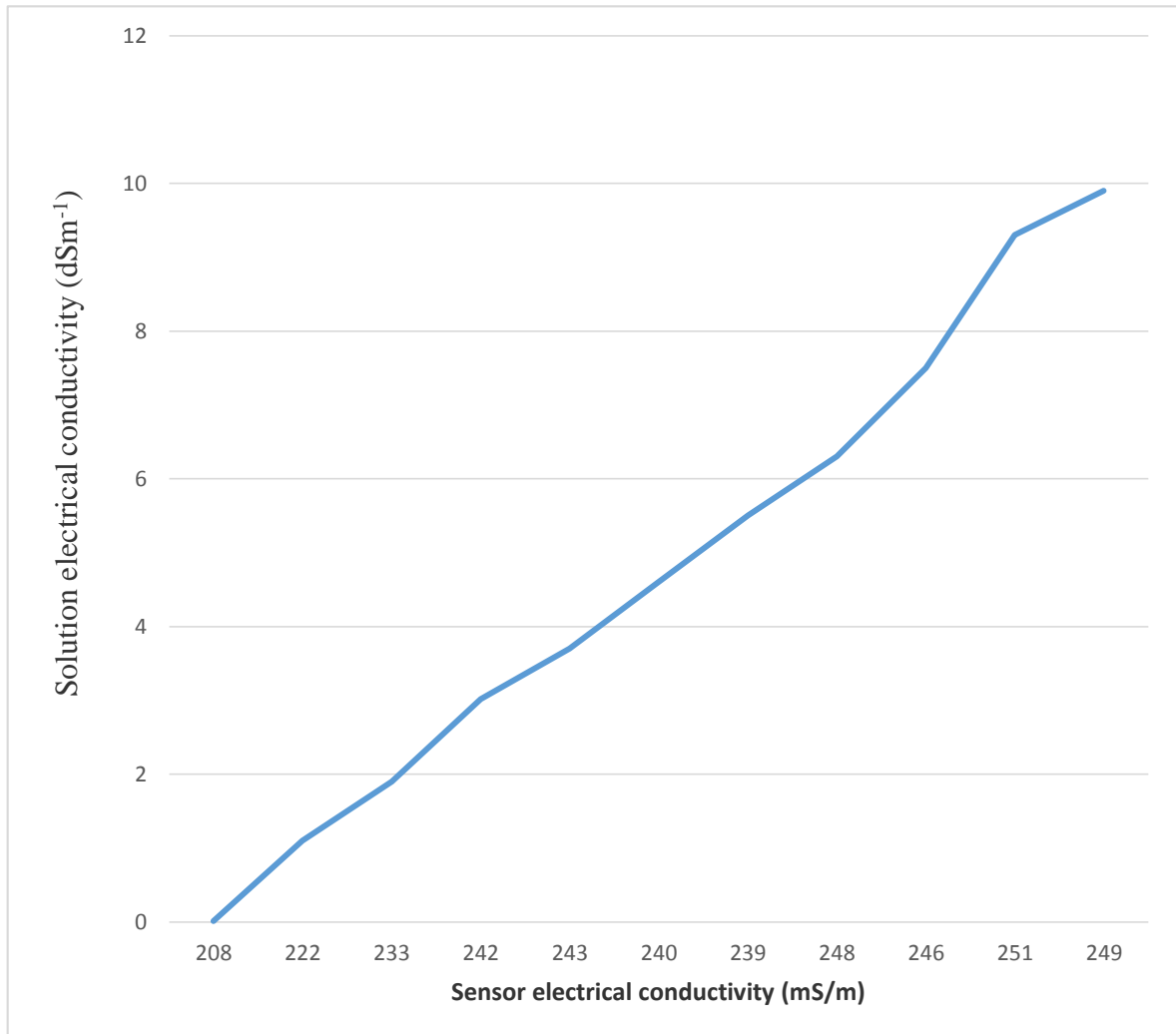


Fig. 4.3 Calibration curve for electrical conductivity sensor

The sensors behaved differently with different concentrations of salts. At lower EC values, the data point followed a linear relationship and as the EC values increased, the relationship became nonlinear and all conductivity sensors followed the similar trend. It was also observed that with increase in the electrical conductivity of solution, the conductivity value of moisture sensor showed increasing trend.

Table 4.2 Calibration of capacitor sensor using different EC solutions

Sl. No.	Quantity of NaCl added in gram	Concentration in ppm	Electrical conductivity (dSm⁻¹)	Sensor electrical conductivity (mS/m)
1	0	0	0.0122	70
2	0.1	500	1.1	124
2	0.2	1000	1.9	127
3	0.3	1500	3.02	127
4	0.4	2000	3.7	125
5	0.5	2500	4.6	125
6	0.6	3000	5.5	130
7	0.7	3500	6.3	127
8	0.8	4000	7.5	127
9	0.9	4500	9.3	128
10	1.0	5000	9.9	136

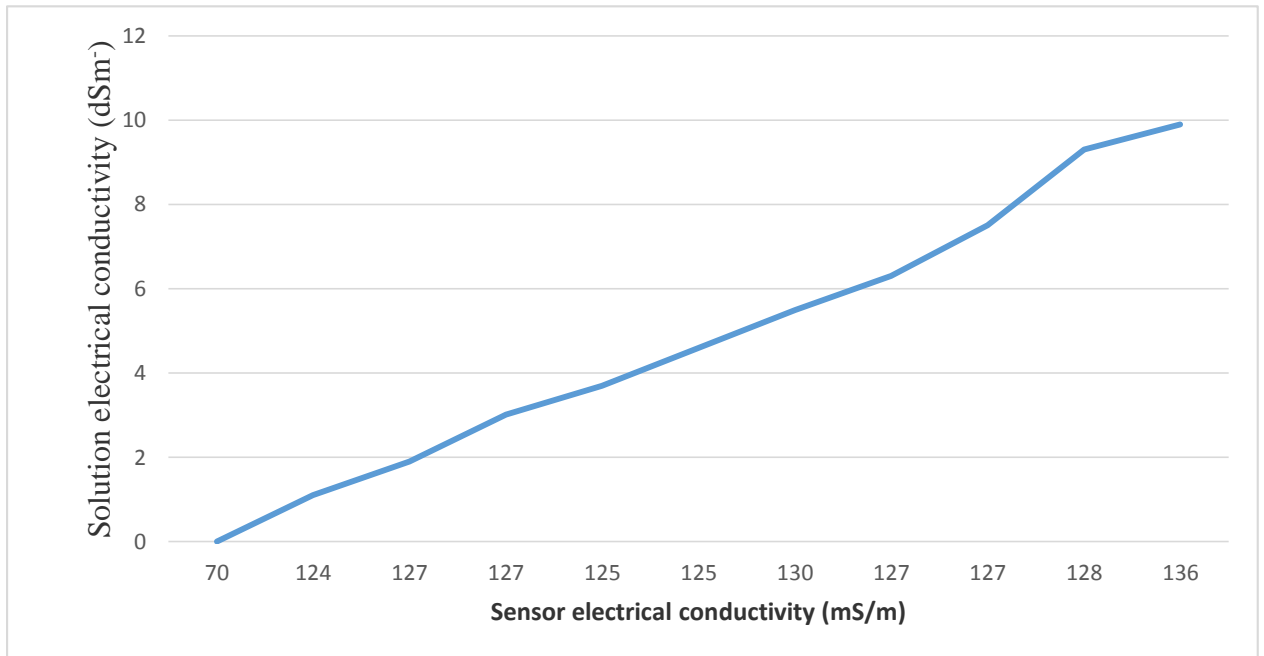


Fig.4.4 Calibration curve for capacitor sensor

In case of the capacitive sensor for different concentrations of salt solutions (EC values) the data point followed a linear trend. It indicated that there is no effect of the electrical conductivity on the sensor performance.

Pure water consists only of water molecules. The electrons in water molecules are held tightly by hydrogen and oxygen atoms and are not free to move. By dipping soil moisture sensor and EC probe to a container of water produces no electric current and it shows the conductivity value as 70 to 251 mS/m with EC of 0.01 dSm^{-1} because pure water is an insulator. But a few grains of table salt added to the water changes things completely. Sodium ions are released from the salt, and the salt water solution becomes conductive. This leads to abrupt change in the shape of graph as shown in Fig 4.4. due to the sudden increase in the conductivity of the salt solution.

From the Fig.4.4. It can be observed that there exists a significant logarithmic relation between electrical conductivity and conductivity of sensor 1, sensor 2 and

sensor 3 with an R^2 values of 0.97, 0.96 and 0.967 respectively with a mean R^2 value of 0.964. It was evident that the logarithmic relation (Farooque, et al., 2011) resulted in high R^2 value compared to linear relation because the sensors were tested for wide range of electrical conductivity i.e. 0.01 dSm^{-1} to 9.9 dSm^{-1} . A small variation in R^2 caused considerable variation in the electrical conductivity over the lower range. However from the evidence of high R^2 value by logarithmic relation, it was confirmed that the results are significant and satisfactory.

The calibration procedure presented in chapter- 3 can be used to measure a wide range of electrical conductivity with respect to electrical conductivity of salt solution. The lowest value of electrical conductivity as measured by sensor was 70 mS/m in the air and zero mS/m . When sensor was in contact with any good electrical conductive metal like copper. The geometry of the sensor and material used affects the attenuation of the sensor reading and thus determines the range of the measurement. However, a very high concentration of salt, which is for higher electrical conductivity, the conductivity value of the sensor is not changing proportionally. The conductivity turns to nonlinear at diminished rate with increasing concentration of salt. At this stage addition of a small quantity of salt increases the electrical conductivity of solution, but does not cause any change in the conductivity value of sensor. This affects the accuracy of the measurement at higher electrical conductivities.

Similarly Mojid et al. (1997) observed that electrical conductivity of medium invaded by TDR sensors can be estimated from the impedance of TDR reflectometer. Four categories of sensors were tested in salt solution and the impedance of TDR pulse waves were correlated to the electrical conductivity of the solution. The relationship between the impedance and electrical conductivity over a wide range of conductivity values was found to be nonlinear but stable.

4.5 Evaluation and calibration of sensors in different soils

The soil types included in the study were sandy loam and laterite soil. Soil electrical conductivity values (mS/m) obtained from data were plotted against water content (%) for each type of soil. The relationship between soil electrical conductivity values of sensors and soil moisture content are shown in Fig.4.5 and 4.6.

4.5.1 Calibration of sensor in sandy loam soil

Soil moisture sensor was evaluated in relation to the moisture content in the sandy loam soil in the laboratory. The electrical conductivity values obtained using the sensor from the laboratory test with respect to soil moisture content for sandy loam soil are presented in Tables 4.3 and 4.4.

Table 4.3 Calibration data of capacitor and electrical conductivity sensors for varying moisture content in sandy loam soil (first trial)

Sl. No.	Moisture content (%)	S1	S2	S3	S4 (Capacitor types)	Mean
1	27.45	7.7	5.5	17.5	12.4	10.8
2	25.34	6.4	5.7	7.9	9.7	7.8
3	23.23	6.7	7.0	7.8	9.7	7.7
4	21.96	3.0	5.8	3.9	10.7	5.7
5	20.04	5.3	7.4	6.1	7.9	6.7
6	17.64	9.0	5.8	11.8	8.2	6.0
7	15.5	8.5	6.0	13.6	8.2	9.1
8	14.2	3.7	5.5	9.9	8.8	7.0
9	11.66	4.8	6.7	6.7	7.2	6.3
10	10.78	6.2	5.9	3.3	5.4	7.5

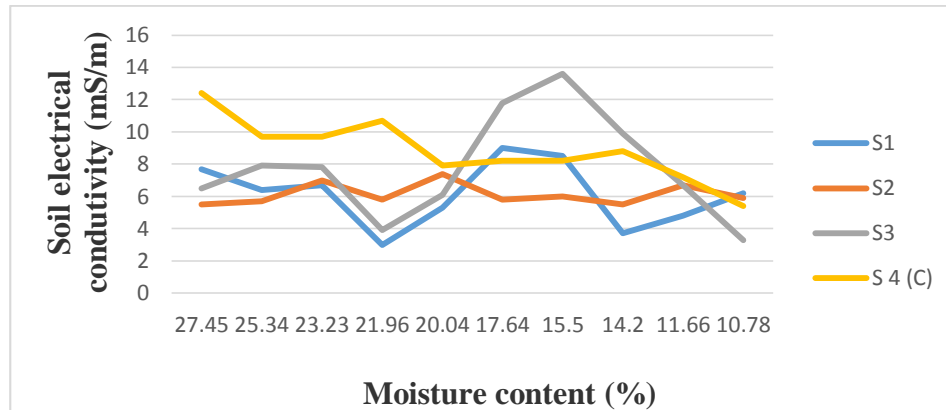


Fig.4.5 Calibration curve for sensors in sandy loam soil (first trial)

Table 4.4. Calibration data of capacitor and electrical conductivity sensors for varying moisture content in sandy loam soil (second trial).

Sl. No.	Moisture content (%)	S1	S2	S3	S4 (Capacitor types)	Mean
1	26.5	4.6	13.0	4.9	10.9	8.2
2	22.8	19.2	9.3	5.9	10.3	11.1
3	21.7	7.4	7.2	5.2	7.7	6.8
4	18.5	7.2	8.6	6.7	8.9	7.9
5	17.6	3.6	5.6	4.4	6.8	5.1
6	14.6	9.3	10.4	9.3	7.9	9.1
7	12.7	2.0	2.5	2.9	7.3	3.3
8	10.6	5.6	4.3	12.0	6.9	7.2
9	10.1	4.0	3.7	6.0	6.6	5.0
10	9.2	3.5	4.8	4.1	5.9	4.3

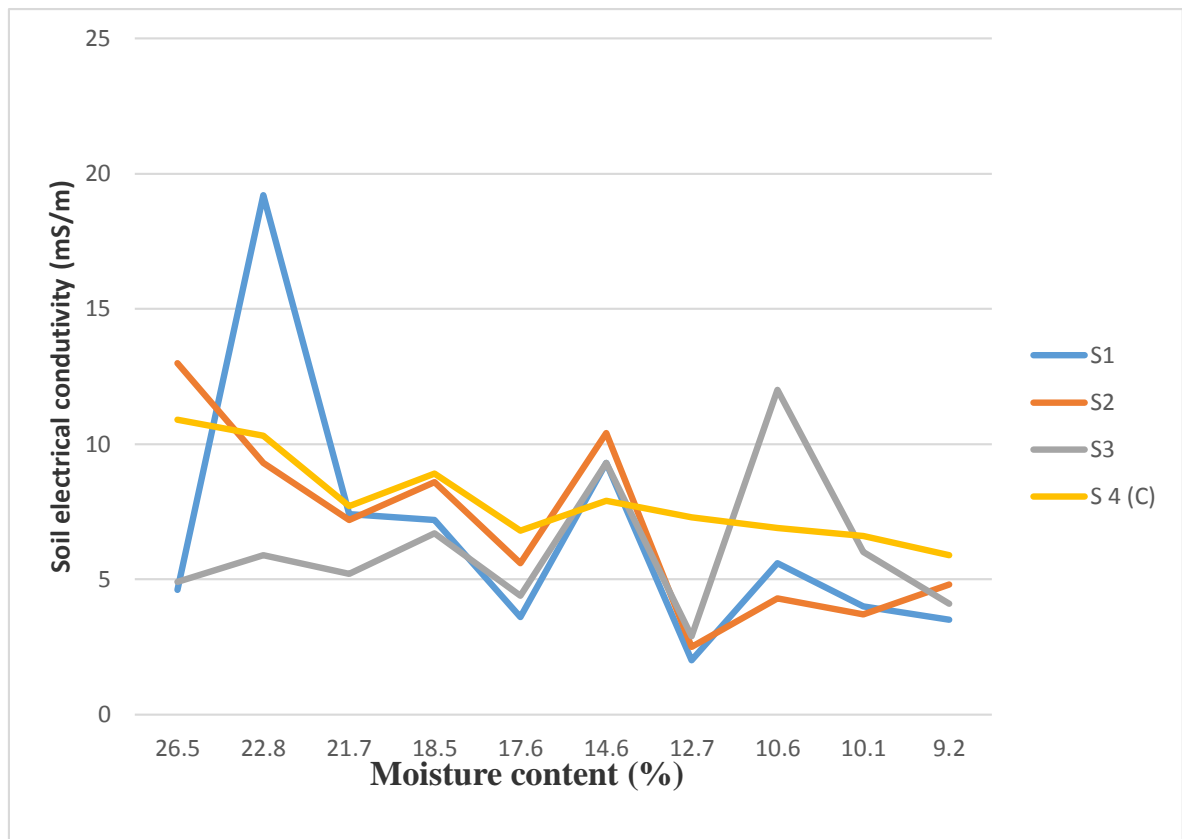


Fig. 4.6 Calibration curve of sensors in sandy loam soil (second trial)

From the table, it can be seen that the maximum and minimum electrical conductivity values were at soil moisture content of 9.2 percent and 27.42 percent. Maximum and minimum values of electrical conductivity indicate that soil is in wet and dry conditions respectively. It was observed that as soil gets dried up, the electrical conductivity decreases.

It was observed from the capacitance sensor that the maximum and minimum conductivity values were 12.4 and 5.4 mS/m at soil moisture content of 27.45 percent

and 9.2 percent. Maximum and minimum values of conductivity indicate that soil is in wet and dry conditions respectively. It was observed that as soil becomes dried up, the conductivity decreases.

The calibration curve were plotted with respect to electrical conductivity and moisture content values from the two different trials and are shown in Figure 4.5 and 4.6. It was observed that a liner relation exits between electrical conductivity and soil moisture content. It is because of the fact that the electrical conductivity decrease with increase in moisture content and increased with decrease in moisture content of soil.

The calibration curve depicts was observe the that during first trial the electrical conductivity varied from 9.0 to 5.8 mS/m at field capacity (17.64 %) and varied between 6.2 to 4.9 mS/m at permanent wilting point of (10.78%). During second trial electrical conductivity of 8.6 to 6.7 at field capacity of (18.5) % and varied from of 5.6 to 4.3 mS/m at permanent wilting point (10.5 %).

But for the capacitive sensor it was observed that during first trial the conductivity was within the range of 8.2 to 7.8 mS/m with respect to field capacity (17.6 %) and within the range of 5.4 to 5.9 mS/m permanent wilting point of (10 %). During second trial conductivity varied from 8.9 to 9.4 mS/m at field capacity of (18.5 %) and conductivity of 4.8 to 5.9 mS/m at permanent wilting point (9.2 %).

The statistical regression analysis reveals that it was observed that R^2 values are 0.936 and 0.968 for first and second trial respectively under laboratory experiment. The higher R^2 value showed satisfactory results in performance of soil moisture sensor for sandy loam soil.

This could be explained based on the fact that sandy soil and weathered granite soils contain more coarse soil particle than silty soil.

4.5.2 Calibration of sensor in laterite soil

Soil moisture sensor was evaluated in relation to the moisture content in the laterite soil in the laboratory. The electrical conductivity obtained using the sensors from the laboratory test with respect to different soil moisture for laterite soil are presented in Tables. 4.5 and 4.6

Table 4.5 Calibration data of capacitor and electrical conductivity sensors for varying moisture content in laterite soil (first trial)

Sl. No.	Moisture content (%)	S1	S2	S3	S4 (Capacitor types)	Mean
1	22.74	4.0	5.8	14.1	9.5	8.3
2	18.30	5.1	7.5	6.7	8.9	7.0
3	17.25	5.4	8.9	5.9	5.7	6.5
4	16.76	4.8	4.3	5.6	4.5	4.7
5	15.21	6.1	6.8	6.2	4.2	5.8
6	14.22	5.0	5.8	5.4	4.9	5.3
7	12.95	4.9	10.8	5.9	3.4	6.3
8	12.53	5.2	7.8	5.6	4.2	5.6

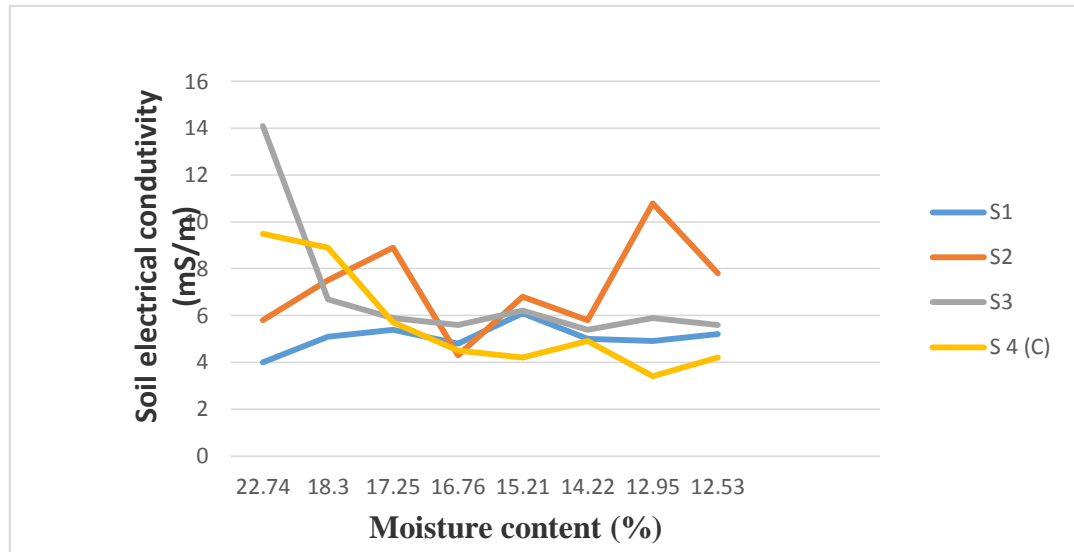


Fig.4.7 Calibration curve for sensors in laterite soil (first trial)

Table 4.6 Calibration data of capacitor and electrical conductivity sensors for varying moisture content in laterite soil (second trial)

Sl. No.	Moisture content (%)	S1	S2	S3	S4 (Capacitor types)	Mean
1	19.57	8.6	15.1	7.0	8.5	9.8
2	17.60	8.3	8.0	6.6	8.4	7.7
3	14.50	8.3	5.0	6.6	8.8	7.2
4	13.80	8.3	15.7	6.1	9.4	9.9
5	11.40	8.4	15.3	6.1	9.4	9.8
6	10.56	3.2	15.8	4.0	6.7	7.3
7	8.44	4.8	8.1	3.1	6.6	5.5
8	7.46	2.4	4.6	2.8	5.7	5.4

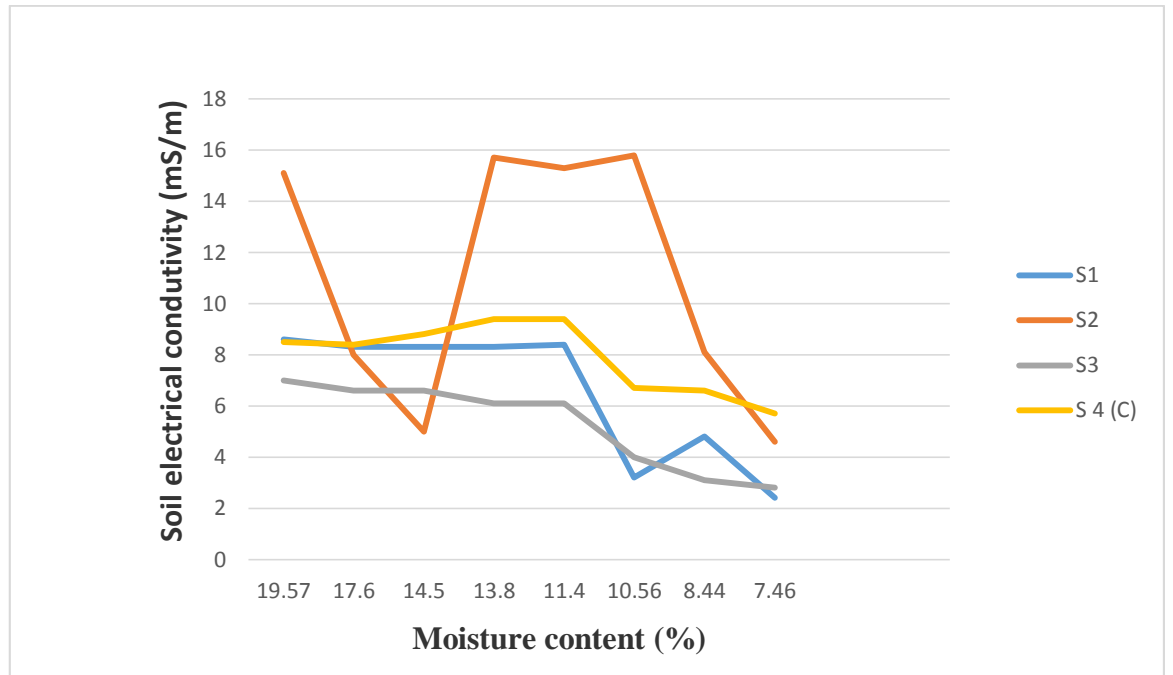


Fig.4.8 Calibration curve for sensors in laterite soil (second trial)

From the table, it can be seen that the maximum and minimum electrical conductivity were 14.1 and 3.4 mS/m at soil moisture content of 12.53 percent and 22.74 percent. Maximum and minimum values of electrical conductivity indicate that soil is in wet and dry conditions respectively. It was observed that as soil becomes dried up, the electrical conductivity decreases.

For capacitance sensor it was observed that the maximum and minimum conductivity values of 9.5 and 4.2 mS/m were at soil moisture content of 22.74 percent and 12.53 percent. Maximum and minimum values of conductivity indicate that soil is in wet and dry conditions respectively. It was observed that as soil becomes dried up, the conductivity decreases.

During second trial electrical conductivity varied between from 15.1 to 15.5 mS/m at field capacity (19.57 %) and varied from 4.6 to 2.4 mS/m at permanent wilting point (7.46 %).

For capacitance sensor values ranged from 8.4 to 8.5 mS/m at field capacity of (19.57 %) and from 5.6 to 5.7 mS/m at permanent wilting point. (10%).

The calibration curve were plotted with respect to electrical conductivity and soil moisture content values from the two different trials and are shown in Fig. 4.7 and 4.8. It was observed that a linear relation existed between electrical conductivity and soil moisture content in laterite soil also, electrical conductivity decreased with decrease in moisture content and increased with increase of moisture of laterite soil.

Overall data showed nearly constant trend in the relationship between the soil electrical conductivity and soil moisture content in all the trials but the calibration of sensors showed different soil conductivity value with respect to moisture content in different type's soils. It may be because of the fact that different soils have different physical properties like bulk density, water holding capacity, texture arrangement etc. even during different trials in the same types of soil, the conductivity value are changing. So it is important to calibrate the sensor in each type of major soils where soil moisture sensors are to be used. This finding is supported by the findings of Whalley et al. (2001) that calibration curve was not repeatable when the sensor are used in different soils.

Abraham et al. (1999) evaluated different sensors based on the electrical resistance. 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.

Yoon et al. (2002) stated the effects of soil types on resistivity. They found that sandy soil and weathered granite soil showed relatively higher resistivity values than silty soil .This could be explained by applying the fact that sandy soil and weathered granite soil contain more coarse soil particle than silty soil.

Adamchuk et al. (2003) observed that soil types (mainly soil texture) significantly affect the output of most commercially available electrical resistivity/

conductivity sensors. Field variability of soil salinity, moisture content and other characteristics interface with this relationship.

Similar results were observed by Hignett and Evett (2008). It was observed that good contact between the sensor and soil are essential. This contact might be problematic in gypsum sensors which is of limited use, as much of the soil water had gone before the fine pores in the gypsum begin to drain and the sensor registered a change. This impact limits the utility of this sensor in its conventional form.

The data obtained from the calibration of sensor in different soils can be used for irrigation scheduling by setting upper and lower limits to increase the water use efficiency.

4.6 Features of the automation system

The soil moisture sensor is simple, precise, sensitive, lightweight and economical in construction and quick in use. The major advantages of the method are speed of measurement, low cost and portability. The system can easily be adapted for use with automatic logging equipment. There is scope for further optimization of the electrode geometry to improve the shape and length of the probe and the cost of the unit.

4.7 Limitation of the automation system

The nonlinearity and apparent soil dependence of the calibration curve and the use in shrinking soils may present difficulties due to development of variable air gap. The nonlinearity of the calibration curve is probably not a major disadvantage over the normal range of moisture change in any given soil.

The equipment needs a high voltage electricity and hence it should be handled with adequate protection and precaution. There is no user serviceable part inside the equipment and if any abnormality is observed, the power has to be put off and for service of a technician has to be called for.

4.8 Field trial

The drip automation system was laid out in the test field planted with red amaranthus and irrigation was scheduled. In addition, wetting pattern of the soil was also studied. The results obtained from the above investigations are presented and discussed below.

About 1 week after the installation of the sensor, some deposits were found to form on the electrode plates that reduced the electrical conductivity between the electrode plates. These deposits may be due to the polarisation of certain ions present in the soil. The same trend was found immediately after the addition of fertilisers to the soil. This is in agreement with Abraham et al. (1999).

Application of fertilizers or chemicals can change the conductivity-moisture content relationship and therefore calibration of sensor is required after adding fertilizers or chemicals. Such variations are not observed for the system based on capacitor type sensors. This is in agreement with Miller et al. (2014).

The capacitor sensor probes with factory calibration were found to be sufficiently accurate for irrigation scheduling purposes in typical sandy coastal plains soils found in South Carolina. Future work can substantiate to determine set points for other vegetable crops for evaluating the performance of capacitor probes in other soil types and farm settings and explore the potential of reduced nutrient application when water and solute movement below the root zone is reduced.

Tested crop amaranthus was used for the study and the yield was used for the seed purpose. Total 5 Kg. seed was obtained from the experimental plot (200 m²) area.



Plate 4.1 Field evaluation electrical conductivity sensors in amaranthus crop



Plate 4.2 Field evaluation capacitor sensor in amrnthus crop

4.8.1 Soil moisture distribution pattern 2 hours after irrigation

In order to study the moisture distribution pattern around the plant the soil moisture content was measured at different depths below the soil surfaces at varying radial distances from the plant. Soil moisture distribution pattern for the 2hr and 6hr after irrigation is shown in Fig. 4.7 and 4.8. At the 2hr after irrigation amount of moisture content decreased as the distance from the plant increased due to lateral spacing and the moisture content near the plant was 9.42 per cent. This is in agreement with Reddy *et al.* (2001). The moisture content at 5cm depth near the plant was 8.5 per cent. The moisture content reduced from 8.5 per cent to 3.4 per cent at a depth of 5cm to 20 cm. The percentage decrease in moisture content near the plant was 60 per cent. At a distance of 10cm from the plant the moisture content increased from 8.3 to 8.56 per cent for a depth of 5cm from surface. After irrigation 2hr the moisture content reduced from 8.56 to 3.52 per cent at a depth of 5cm to 20cm. The percentage decrease in moisture content at a distance of 10cm from the plant was 58.8 per cent for a depth of 5cm to 20cm.

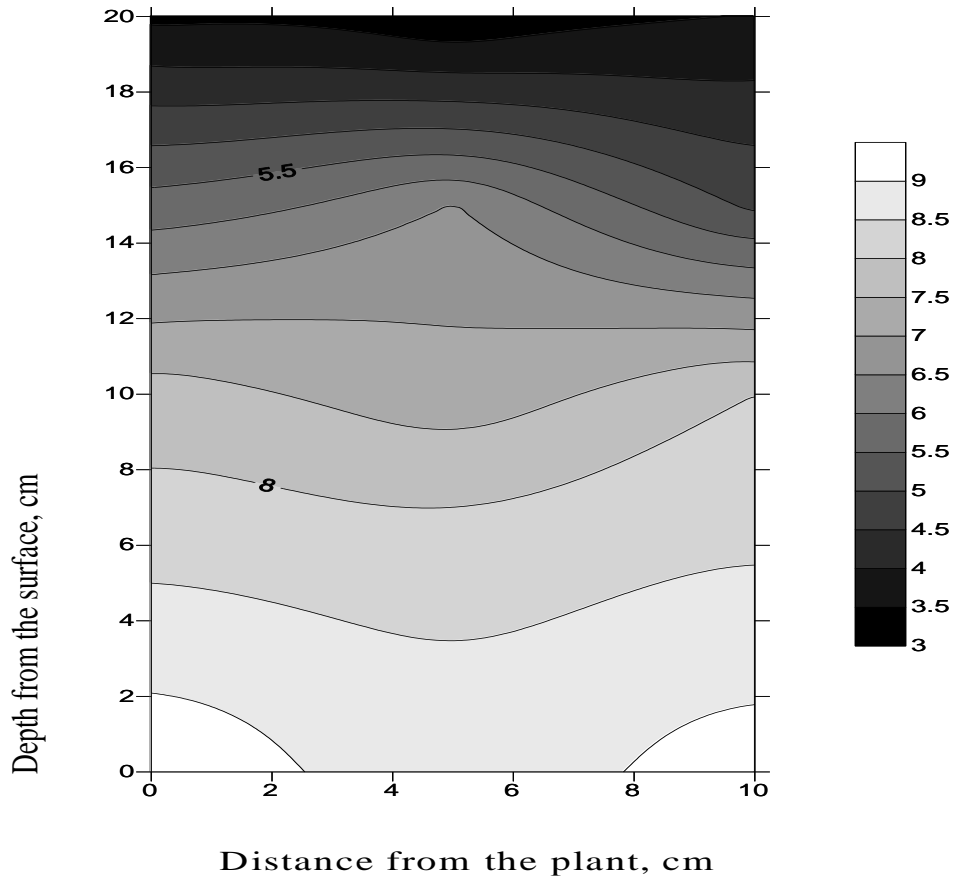


Fig.4.9 Soil moisture distribution pattern 2 hr after irrigation.

4.8.2 Soil moisture distribution pattern 6 hours after irrigation

The moisture content found to decrease with increase in time and also with increase in the lateral distance at a depth of 20cm. After 6hr soil moisture content decreased as the distance from the plant increased due to increase in spacing of laterals. After 6hr the moisture content near the plant was 8.2 per cent and the moisture content at 5cm depth near the plant was 7.6 per cent. The moisture content reduced from 7.6 per cent to 1.85 per cent from the depth of 5cm to 20 cm. The percentage decrease in moisture content near the plant was 75 per cent. At a distance of 10 cm from the plant the moisture content decreased from 7.6 to 5.5 per cent for a depth of 5cm from surface. After 6hr of irrigate on the moisture content reduced from 5.5 to 1.69 per cent

for the depth of 5cm to 20cm, The percentage decrease in moisture content at a distance of 10cm from the plant was 69 per cent for a depth of 5cm to 20cm.

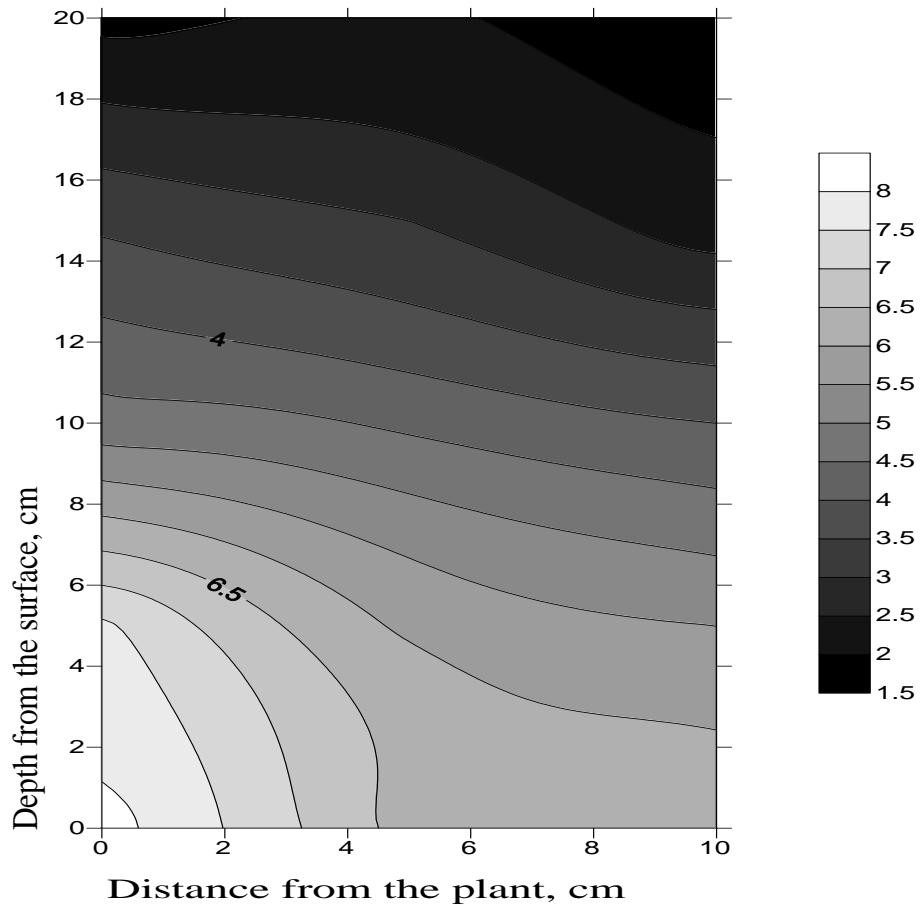


Fig.4.10. Soil moisture distribution pattern, 6 hr after irrigation

CHAPTER V

SUMMARY AND CONCLUSIONS

In irrigation management, automation refers to those innovations which partially or fully replace manual intervention from the irrigation operation using a computer specifically programmed for the purpose. The present study has been undertaken to design and develop a low cost automation system for drip irrigation so that it can measure the field moisture level and irrigate the field based on the soil moisture. The study involved the development and evaluation of the soil moisture sensors, development of automation system and laboratory and field testing of the system.

The soil moisture sensors used for experiment were developed, tested and calibrated for scheduling irrigation automatically. In order to pierce to selected depths and for easy installation in soil, sensor has cylindrical rod shape in bottom end. Drip automation unit is simple to install and uninstall. The instrument consists of constant current source, electrode, amplifier, relay, display unit and microcontroller.

Drip automation system switches ON the irrigation system when the sensor value reaches a pre-set reading. The irrigation system will be operated until the soil moisture content reaches the field capacity of soil. As the soil dries, water content decreases and the conductivity value in data logger decreases. The irrigation system will run until the conductivity reaches the pre-set critical value. There is a provision to start the motor also. In this way soil moisture sensors continuously record the fluctuations in soil water content under field conditions and store the data for every one hour and that can be transferred to PC for further analysis.

Experiments were conducted in the laboratory of the Department of Soil and Water Engineering, KCAET, Tavanur. Soil moisture sensor was placed in the soil pot and conductivity values were recorded related to soil moisture content in soil. Soil samples were collected from the experimental plots and two other sites of the college

campus and soil constants were determined. Laboratory tests were conducted to evaluate the sensor performance of the drip automation system in salt solution, sandy loam and laterite soil to develop the calibration curves.

The sensors were calibrated with different EC solutions prepared by adding NaCl salt in distilled water. A significant relation between electrical conductivity and conductivity value of sensors was observed. It was observed that a significant logarithmic relation exists between electrical conductivity and conductivity value of sensor 1, sensor 2 and sensor 3 with R^2 values of 0.97, 0.96 and 0.967 respectively. It was evident that the logarithmic relation resulted in higher R^2 value compared to linear relation as the sensors were tested for wide range of electrical conductivities.

Soil moisture sensor was evaluated with respect to the moisture content for sandy loam soil and laterite soil. It was clearly observed that as the moisture content decreases, the conductivity of sensor decreases. During calibration of the sensors in the same type of soil under different trials, different values with respect to the moisture content was noticed. This might be due to the difference or non-uniformity in soil texture and air gap between the soil and soil moisture sensor.

In some soils, cracks were easily formed which were responsible for the air gap between the soil and the sensor. So it is important to calibrate the sensor in different types of major soils where soil moisture sensors are to be used. Also care should be taken while fixing the sensors in the soil for measurement

The equipment needs high voltage electricity, hence it should be handled with adequate protection and precaution. There is no user serviceable part inside the equipment and if any abnormality is observed, the power has to be put off and the service of a technician has to be called for.

Thought developed automation system shows positive results, unfortunately, these results have not yet been adopted by manufactures and farmers. A greater effort must be done to popularize and demonstrate the advantages of the these advanced

technique (improving crop management, yield, water use efficiency and accuracy) in order to boost the commercialization of the new product which can lead to a more sustainable and rational use for resources.

Conclusions

- The drip automation system based on soil moisture deficit was developed, which works on the principle of electrical conductivity offered by soil when current passes through it.
- The developed sensors were evaluated in different concentrations of salt solutions and it showed a logarithmic relation between electrical conductivity and sensors electrical conductivity.
- The system was installed in the field for a season under the crop amaranthus and it was observed that the system is working properly and the motor gets switched “ON” and “OFF” automatically with respect to pre-set value of moisture content.
- The developed system is economical, light weight and water proof.
- Future research on the system is possible by calibrating the sensors in different soils using different concentrations of saline water.
- For standardization of the sensor it is to be calibrated in different soils.
- These are scope for further optimization of the electrode geometry to improve the shape and length.
- Irrigation can be divided into different section and use of solenoid valve for each section is possible. DC supply for the sensors can be used in future.
- Solar power based automation instrument could be developed. The instrument further can be modified to wireless control system.
- The capacity of the system can be modified in order to store large number of readings. The size of the display board can be modified in future.
- The system can be modified for multiple sensors and multiple water pump control.

- A power conservation method can be introduced using which the wireless sensors would work with the help of electricity from the solar panels. Each sensor would have a panel attached to it to derive the necessary working current.
- This circuit can also be extended with atmospheric temperature and humidity sensors for switching on sprinklers when humidity is low.
- The monitored parameters can be wirelessly transferred and displayed and can be modified with the controlling of water pumping mechanism through the GSM modem.

REFERENCES

- Abraham, N., Hema, P.S., Saritha E.K. and Subramannian, S. 1999. Irrigation Automation Based on the Soil Electrical Conductivity and Leaf Temperature. *Agricultural Water Management*. **45**:145-157.
- Adamchuk, V.I., Upadhyaya, S.K., Hummel, J.W. and Morgan, M.T. 2003. On-the Go-Soil Sensors for Precision Agriculture. *Computer and Electronics in Agriculture*.**44**:71-91.
- Anil Kumar Singh, Manoj Khanna, D., Chakraborty and Ashwani Kumar. 2001. Increasing water and nutrient use efficiency in Broccoli through Fertigation. In: Singh, H.P., Kaushish, S.P., Ashwani Kumar, Murthy, T.S., Jose, C and Samuel. (eds.). 2001. *Micro Irrigation*. Central Board of Irrigation and Power, New Delhi, 442p.
- Bierman, P. 2005. Managing Irrigation for High-Value Crops. University Of Alaska Fairbanks Cooperative Extension Service. FGV- 0064.
- Brace Center for Water Resources Management. 2008. Sand –Filter Used For Wastewater Treatment: Buildup and Distribution of Microorganisms. *Water Resources*. **33**(8): 1994-1955.
- Brandelik, A. and Hibner C.1996. Soil moisture determination – accurate, larger and deep. *Phys.Chem. Earth*. 21(3): 157-160.
- Brevik, E.C., fenton T.E., and hortan R. 2004. Darily soil temperature fluctuations on soil Electrical Conductivity as measured with the geonics EM-38. *Precision Agriculture*.**5**:145-152.
- Campbell C., Butler M. and Middlestandt, B. 2005. Comparison of two soil moisture sensors in drip-irrigated. User guide. Campbell scientific, Inc. Logan, UT.
- Campbell G.S. and Mulla, D.J.1990. Measurement of soil water content and potential. Chapter 6 In Stewart B.A. and Nielsen D.R. (co-editors). Irrigation of

- agricultural crops. *American Society of Agronomy*. Madison, USA, pp127-142.
- Cardenas-Lailhacar, B., Dukes, M.D. and Miller, G.L., 2010. Sensor-based automation of irrigation on Bermuda grass, during dry weather conditions. *Journal of Irrigation and Drainage Engineering* 136, 184.
- Carpena R.M. and Dukes, M.D. 2005. Automatic Irrigation Based on Soil Moisture for Vegetable Crops. Department of Agricultural and Biological Engineering, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. First published: June 2005. Reviewed: June 2008 and March 2011.
- Carpena, R.M. Dukes, M. D., Yuncong C. L., and Waldemar Klassem 2005. Field Comparison of Tensiometer and Granular Matrix Sensor Automatic Drip Irrigation on Tomato *hortitechnology* July–September 15(3).
- Cardenas, C.A., Barrett, M.E., Walsh, P.M., Malina J.F. and Charbenau, R.J.2001. Sensor- based on automation of irrigation on Bermuda grass during wet weather conditions. Reflec published in *soil sci. soc. Am. J* 65:25-34.
- Casadesús J., Mata, M. Marsal, J. and Girona J.2012. A general algorithm for automated scheduling of drip irrigation in tree crops. *Computers and Electronics in Agriculture* 83:11–20.
- Castanon, G., 1992. The automation irrigation. *Maquinas of tractors agricols* 3 (2), 45-49.
- Chard, J., 2004. Watermark soil moisture sensors: characteristics and operating instructions. *Technical report*. Utah state university.
- Charlesworth, P. 2005. Soil water monitoring, irrigation insights no.1, second edition.
- Choudhary D.R. and Jain S.B.2003. Linear integrated circuits (2nd edition). New age international publishers.

- C.W.C.2005. Drip irrigation system and its relevance in water use. Irrigation research management improvement organization. *Central Water Commission, New Delhi*.
- Czarnomski N.M., Moore G.W., Pypker T.G., Licata J., and Bond B.J.2005. Precision and accuracy of three alternative instruments for measuring soil water content in two forest soils of the Pacific Northwest. *Can. J.For. Res.* 35:1867-1876.
- Dhanpal, R., Yusuf, M. and Bopaiah, M.G. 1998. Moisture movement studies under drip irrigation in coconut basin. *J. Plantn Crops.* 23(1): 28-34.
- Divya, V. and Umamakeswari, A. 2013. Smart irrigation technique using vocal commands. *International Journal of Engineering and Technology (IJET)* Vol 5 No 1.
- Dukes M.D.,Eric H., Simonne, W. E.,DavisD. W. and Studstill, R. H.2003. Effect of sensor-based high frequency irrigation on bell pepper yield and water use, Proceedings 2nd International Conference on Irrigation and Drainage, Phoenix, AZ May 12-15., pp. 665-674.
- Dukes, M.D., Carpena, R.M., Zotarelli, L., Icerman, J. and Scholberg J.M. 2007. Soil moisture-based irrigation control to conserve water and nutrients under drip irrigated vegetable production *Estudios de la Zona No Saturada del Suelo Vol. VIII.* J.V. Giráldez Cervera y F.J. Jiménez Hornero.
- Dursun, M. and Ozden, S. 2011. A wireless application of drip irrigation automation supported by soil moisture sensors. *Scientific Research and Essays* Vol. 6(7), pp. 1573-1582.
- Fares A. and Polyakov, V.2006. Advances in crop water management using capacitive water sensors. *Advances in Agronomy.*90:43-77.
- Farooque, U.M. 2011. Design and development of moisture deficit based drip automation system. *Indian journal of natural sciences*, vol 2, oct 2011.

- Fernandez, J.E., Romero, R., Díaz-Espejo, A., Cuevas, M.V., Muriel, J.L., and Montano, J.C. 2008 b. A device for scheduling irrigation in fruit tree orchards from sap flow readings. *Acta Horticulturae* 792, 283–290.
- Gartley, K.L. 2003. Recommended soluble salts tests. Review paper.
- Gonc, A., Rodrigues, C., Paredes, P. Gonc, J.M., Alves, I. and Pereira, L.S. 2013. Comparing sprinkler and drip irrigation systems for full and deficit irrigated maize using multi criteria analysis and simulation modelling: Ranking for water saving vs. farm economic returns. *Agricultural Water Management* 126 85– 96.
- Evans R., Cassel D.K. and Sneed R.E. 1996. Calibrating soil-water measuring devices published by North Carolina cooperative extension service, publication number AG 452-3.
- Gupta J.B. 2002. Electronics device and circuits. S.K. kataria & sons publishers.
- Hanson, B., and Orloff, S. 2007. Monitoring soil moisture for irrigation water management.
- Hartsock N.T., Mueller T.G., Thomas G.W., Barnhisel R.I., Wells K.L. and Shearer S.A. 2000. Soil Electrical Conductivity variability. Proc. 5th international conference on precision agriculture. ASA Misc. Publ.
- Heng, L.G. 2003. Comparison of soil moisture sensors between neutron probe, time domain reflectometry and capacitance probe. Report of the FAO/IAEA. Final consultants meeting held in Vienna.
- Hignett, C. and Evett, S. 2008. Electrical resistance sensors for soil water tension estimates. Field estimation of soil water content: a practical guide to methods instrumentation and sensor technology. International atomic energy agency, Vienna: 123-131.

- INCID .2004. Drip irrigation in India, Indian national committee on irrigation and drainage, New Delhi.
- Jain, V.K, Shukla, K.N. and Singh, P.K. 2001. Response of potato under drip irrigation and plastic mulching, In: Singh, H.P., Kaushish, S.P., Ashwani Kumar, Murthy, T.S., Jose, C and Samuel. (eds.). 2001. *Micro Irrigation*. Central Board of Irrigation and Power, New Delhi, pp. 49-27.
- Jeffrey, P., Walker, Garry, R. W. and Jetse, D.K. 2004. In-situ measurement of soil moisture: a comparison of technology, Department of Civil , Survey and Environment Engineering, The University of Newcastle, Callaghan, NSW 2308, Australia.
- José A. Neto S. Zolnier., and LopesD.C. 2014. Development and evaluation of an automated system for fertigation control in soilless tomato production. *Computers and Electronics in Agriculture* 103, 17–25.
- Kati W. M., Schaffer B., Jonathan H. C., Frederick S. and Davies 2010. Plant response to evapotranspiration and soil water sensor irrigation scheduling methods for papaya production in south Florida. *Agricultural Water Management* 97 1452–1460.
- Kelleners T.J., Seyfried, M.S., Blonquist, J.M.Jr., Bilskie, J.and Chandler, D.G. 2005. Improved interpretation of water content reflectometer measurements in soils. *Soil sci. soc. Am. J.* 69(6):1684-1690.
- Kolev, N. 2005. Instrumental evaluation of soil moisture content by using electrical resistance methods and soil moisture meter with gypsum blocks housing in the soil profile teaching module: *field measurement guide European soil bureau*.
- Krishna S., Nemali, Marc W. and Iersel V. 2006. An automated system for controlling drought stress sand irrigation in potted plants. *Scientia Horticulturae* 110 292–297.

- Kuligud, V.B. Salimath, S.B., Jayashekhar K.V., Upperi S.N., and Balakrishnan P., 1999. Application of Em38 for soil salinity appraisal: an Indian experience. *International institute for land reclamation and improvement, Wageningen, Netherlands.*
- Lailhacar, B. C. and Dukes, M.D. 2010. Precision of soil moisture sensor irrigation controllers under field conditions. *Agricultural Water Management* 97 666–672.
- Lee, N. M., Bos H. L., Molenveld K., Teunissen A.M. and Wingerde.2006. Behaviour of sensors in distribution systems. *Journal of Material Science*, 38:2159.
- Leib, B.G., Hattendorf, M., Elliott, T. and Matthews, G. 2002. Adoption and Adaptation of scientific irrigation scheduling: Trends from Washington, USA as of 1998. *Agric. Water Manage.* 55: 105-120.
- Luthra, S.K., Kaledhonkar, M.J., Singh, O.P. and Tyagi, N.K., 1997. Design and development of an auto irrigation system. *Agricultural Water Management* 33, 169–181.
- Mathew, A.C. and Senthilvel S. 2004. Studies on locating moisture sensor for automatic regulation of furrow irrigation systems. *Madras agric.J.* 91(1-3):10-14.
- McCann, I.R., Kincaid, D.C. and Wang, D. 1992. Operational characteristics of the watermark model 200 soil water potential sensor for irrigation management. *Applied Engr. In Agriculture* 8(5):605-609. ASAE, 2950 Niles Rd.,St. Joseph, MI 49085.
- Meron, M., Hallel R., Peres M., Bravdo B. and Wallach R. 2001. Tensiometer actuated automatic micro irrigation of apples. *Acta Horticulturae.* 562:63-69.
- Mojid, M.A., Wyseure G.C.L. and Rose D.A. 1997. Extension of the measurement range of electrical conductivity by time domain reflectometry (TDR). *Hydrology and Earth system science* 1:175-183.

- Moorthy, V.V.N.1982. Land and water management Engineering. Kalyani Publishers New Delhi.
- Morgan N.E., Bratieres, K., Fletcher T.D.,Deletic A. and Zinger Y.1998. Variation of of electrical conductivity in distributed systems: optimization study. *Water Research* 42(14):393-398.
- Morris, M.2006. Soil moisture monitoring: low-cost tools and methods. A publication of ATTRA- National Sustainable Agriculture Information service.1-800-346-9140.
- MOWR, 1999. Vision for integrated water resources development and management. Ministry of water resources, government of India, New Delhi.
- Millera, G.A., Farahanib, H.J., Hassellc, R.L. , Khaliliand, A., Adelberge, J.W. and Wellsf, C.E. 2014. Field evaluation and performance of capacitance probes for automated drip irrigation of watermelons. *Agricultural Water Management* 131: 124– 134.
- Miranda, F.R., Yoder, R.E., Wilkerson, J.B. and Odhiambo, L.O., 2005. An autonomous controller for site-specific management of fixed irrigation systems. *Computers and Electronics in Agriculture* 48, 183–197.
- Mulas,P. 1986. Developments in the automation of irrigation. *Colture Protelte* 15(6), 17-18.
- Narayanamoorthy.2001. correlation study among water quality parameters- An approach to water quality management. *Journal of environmental science and engineering*, 51(2):111-114.
- Nemali, K.S., Montesano F. Dove S.K. and VanIersel M.W.2006. Calibration and performance of soil moisture sensors in soilless substrates: ECH₂O and Theta probes. *Scientia Horticultrae*.112 (2):227-234.

- O'Shaughnessy, S.A. and Evett, S.R. 2010. Canopy temperature based system effectively schedules and controls center pivot irrigation for cotton. *Agricultural Water Management* 97, 1310–1316.
- Pathan, S.M., Barton L. and Colmer T.D.2003. Evaluation of a soil moisture sensor to reduce water and nutrient leaching in turf. *Horticulture Australia project number TUO 2003*.pp2
- Phogata, V., Skewesa,M.K., Mahadevana, M. and Coxa, J.W. 2013. Evaluation of soil plant system response to pulsed drip irrigation of an almond tree under sustained stress conditions. *Agricultural Water Management* 118 1– 11.
- Plauborg, T.L., Haller, D., Walker, J., Bartram and Cairncross S. 2004. Sensors for complex situations. Review on current problems in Agro physics.5 (4):599-608.
- Prathyusha, K. and Chaitanya, S. 2012. Design of Embedded System for the automation of Drip Irrigation. *International Journal of Application or Innovation in Engineering and Management (IJAIEEM)*. 1: 254-258.
- Razali, M.H., Masrek, M.N. and Roslan S. 2013. Microcomputer Application for Instrumentation development in Drip Irrigation System. *Journal of Computer Sciences and Applications*. (3):39-42.
- Reddy Yellamanda, T., Bhargavi, K., Balaguravaiaht, D. and Giridhara Krishna, T.2001. Water, nutrient and root distribution of sweet orange as influenced by drip irrigation and micro nutrient management. In: Singh, H.P., Kaushish, S. P., Ashwani Kumar, Murthy, T.S., Jose, C and Samuel. (eds.). 2001. *Micro Irrigation*. Central Board of Irrigation and Power, New Delhi, 256p.
- Reddy, M.S. 2002. Water resources development in 21 century- policy options in India, manual of CWRDM, Kerala.

- Ristolainen, A., Jaakkola,.,Hannien, P. and Alakukku.2005. Temporal variation in soil electrical conductivity. In: Grzegorz jozefaciuk, Cezary Slawinski, Ryszard T, Walczak (eds.). Review on current problems in Agro physics.
- Romero, R., Muriel, J.L., Garcia, I., Green, S.R., and Clothier, B.E., 2012. Improving heat pulse methods to extend the measurement range including reverse flows. *Acta Horticulturae* 951, 31–38.
- Romeroa, R., Murielb, J.L., Garcíab, I., Munoz D. and Penac, de la 2012. Research on automatic irrigation control: State of the art and recent results. *Agricultural Water Management* 114 59– 66.
- Rosegrant, 2002. Performace of drip and surface irrigation for tomato in heavy soils. In Proc.XI international congress on the use of plastic in agriculture. New Delhi.
- Saleth.2004. Environment Analysis – water, soil and Air, 2nd edition. *Agro Botanical publishers*, Bikaner, India, pp 4-86:121-125.
- Shinn J.D., Timian D.A., Morey R.M., Mitchell G. Antle, C.L. and Hull R. 1997; Development of a CPT deployed probe for in situ measurement of volumetric soil moisture content and electrical resistivity. *Field analytical Chemistry & technology*.2 (2): 103-109.
- Shirahatti, M.S., Itnal, C.J. and Mallikarjunappa Gouda, D.S. 2001. Comparison of drip and furrow irrigated cotton on a red soil. In: Singh, H.P., Kaushish, S.P., Ashwani Kumar, Murthy, T.S., Jose, C and Samuel. (eds.). 2001. *Micro Irrigation*. Central Board of Irrigation and Power, New Delhi, pp. 590-666.
- Shock, C., Feibert E. and Jaderholm S.2001. A comparison of six soil moisture sensors information for sustainable agriculture. *Madras Agric. J.* 91 (4-6):215-220.
- Shock, C., David J., Shock A., and Kimberlin C.A. 1999. Innovative, automatic, low-cost reading of watermark soil moisture sensors. Irrigation Association.

- Proceedings of the International irrigation Show. Annual special report 964. Malheur experiment station, Oregon state University. pp 147 -152.
- Singh, S. and Sharma, N. 2012. Sensor Technology and Its use in Drip Irrigation Management. *International Journal of Engineering Research & Technology* (IJERT) Vol. 1 Issue 5.
- Spaans, E.J.A. and Baker, J.M. 1992. Calibration of watermark soil moisture sensors for soil matric potential and temperature. *Plant and Soil* 143:213-217.
- Spectrum technologies Inc. 2007. Instruction manual for field scout TDR 300.
- Streetman, B. and Banerjee, S.2010. Solid state electronic device (6th Ed.). Pearson/presentics hall.
- Sudduth, K.A., Kitchen N.R., Wiebold W.J., Batchelor, W.D., Bollero, G.A. and Bullock D.G.2005. Relating apparent electrical conductivity to soil properties across the north-central USA. *Computers and Electronics in Agriculture*.46:263-283.
- Sun Y., Zhou H. Y., Qin P., Lammers, S. A., Berg H., Deng, X. Cai, D. and Wang, S.B (2014). Jones 2014. Horizontal monitoring of soil water content using a novel automated and mobile electromagnetic access-tube sensor. *Journal of Hydrology* 60:30.
- Suryawanshi, S.K. 1995. Success of drip in India: An example to the third world. 5th International Microirrigation congress. *American society of agricultural engineers*, Florida,pp 347-352.
- Thakur, D. S., Sharma A. and Sharma, D.K. 2013. A Low Cost Design & Monitoring Of Automatic Irrigation System Based On Zigbee Technology. *International Journal of Engineering Research & Technology* (IJERT) 2(5).

- Thompson, R.B., Gallardo M., Valdez L.C., and Fernandez M.D.2004. Thresholds of soil matric potential and available soil water content required to prevent water limitations between irrigations. *Irrigation science*.24 (3):185-202.
- Thompson, R.B., Gallardo M., Valdez L.C., and Fernandez M.D.2006. Using plant water status to define threshold values for irrigation management of vegetable crops using soil moisture sensors. *Agricultural water management*. Volume 88. Issues 1-3.p147-158. University of California Agricultural Extension service. Published by ANR Publications.
- Thompson, R.B., Gallardo M., Aguera T., Valdez L.C., and Fernandez M.D.2006. Evaluation of the watermark sensor for use with drip irrigated vegetable crops. *Irrig. Sci*.24:185-202.
- Thompson, R.B. Gallardo, M., Agu, T.C., Valdez, M.D. and Fernandez 2006. Evaluation of the Watermark sensor for use with drip irrigated vegetable Crops. *Irrig Sci* 24: 185–202.
- Thompson, R.B., Gallardo M., Valdez L.C. and Fernandez, M.D. 2007. Using plant water status to define threshold values for irrigation management of vegetable crops using soil moisture sensors. *Agricultural Water Management*.88: 147-158.
- Thompson, R.B., Gallardo M., Valdez L.C. and Fernandez, M.D. 2007. Determination of lower limit for irrigation management using in situ assessments of apparent crop water uptake made with volumetric soil water content sensors. *Agricultural Water Management*.92:13-28.
- Thompson, R.B., Gallardo, M., Valdez, L.C. and Fernandez, M.D. 2 0 0 7. Determination of lower limits for irrigation management using in situ assessments of apparent crop water uptake made with volumetric soil water content sensors. *Agricultural Water Management* 9 2 1 3 – 2 8.

- Thompson R.B., Gallardo, M., Valdez, L.C., Fernandez, M.D. 2007. Using plant water status to define threshold values for irrigation management of vegetable crops using soil moisture sensors. *Agricultural water management* 8 (8):147 – 158.
- Walker, J.P., Willgoose G.R. and Kalma J.D. 2004. In-situ measurement of soil moisture: a comparison of techniques. *Journal of Hydrology*.293:85-99.
- Whalley, W.R., Wattsm C.W., Hilhorst A., Bird N.R., Balendonck J. and Longstaff, D.J. 2001. The design of porous material sensors to measure the matric potential of water in soil. *European Journal of Soil Science*.52:511-519.
- White, I., Zegelin, S.J., Topp, G.C. and Fish, A. 1994. Effect of bulk electrical conductivity on TDR measurement of water content in porous media.pp.294-308.
- Zhenga, J., Huang, G., Jia, G., Wang, J., Motac, M., Luis S., Pereirac, Huang, B., Xua, X. and Liua, H. (2013) Responses of drip irrigated tomato (*Solanum lycopersicum* L.) yield, quality and water productivity to various soil matric potential thresholds in an arid region of Northwest China. *Agricultural Water Management* 129, 181– 193.

Appendix I

Particle size distribution of soil sample 1

Mass of dry soil sample = 1640g

IS Sieve	Particle size(mm)	Mass retained(g)	% retained	cumulative % retained	cumulative % finer
4.75mm	4.75	327.049	19.942	19.942	80.058
2mm	2	361.475	22.041	41.983	58.017
1mm	1	242.622	14.794	56.777	43.223
600	0.6	185.245	11.295	68.073	31.927
425	0.425	71.311	4.348	72.421	27.579
300	0.3	73.770	4.498	76.919	23.081
212	0.212	238.524	14.544	91.463	8.536
150	0.15	27.868	1.699	93.163	6.837
75	0.075	49.180	2.998	96.162	3.838
Tray		50			

Appendix II

Particle size distribution of soil sample 2

Mass of dry soil sample = 1000g

IS Sieve	Particle size(mm)	Mass retained(g)	% retained	cumulative % retained	cumulative % finer
4.75mm	4.75	327	32.7	32.7	67.3
2mm	2	248.5	24.85	57.55	42.45
1mm	1	153.6	15.36	72.91	27.09
600	0.6	190	19	91.91	8.09
425	0.425	44.5	4.45	96.36	3.64
300	0.3	33.5	3.35	99.71	0.29
212	0.212	37	3.7	103.41	-3.41
150	0.15	4.5	0.45	103.86	-3.86
75	0.075	12	1.2	105.06	-5.06
tray		12			

Appendix III

Hydrometer Analysis of soil sample 1

Time	density	Rh	He	D	Wd	N
30sec	1.015	15	13.6	0.076	$24.868 \cdot 10^{-3}$	49.73
1min	1.0135	13.5	14.6	0.054	$22.4 \cdot 10^{-3}$	44.8
5	1.0115	11.5	15.3	0.0248	$19 \cdot 10^{-3}$	38
10	1.0095	9.5	15.75	0.0178	$15.75 \cdot 10^{-3}$	31.5
20	1.008	8	16.4	0.01285	$13.264 \cdot 10^{-3}$	26.5
30	1.007	7	17	0.01068	$11.6 \cdot 10^{-3}$	23.2
1hr	1.006	6	17.2	0.007598	$9.94 \cdot 10^{-3}$	19.8
2	1.0055	5.5	17.5	0.005419	$9.11 \cdot 10^{-3}$	18.2
4	1.005	5	17.7	0.00385	$8.29 \cdot 10^{-3}$	16.58
8	1.005	5	17.7	0.002725	$8.29 \cdot 10^{-3}$	16.58
12	1.005	5	17.7	0.002225	$8.29 \cdot 10^{-3}$	16.58
24	1.004	4	18.1	0.00159	$6.632 \cdot 10^{-3}$	13.26

ABSTRACT

The present study was conducted to design, develop and evaluate an automated drip irrigation system working on the basis of soil moisture deficit and to establish the relationship between soil moisture content, electrical conductivity. The study involved fabrication of a soil moisture deficit based automation system and testing of the system under laboratory and field conditions. The system was tested and calibrated for automatic irrigation scheduling. As the soil started drying up, water content decreased and the conductivity reading in the data logger decreased. When the sensor readings reach the preset threshold level, the system gets automatically switched on. The irrigation setup was operated until the moisture reached the preset level of field capacity. Conversely, an increase the soil water content increased the conductivity. In this way, automation system continuously recorded fluctuations in soil moisture content under varying field conditions. Laboratory tests were conducted to evaluate the performance of the drip automation system in salt solution, sandy loam and laterite soils to develop the calibration curves. It was observed that there existed a significant correlation between the soil moisture content and electrical conductivity of sensors. Soil moisture sensors were evaluated with respect to the moisture content of sandy loam and laterite soils. In sandy loam soil, the values of maximum and minimum sensor output values were 17.5 to 3.3 mS/m and for laterite soil it was 15.1 to 2.4 mS/m. In the field evaluation using amaranths crop, the moisture distribution was more or less uniform near the soil surface soon after irrigation. The developed electrical conductivity based soil moisture sensors performed well in the laboratory study using sandy loam and laterite soils, but during field evaluation in sandy loam soil its performance was not satisfactory. In case of capacitor type soil moisture sensor, the performance was satisfactory in both conditions. Capacitor type soil moisture sensor performed well in sandy loam soil in the field evaluation. From the results of this study it can be concluded that capacitor type soil moisture sensor can perform better than electrical conductivity based soil moisture sensor for field use. The drip automation

system developed was simple, precise, sensitive, light weight, cost effective in construction and fast responding. The speed of measurement, cheapness and portability are the key advantages and the system is easily adaptable for use with automatic logging equipment. There is scope for further studies on optimization of the electrode geometry and evaluation of electrical conductivity based soil moisture sensors with different fertilizer and chemical application.